DESIGNING WITH PEOPLE WITH VISUAL IMPAIRMENTS: AN EXPLORATION OF THE VALUE OF EXTRAORDINARY USERS IN DESIGN

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This research was undertaken under the auspices of Cardiff Metropolitan University.
DECLARATION

This work has not previously been accepted in substance for any degree and is not being currently submitted in candidate for any degree.

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This work is the result of my own investigations, expect where otherwise stated.

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I. ABSTRACT

Resonance is the correlation of needs between extra-ordinary users and ordinary users in extra-ordinary situations. Instances of resonance are common and plentiful, for example: attempting to talk to a friend whilst at a loud concert sees similar problems to those that people with hearing impairments overcome everyday, or, using a device whilst wearing thick gloves shows resonance with people with limited dexterity. During a literature review a resonance was identified between people with visual impairments, and people without impairment whilst walking; in that, people with visual impairments cannot visually engage with mobile devices, and, pedestrians without impairment should not visually engage with devices as it causes dangerous and anti-social pedestrian behaviours.

This thesis investigates the theory of resonance and the use of extra-ordinary users as design informants utilising the design of a tactile navigation aid as vehicle for investigation and to provide a response to the research question of:

“How might the employment of theories of resonance and extraordinary users in the collaborative design process result in better design outputs?”. 

The research uses a two phase approach; the first phase is a practise-led approach using a participatory design process in which the integration of people with visual impairments into a product design process is documented and a reflective analysis takes place on the techniques utilised, their outcomes and their effectiveness. The second phase moves on to assess the output of this participatory design process against more traditional commercially
available aids in a comparative study designed to evaluate the perceived benefits and disadvantages for the resonant scenario of pedestrians without visual impairments.

The results show a selection benefits brought about by the recognition of resonance and the inclusion of extra-ordinary users in the design which confirms that working with extra-ordinary users, in this case people with visual impairments, can produce benefits for all users. It also contributes to knowledge by making a series of recommendations for future researchers who plan to design collaboratively with people with visual impairments and finally, by demonstrating the benefits of tactile interaction for mundane navigation commands.
II. ACKNOWLEDGEMENTS

After a long and bumpy journey, I’d like to start by thanking my supervisory team; Prof. Steve Gill, Dr Gareth Loudon and Prof. Wendy Keay-Bright for helping me find my way and pointing me back to the right path every time I drifted away. Thank you. You are excellent.

Tony and Andrea, your time and creative contributions are the essence of this work without you it was not possible, thank you. And to all of the other research participants for their time and contributions, thank you.

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V. TERMINOLOGY

Whilst correct terminology around people with disabilities is constantly evolving I have endeavoured to use the most up to date language available at the time of writing.

General language guidelines are advised by the UK’s Office for Disability Issues (2014).

Visual Impairment, as defined by the UK National Health Service (NHS, 2015), is a blanket term used to cover all levels of sight-loss not correctable by glasses or contact lenses; furthermore the term “people with visual impairment” will be the chosen term used throughout the thesis.

Common Terms and Abbreviations

- Extraordinary Users/People
  Users whose usage requirement fall outside of mainstream usage, this may be due to a temporary or permanent disablement. (Pullin & Newell, 2007)

- Design Resonance, or, “Resonance”
  Similarities between product usage by extraordinary people in ordinary contexts and ordinary people in extraordinary contexts. (Pullin, 2009)

- Product Usage Context, or, “PUC”
  The usage factors which characterize environment and application. (Green, et al., 2004)

- Mobile Device
  A portable, consumer, electronic device. For example: a mobile phone, an mp3 player or a GPS system.

- Pedestrian Navigation Device, or “PND”
A device intended to aid pedestrian navigation by providing live updates on route information. (Pielot, et al., 2010)

- **User-Centred Design, or, “UCD”**
  
  A design process in which the users are engaged from an early stage.

- **Participatory Design, or, “PD”**
  
  A design process in which the users are asked to actively input into the design process in a creative manner, as opposed to insight driven through observations and interviews. (Sanders, 2002)

- **Navigation**
  
  A catch-all term for both wayfinding and navigation practices, i.e. the user determining a route and travelling along it.

- **Tactons**
  
  The delivery of structured information through the tactile sense. (Brewster, et al., 2003)
This thesis was initially conceived as part of a broader commercial R&D programme with the company Peepo GPS Ltd under a scholarship scheme. The scholarship scheme, similar to a Knowledge Transfer Partnership (Innovate UK, 2015), intended to place academic researchers into commercial development programmes on an industrial placement scheme. The academic partner was PDR, a unit of Cardiff Metropolitan University (then University of Wales Institute Cardiff) which specialised in user centred design techniques and the industrial partner, Peepo GPS based in the Insitute of Life Science in Swansea intended to manufacture a navigation aid for people with visual impairments.

I was already aware of the Peepo GPS system when initially approached about the research project. Developed as part of a Cardiff Metropolitan masters project (whilst I undertook an undergraduate degree at the same institution) the novel concept gained a lot of attention due to the award of a Red Dot Design Award (Red Dot Design Award, 2010) and high praise from James Dyson. The project appealed to me for many reasons: I had a particular interest in inclusive design since my very first university report (a review of OXO good grips against standard competitors) but also due to my enjoyment of user-centred design and research techniques which I had undertaken throughout the major projects in the final year of my undergraduate.
“Peepo” is a conceptual navigation aid for people with visual impairments. Originally conceived in 2009 the device, attached to a guide-dog harness, guides the user by means of directional vibro-tactile feedback. The scholarship project tasked me with uncovering strategies and techniques around navigation and handheld device usage unique to people with visual impairments. The insights uncovered in this research could then be translated into a design specification for the Peepo product and would in-turn drive forwards product development. Early conversations with the directors of Peepo identified a variety of markets where they believed tactile output may add value to navigation devices and therefore the scope of the commercial output was purposefully left broad, and not limited to specifically targeting people with visual impairments.
PROBLEMS ENCOUNTERED

Unfortunately, around a year and a half into the 3-year scheme both the company and the scholarship scheme collapsed. The funding body did agree to continue to fund the PhD by means of payment of tuition fees and stipend as per the contractual agreement but due to the company collapse, finance for development of the product itself was no longer available. As such, the focus of the research took a slight shift initially it was intended that the research project would be based in HCI (Human Computer Interaction) attempting to understand the optimum method of communicating navigation commands through the tactile modality utilising the Peepo system as a case study; this would culminate in longitudinal, large scale studies made possible by the commercial development of Peepo GPS. However, through the secondary research phases it became clear that many other gaps in the research were prevalent and in-fact, there was already research being conducted in the area, and so even whilst Peepo GPS existed, the research had already begun to shift towards an exploration of the concept of ‘resonant design’ (explained further throughout the thesis); therefore the lack of support from the industrial partner, whilst at the time frustrating, did not render the work already conducted unusable.

This thesis presents the refocused research, which explores involving people with visual impairments in the design process on a broader level than had initially been envisaged, utilising the design of a tactile navigation aid as a vehicle to evaluate the benefits and constraints.
The design of a tactile navigation aid was inherent in the project origin and in the initial stages of discussion. A link between the needs of device users with visual impairments (who cannot visually engage with their device) and the needs of sighted device users whilst walking (who should not visually engage with their device) was recognised and thus became a driving force behind the project.

The usability issues of visually reliant mobile device (i.e. smartphones, mp3 players, navigation devices) use whilst actually mobile are not uncommon in the media however attention usually focuses on the dangers of using a device whilst driving; media coverage of the dangers of using devices whilst walking is not so prevalent. However, research shows it is an increasing issue. In a sample of 2000 British people 7% claim to have been hit by a car whilst texting and crossing the road (TolunaQuick, 2012) and so it seems that mobile devices such as: mobile phones, smartphones, handheld GPS systems and MP3 systems are not particularly well designed to suit the challenges of mobile use. Some academics (Cardin & Thalmann, 2008; Gustafson-Pearce, et al., 2005) believe that this is due to the visual engagement required to utilise mobile devices that redirects the valuable sense and also causes cognitive overload. It is fair to assume that when utilising visual based maps and navigational guidance these issues are only exacerbated due to the expected lack of orientation, the cognitive effort of computing a route and other social and safety concerns related to travelling along an unknown path. With this in mind, it seems sensible to attempt to decrease the visual engagement of these devices, and turn to the experts of using such devices with minimal visual engagement, users with visual impairments. Pullin and Newell
term this type of expert “extra-ordinary users”, users who through some form of permanent or temporary impairment interact with products in novel ways, and recognise that in many scenarios their normal needs “resonate” with the needs of mainstream users in particular situations. This theory is therefore called “resonant design”.

On review of the literature a severe lack of documentation on how to integrate people with visual impairments into the design process was found, alongside this was a lack of in-depth case studies utilising extra-ordinary users and assessment of the value of the output. Using the design of a tactile navigation aid as a case study, the literature review also highlighted that whilst many practitioners have theorised that a tactile method of communicating navigation commands may be a better solution than the visual norm, a lack of rigorous testing methods means that very little evidence is provided to support this theory. With this in mind, this thesis documents and critically assesses the use of extra-ordinary users, in this case people with visual impairments, as design informants for a personal navigation device, contributing to knowledge by responding to the research question of:

*How might the employment of theories of resonance and extra-ordinary users in the collaborative design process result in better design outputs?*

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Throughout the project 16 studies (some with multiple components) were conducted, the studies were devised to both further the research aim as well as work towards the navigation aid product development. Table 2 (next page) details the studies, the outputs,
and where they are presented within this thesis. An expanded table with supplementary information on the aim of each individual study is provided in Appendix I.

Table 2: Studies Undertaken Throughout Thesis

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2. LITERATURE REVIEW

2.1. INTRODUCTION

This chapter presents a literature review providing a foundation level of knowledge around the research area. The initial research question that stimulated this research was:

*Understanding how innovations created for users with visual impairments could add value to products designed for mainstream consumer in the handheld computing market.*

However, this research question is revised in response to the literature in ‘Chapter 4: Revised Research Question’.

The literature review aims to uncover existing research around best practice for an inclusive design process alongside reviewing known problems and existing solutions around pedestrian navigation aids.

The literature review is split into three sections:

1. Inclusive Design Process – researched to ensure that best practice is utilized throughout the design project.
2. Mobile Device Design Issues – to understand prior research and to highlight areas for potential development.
3. Existing Work on Tactile Navigation – to understand the current state of the art in the field and identify gaps in the research.
The conclusion of the chapter details gaps in the research literature that allowed for a refinement of the research aim and the generation of objectives.

2.2. INCLUSIVE DESIGN PROCESS

When tasked with developing a product for people with visual impairment care must be taken to ensure the product is both accessible and desirable for the user. This section reviews relevant design practice to ensure that the product is attractive and suitable for the intended user.

2.2.1. Inclusive Design

Inclusive design or Universal design is the term used for designs created with the whole population in mind, focusing on creating usable products for even the most marginalised of users (Clarkson, et al., 2007). Inclusive design was a reaction against the badly accepted, stigmatising, assistive design products on the market; believing that rather than making products specifically for people with certain disabilities, through proper research and application of knowledge, products can be made accessible and acceptable to the vast majority of people (Coleman, 2003). Inclusive design emphasises how ‘good design’ of mainstream products negates the need for assistive or adaptive products;

The design of mainstream products and/or services that are accessible to, and usable by, as many people as reasonably possible

(BS 7000-6:2005)

Good inclusive design means that products created to be usable for people with disabilities become accepted into the mainstream, often without users even knowing that the
products were originally created with a more specialized market in mind. Coleman (2003) phrases this nicely in the title of a book chapter “from the margins to the mainstream”.

Examples of such products are:

- Cassette tape recorders – originally created to allow people with visual impairments to record notes it was never thought that the cassette would break into the mainstream market due to its low sound quality (Pullin & Newell, 2007).

- Predictive typing used by most mobile phones – originally developed for people with dexterity problems that only allow them to use a limited amount of buttons (Pullin & Newell, 2007).

- OXO goodgrips – a successful brand name in kitchenware was originally designed with people with arthritis in mind (OXO Goodgrips, n.d.)

“Inclusive design has contributed to such innovations as the typewriter, the telephone, email, the PDA, speech synthesis and recognition. All these innovations were motivated by a need to address the needs of people with disabilities.”

(TREVIRANUS, 2007)

The above quote from Jutta Treviranus (2007), director of the Inclusive Design Research Centre at Ontario College of Art and Design University, shows how inclusive, assistive and adaptive products can be a catalyst for good design for all. This raises the question, are there any assistive or adaptive navigation devices with technology that could transfer to innovative mainstream devices? This ‘outside in’ approach of bringing innovations from design for the margins into the mainstream is discussed by Pullin and Newell (2007). They argue that by designing for “specific groups of older and/or disabled people... can lead to
better products for all users” and they call these target audiences “extra-ordinary users” (this will be discussed further in section 9.2.2.2).

Common outcomes of inclusive design research are guidelines; some that relate to mobile devices for people with visual impairment include: (Gill, 2000; Albu, et al., 1998; Gerber, 2002; Plos & Buisine, 2006). These guidelines are often in a ‘checklist’ style for dictating the features and functions that should or should not be included. However, though these guidelines make a product usable by people with visual impairment there is no evidence that it makes a product desirable (in fact, the focus group discussions documented in chapter 3 demonstrated that some people with visual impairments would rather put in the extra effort to learn a more difficult interface so they can own a more desirable product).

As such, an effort must be made to ensure that these design guidelines are integrated into a full design process that accounts for usability and desirability and not just accessibility and only through this integration will the product become truly inclusive.

The Inclusive Design Toolkit (Clarkson, et al., 2007) provides a handbook-like breakdown of inclusive design best practice and process, which is intended to account for both accessibility and usability. The process encourages user involvement from the early stages to understand real life issues and problems, then working through the concept phases to the end of the design with iterative feedback and product testing with ‘users’ and ‘experts’ (see figure 2). This type of regular user engagement is

![Inclusive Design Process Diagram](image)
indicative of a user centred design (UCD) process (Steen, et al., 2007). Coined by Norman in his seminal “The Psychology of Everyday Things” (Norman, 1988), User, or Human, centred design is characterised by these engagements which are typically driven at gathering initial user requirements and testing potential solutions (Abras, et al., 2004). Norman (1988) identified that with the coming of the digital age, product engagements became disconnected from the action they performed and without a visible mechanism, users became reliant on iconography and instructions for use. Thus the products were not intuitive. He argued for user involvement throughout the process both to identify initial needs and desires as well as testing that the proposed designs are intuitive and fit the users’ mental model of usage (Norman, 1988, Abras et al., 2004). This approach to design is now widely accepted within the design community and for the past 20 years and become commonplace in both industry and design education (Green & Jordan, 2002).

Inclusive design could be seen as a sub-set of UCD where the focus is particularly placed on users with impairments. Clarksons’ (2007) ‘Inclusive Design Toolkit’ differentiates between experts and users as separate entities. However, there is no definition or advice on who falls into these groups. The next section will investigate who could be considered as expert and/or users.

2.2.2. Lead Users and Extra-ordinary users

The previous section introduced the idea of using users and experts to evaluate a product throughout the design process. However, there was no explanation of who these experts and users may be. When designing with a tactile interface in mind it could be considered that people with visual impairment may have valuable and expert opinion due to their heightened day-to-day use of touch and the tactile sense. Their insight into the tactile domain may class them as ‘experts’ but they are also the people who would need and use
the product making them ‘users’. For this reason, they may ‘lead’ the way to novel product innovations for all users.

Von Hippel’s (1986) notion of ‘lead users’ proposes that typical product users are not well positioned to highlight latent user-needs and that other common user-needs assessment techniques, such as focus groups and interviews with typical users, are constrained by the user’s experience. Hannukainen and Holtta-Otto (2006) refer to this constraint as “functional fixedness” where a user is blocked from seeing new functionality by a familiarity with current functionality. Von Hippel (1986) suggests that expert-users could be the key to product innovation. He defines these expert-users as Lead Users.

“Lead users are users whose present, strong needs will become general in the marketplace in months or years in the future”.

VON HIPPEL, 1986

Often these people are those who use the product or service at an above average level, using this definition it could be argued that people with visual impairment are lead users when it comes to mobile device design. For many years people with visual impairment have struggled with using mobile devices. Even with tactile keypads, people with visual impairment have had to find coping strategies to engage fully with mobile technology. It is only in recent years, since a huge expansion in using hand-held devices whilst on the move, combined with these interfaces becoming more visually demanding (through the heavier utilisation of Graphic User Interfaces and touchscreen technology), that these same issues are really affecting the mainstream.

Many other researchers have suggested that disabled people may have a role in leading product innovation; Lin and Seepersad (2007) agree that evaluating a product from a
disabled person’s perspective may lead to novel insight and propose using ‘empathic lead users’. They suggest that genuine lead users may be hard to find and that it is possible to transform a typical user into a lead user by forcing them to experience the product in a new way, for example using dark glasses to simulate visual impairment when testing a product. These exercises are "designed to break the mold of the customer’s thought process and usage pattern" and so overcome functional fixedness. However, it could be argued that Empathic Lead Users may be overwhelmed with tangential issues and different styles of usage, and this may mean that the ability to clearly verbalise what they are experiencing could be difficult. Using navigation devices as an example, if a designer were to blindfold a fully sighted user and ask them to feedback on an audio-interface navigation device, it is likely that many of the problems a blindfolded person may encounter will be related to macro-navigation, such as tripping and bumping into objects, and disorientation rather than the actual nature of the device itself. People with visual impairment on the other hand will have had mobility training and will be able to focus more wholly on the device purpose. Hannukainen and Holtta-Otto (2006) seem to agree with this as, although they also use able bodied users in their studies, they are careful not to add impairment beyond reasonable expectations. Rather than add impairments to typical users they change the context of use of the product, creating a much more realistic testing structure. Citing Green et al. (2004) they refer to this as Product Usage Context (PUC) defining it as,

"the usage factors characterizing the application and environment in which a product will be used that may significantly impact customer attribute preferences". 

(HANNUKAINEN & HOLTTA-OTTO, 2006)
Hannukainen and Holtta-Otta’s testing shows that in some PUCs the physical ability of an able bodied user matches up to those of a disabled user. An example is used of a mobile device user in a dark room who has some common usability issues with a person with visual impairments. This means that as people with visual impairment live with these issues on a day-to-day basis they may have some deeper insights, coping strategies or at least a better ability to verbalise the problem than a sighted person who only experiences it occasionally. This pairing of functional ability between able bodied and disabled people is referred to by Pullin and Newell (2007) as ‘resonant design’. Hannukainen and Holtta-Otta’s results evidence resonant design and they show that products designed for users with disabilities could filter into the mainstream to solve PUC usability issues. They give the example of a ‘Menoma plus’ a Braille note taker which has been used for years by people with visual impairment which has similar functionality to PDAs released years after for the mainstream market. Could this example of moving from the margins to the mainstream be utilised in the design of a navigation device? Could the design features, such as a tactile interface be used to overcome the PUC issues in current mainstream products?

So far the majority of the research discussed in this chapter is about defining user-needs at the start of the design process. This is contrary to what many people perceive to be the best practice when considering access for people with impairments, which is regularly seen as an ‘add-on’ near the end of the process (Pullin and Newell, 2007). Assessing usability at the end of the process may produce accessible but not necessarily usable results; an existing example of this in the navigation device realm is that of adding audio interface; by adding audio, the product becomes accessible to people with visual impairment. However, it does not sufficiently deal with the usability issues as the audio may obscure ambient noise important for both navigation and safety. By conducting summative testing of
existing products to find usability issues, the solutions may seem ‘add-on’ rather than integrated into the design of a product. This worry is discussed by Pullin and Newell (2007), who believe that the modification of mainstream products to suit the needs of the extra-ordinary user can be seen as patronizing, it can increase costs and it can cause unnecessary compromises in the design of the product. They also suggest that this summative rather than formative use of ‘extra-ordinary’ design informants lacks emotional engagement,

“Many such products show evidence that the teams that design them do not engage emotionally with the users groups and assume that older and disabled people lack any aesthetic sense, and unlike other user groups, are motivated entirely by the functionality of products”

(PULLIN & NEWELL, 2007)

A design process that only focuses on access rather than usability and desirability leads to designs that are not only poorly accepted in their intended market but also have no chance of ever filtering into the mainstream. They suggest that this comes from an over generalisation of disabled and older people’s needs and that current inclusive design practice is too broad; it is not possible to create a product that is truly ‘usable by all’ and by forcing this unattainable goal on designers will only discourage them. Instead he suggests that creating a truly user-centred product for one relevant user will produce more innovative ideas and this can later be moulded to suit a mainstream market rather than vice-versa. It is specified that the chosen extra-ordinary user must be appropriate,

Each “extra-ordinary user” should not be considered as representing a specific disability, but should be considered as an individual person who happens to have
a specific disability as well as a range of other characteristics which are important for defining them as a person, but may not be related to their disabilities

By adding depth to the user, their wants, needs and desires, they suggest you can generate a greater empathy amongst designers. By extending the concern for their needs to the whole design process a more user-centric product will be created which will have more value than the patronising ‘add-on’ functions seen in many products designed for disabled or ageing communities and they define the advantages as:

- “More radical starting points create more radical solutions”
- Less constraining than ‘fixing’ mainstream products
- Encourages simplicity

Ulwick (2002) raises a concern that gathering requirements from lead users could result in products which are too sophisticated for the average user. Schluza’s (2013) research supports this notion; Schluza investigated the types of input gathered from both novice and expert users on the early stage of product design. The results showed that novice users generated a greater number of requirements related to usability of the system and expert users generated a greater number of requirements related to functionality of the system.

Pullin and Newell (2007) also recognise that development alongside extra-ordinary users could potentially result in an exclusionary product but feel that it falls on the skill of the designer to take the information and mould it into a product suitable for the mainstream. However, this requires a clear recognition of the resonance of the design and potential PUCs from an early stage that is not always present, Hannukainen and Hölttä-Otto (2006) show an example of this whilst arguing resonance itself. After conducting experiments which conclude that users with impairments could be valuable in needs assessment in a
similar way to lead users, they give various examples of where assistive products have preceded very similar mainstream designs including the previously mentioned “Memona Plus”, a Braille note taker, which had very similar functionality to the first Palm Pilots released four years later. Though they highlight the similarity of needs and how assistive products were ahead of the market, they fail to highlight the commercial mistake that the designers of Memona Plus made by not recognising the resonance of needs between people with visual impairment and typical users in mobile situations and they limited their market to not just people with visual impairment, but an even smaller group within that, those who can use Braille. Often heard is the argument that ‘good design’ is when designers have considered needs of extra-ordinary users, but the opposite argument is also regularly true, if the designers of Memona Plus had considered the needs of the typical user then perhaps they would have created a more commercially successful and less exclusionary product.

This section discussed that the utilisation of the knowledge, gained skills and coping strategies currently used by people with impairments has value within the design of mainstream products. This raises the question that in certain product usage contexts do the usability issues present in the use of pedestrian navigation aids have resonance with the day-to-day issues of device use for people with visual impairment? Would a navigation device designed in a user-centric method by people with visual impairment also create a functional, usable and desirable device for the population as a whole? The concept of a tactile interface may prove to be an apt solution to existing usability issues for people with visual impairment. What will their experiences, coping strategies, and desires add to the design that people (more specifically designers) without visual impairment may not have yet uncovered?
2.2.3. Non-Users

Whilst searching for examples of ‘extra-ordinary’ user case studies in texts dedicated to the development of a product (rather than texts directly discussing the hypothesis and theory of extra-ordinary users) very few examples were found. Burnett and Porter (2001) however, utilise design input from people with visual impairments for a product that they would not be able to use, as such they are non-users.

Burnett and Porter (2001) suggest, and in later papers test (Porter, et al., 2005; Summerskill, 2010), that people with visual impairment may have innovative insight into design of products for mainstream users in the early stages of the design process. They suggest three explanations for why people with visual impairment may be of aid:

1. Due to their greater focus on the tactile and physical elements to make use of everyday products they may be in a better position to verbalise useful tactile features.

2. Tactile guidelines for the design of accessible products already exist and may be of some use.

3. As they are not direct users of the product their lack of experience may lead to innovation.

As Burnett and Porter are talking in reference to in-car control systems it is highly unlikely that people with visual impairment will use or, if their impairment is congenital, have any experience in the product. For this reason they consider them ‘non-users’ and refer to their involvement in the design process as ‘non-user involvement’. In the case of a navigation aid this may not be true, however points one and two remain held when involving people with visual impairment in the development of a navigation aid. The study conducted, detailed in detail by Summerskill (2010) investigated the explorations and coping
mechanisms of people with visual impairments when using a new electronic product. They documented key features of tactile control mechanisms that aided or subtracted in usability of the electronic device which were then considered in the design of an in-car control system. The new control system proved to reduce the need of visual engagement and thus increased eyes-on-road time, indicating that the engagement of people with visual impairments could aid design for non-visual interaction.

2.2.4. Including the User in the Design Process

With many researchers argue the case for UCD, a variety strategies and methods have been produced to enable this. Traditional UCD focuses on requirement gathering and concept testing achieved through methods such as:

- Focus groups
- Semi-structured interviews
- Observational ethnography
- Usability testing

(Abras, et al., 2004)

However, as UCD has developed there has been a movement towards more significant engagement with the user allowing them to become innovators in their own right (Sanders, 2002). Kaulio (1998) defines three levels of user involvement:

1. Design for customers
2. Design with customers
3. Design by customers

This is then further described by Cybis (2007) and translated by Scariot et al. (2012) as:
1. Informative involvement (Design for Users): the user is seen as a source of information. Using techniques such as interviews, questionnaires, focus group or observation, the designer collects information considered necessary for project development;

2. Consultative involvement (Design with Users): the designer proposes solutions and brings them to users, so that they can evaluate and build opinions on such solutions. This kind of involvement can be achieved through the same techniques used in the previous level, plus usability testing;

3. Participatory involvement (Design by Users): the organization transfers to the user the power over project decisions, utilizes the techniques of experience exchange and idea generation (e.g., storytelling workshop, card sorting, brain-drawing, journal, etc.), demanding a greater effort on planning, organization and execution when compared to the previous levels.

Liz Sanders (2002) discusses Participatory Design (PD) and identifies it as a strategy that facilitates ‘design by users’ and creates a clear divide between PD and UCD which she considers ‘design for users’. Participatory Design can be traced back to the late 1970s in Scandinavia, where a set of co-design tools and techniques were developed to allow trade union workers to have input in the new innovations and technology that would have impact on their job roles. It takes a democratic view on design where users get equal, or weighted opinion and control of the design as they are considered “experts of their own experience” and the designer becomes simply a facilitator (Scariot, et al., 2012). Sanders (2002) challenges traditional UCD techniques such as interviews, focus groups and observation arguing that talking and watching will only give the researcher what the user wants to see or hear and that this is not enough. She proposes that a step further is required and attempts to allow users to express their feelings, thoughts and dreams through the
provision of a creative co-design toolkit; she claims that it is from this mix of “say [talking], do [observing] and make [creating]” that the researcher will develop true empathy with the user. Simplistically she sees the difference is that in traditional UCD methods the user is not part of the team, but their words and actions are “spoken for by the researcher” with a focus on defining needs, wants and desires, whereas in PD the user (or other non-design based stakeholder) becomes part of the creative team with a focus on experience and the users own creative solutions (Sanders, 2002).

Steen (2007) does not make the same distinction as Sanders (2002) and instead uses Human Centred Design (a term often used interchangeably with UCD) as an umbrella term for all processes integrating the final user. Both Scariot (2012) and Steen (2007) recognise that amongst the literature definitions of design research techniques are loose and can regularly be contradictory. They recognise that in reality a mix of techniques will be used, and methods cherry picked in order to generate the required output, and that separation between techniques is regularly artificial as there is no reason why a research cannot use both traditional UCD techniques alongside the co-creation tools generated in a PD process.

2.2.5. Design Methods for People with Visual Impairment

Brandt (2006) notes that “designing the design process itself is just as important as designing the artefact”, in the context of the design project in hand, care and consideration has to be taken in making the methods themselves accessible to the participants. Sanders and Brandt (2010) work together to round up various methodologies created by practitioners to engage and involve users within the design process into a framework for Participatory Design. Regularly the users will not have a design background and so games
and activities are utilised to make the process accessible and fun for the participants with the main purposes defined as:

- Probing
- Priming (in order to immerse them in the domain of interest)
- Understanding (experiences)
- Generating (ideas or concepts)

A mix of both the traditional UCD methods, to uncover how the user perceives the design and experience, and the participatory methods to uncover emotions and desires that are not so easily put into words would arguably be the most well rounded method to design a product.

However a large amount of the methods reviewed in Sanders and Brandt’s framework (2010 - figure 3) are reliant on visual capabilities. This is not simply the case in these co-design methods but also throughout the design process with methods such as: sketches, prototypes, information layouts, mind maps, mood boards and existing product feedback. All these day-to-day methods may need to be adapted for a non-visual approach. Various sources lay out suggestions for more traditional research methods such as focus groups and interviews with people with visual impairments which include considerations such as: room layout, communication, consent, location,
recruitment and preparation (Albu, et al., 1998; Petrie, et al., 2006; Kroll, et al., 2007; Gerber, 2002; Henry, 2007). However very little work has been found on which PD techniques can be used with people with visual impairments, or how you may edit existing PD techniques to suit the needs of people with visual impairments. When investigating PD with people in developing countries Hussain et al. (2012) also recognise that current PD literature is limited by an assumption that all participants “are available [and] have the skills for contributing to the design process” yet this is regularly not the case. Whilst the context and culture under study were different Hussain et al. encountered similar problems in that whilst PD was being reported as a useful method for the context but little to no literature could be found on the application of tools and their success.

Miao et al. (2009) describe how they adapted the ‘Paper Prototyping’ technique used for screen-based interfaces to be accessible for VI research participants; this was achieved through two main techniques: adding a tactile element to sketches and having the facilitator act as speech output. They also noted the differences between the exploratory tactics of people with and without visual impairment, where people without visual impairment take in the whole picture (visually) first and then focus on detail, people with visual impairment must explore through touch which means localised focus initially, exploring the detail, before building up a full mental model. This difference in exploration techniques means that tools and prototypes must not be unnecessarily cluttered, especially if being used to gather feedback on one finite element of a larger system or product. It also means any tactile or audio elements that are not the main focus of the research must be shown and explained to the participant beforehand as they may be an important part of building up the mental model of the product without actually being part of the investigation.
2.2.6. Conclusion

Inclusive design practice shows us how products designed with disabled users in mind can lead to better products for the mainstream. This is an area of opportunity as assistive products initially conceived for a smaller market may have broader market appeal. Inclusive design practice would indicate that the two tasks could be achieved at once. A well designed product for people with visual impairment will also be well designed for people without visual impairment.

Various design practitioners (Lin & Seepersad, 2007; Hannukainen & Holtta-Otto, 2006; Pullin & Newell, 2007; Pullin, 2009) confirm that by integrating expert and extra-ordinary users into the design process and designing with the users rather than for the users aids the production of design solutions by:

- Uncovering latent user needs
- Producing more innovative and radical design solutions
- Creating more usable products

In regards to the design of tactile interfaces people with visual impairment could be considered both expert (due to their more common utilisation of the tactile sense) and extra-ordinary (due to their atypical physical needs). However, Pullin and Newell (2007) clarifies that these design informants should not be used as an ‘add-on’ but integrated fully into a user-centric process and that relevant and interested informants should be targeted to provide a depth of research beyond simple requirements and product specification.
2.3. MOBILE DEVICE DESIGN ISSUES

This section investigates documented issues with mobile device design in order to understand potential areas for development.

2.3.1. How mobile are mobile devices?

Using handheld mobile devices has become the norm for many us; mobile phones, GPS, MP3 players, along with advances in wireless communications and global positioning has made it not only possible but almost irresistible to use these devices.

One common use of mobile devices is for way-finding functions. Advances in GPS, Wi-Fi triangulation techniques and mobile internet, along with extensive free mapping services allow pedestrians to use mobile devices to aid navigation to unknown places in the same way larger products have done for many years inside vehicles. Pielot and Boll (2010) refer to these products as personal navigation devices (PNDs). These PNDs can be either standalone products or integrated as an app on a smartphone. However, a large proportion of these products rely heavily on visual and audio feedback which many argue (Brewster, et al., 2003; Lin, et al., 2008; Pielot, et al., 2011) is not the optimum interface method as it draws attention away from the routine safety checks we all perform everyday whilst navigating.

Many studies have recognised usability issues within navigation devices for driving scenarios (Tornros & Bolling, 2005; Haigney, et al., 2000; Tomros, 2006). However, a significant proportion of pedestrian / vehicle accidents are thought to have been caused by pedestrians. Bungum et al. (2005) state that pedestrian behaviours such as “improper crossing of roadways, inattentiveness and failure to obey traffic signs” are causes of many pedestrian / vehicle collisions. It seems contradictory that a device used to get you from location A to location B would also put you at risk whilst navigating. However, often PNDs,
be it stand alone devices or mobile apps, use the same style of interface as any other function you may find on a mobile phone, an interface based around visual and audio interaction with a small screen. A small selection of studies have been performed which investigate the effect of mobile devices on pedestrian behaviours; these researchers have discovered that the use of a mobile phone fosters negative pedestrian behaviours (Hyman, et al., 2010; Nasar, et al., 2008; Neider, et al., 2010; Schwebel, et al., 2012; Stavrinos, et al., 2011). Hyman, et al (2010) compared walking with a mobile phone, an mp3 player, walking in a pair and walking alone. It was found that participants using a mobile phone walked slower, changed direction more often and were less likely to acknowledge other walkers. The focus of the study centred around ‘inattentional blindness’, a phenomenon where a person involved in divided attention tasks are “less likely to notice new and distinctive stimuli”, this is more likely to occur when the working memory is engaged and relates directly to Cognitive Load Theory (Fougnie & Marois, 2007).

Schwebel et al. (2012) studied, more specifically, the effects of texting on pedestrian road crossing behaviour. They concluded that users inputting text into their mobile device whilst crossing a road are more likely to be hit by a car, they are also more likely to look away from the road.

As many of the studies have correlating outcomes suggesting that the use of mobile devices create negative pedestrian behaviour patterns it could be suggested that mobile devices are not well designed for mobile situations. Nevertheless, these studies do not suggest any design solutions to the problems they report. Schwebel (2012), Hyman (2010), Nasar (2008) and Neider (2010) all comment on the cognitive abilities involved in using mobile devices and suggest that the high cognitive demand could be a reason for lesser navigation performance; if this is the case then decreasing the cognitive load involved in using these
devices may aid safer pedestrian navigation. Also, Hyman’s use of the phrase ‘inattentional blindness’ implies that the issue may be related to overloading the visual sense. It is clear that any mobile device intended for use as a PND must address these usability issues to ensure pedestrian safety, especially in an unknown environment. Utilising a PND is currently a highly cognitively demanding exercise: studying a small screen to understand a map, whilst listening to, or reading directions and trying to relate these directions to the surrounding environment. Therefore, care should be taken in the design phase to reduce risk of pedestrian accident, and innovative research and design solutions must be in place to create a truly usable PND.

2.3.2. Design Issues Fostering Negative Pedestrian Behaviour
This section provides a basic overview of the usability issues that lead to PNDs being potentially unsafe to use.

Cognitive Load
Whilst navigating, a large amount of information has to be cognitively processed. Cognitive load theory (CLT) approaches cognition as an information processor. It states that humans have both working memory and long term memory. Working memory processes new data but is limited, this means that one can only process a controlled amount of new information at any one time (Sweller, 2009). Long term memory stores information once it has been processed. When one’s working memory is ‘overloaded’ it results in a decrease in the processing effectiveness (Kalyuga, et al., 2003). Sweller (2009) and Clark (2008) suggest that an overload of information from a single sensory modality is more likely to cause cognitive overload. This could easily happen whilst attempting to navigate an environment
whilst visually or aurally interacting with a mobile device (Cardin & Thalmann, 2008; Gustafson-Pearce, et al., 2005)

Sweller (2009) and Clark (2008) discuss the various methods of conveying information and the results it will have on cognitive load, these include:

- The worked example effect – lesser cognitive loads can be achieved by working through completed examples rather than problem solving. Sweller (2009) states “instruction should be explicit and complete”.

- The split attention effect – when multiple sources of information are not properly integrated causing the user to split their attention between sources. An example of this in regards to a PND would be if the user was presented with a blank map (i.e. a map with no route indicated) and a written description of a route. The user must switch between the two information sources to fully understand the navigational information.

- The modality effect – splitting information through sensory processors (when properly integrated) will increase working memory capacity, for example, conveying information in a mix of audio and visual will increase processing capacity when compared to the same amount of information in a purely visual format.

- The redundancy effect – repetition of information causes unnecessary cognitive load.

- The expertise reversal effect – As expertise increases cognitive load effects decrease, but there is a tipping point at which effects reappear but in reverse, for example: instructional methods for novice learners can confuse expert users.

The act of pedestrian navigation itself is a highly cognitively demanding task requiring the walker to be constantly relying on visual processes to: look at the proximate surroundings for immediate hazards (such a tripping hazards, changes in surface texture and paths), to
look ahead for oncoming hazards (such as other pedestrians or vehicles and to judge their
distance, time till interception, likelihood of collision) and do all this whilst also looking for
pedestrian aids, both far ahead (for example road crossings and sign posts) and proximate
(handrails and pelican crossing buttons). This visual demand is also supported by an audio
demand, listening for pedestrian safety cues for instance, the sound of an oncoming
vehicle, the bell of a pedestrian crossing or even social aspects like a friend in the distance
shouting your name. It is fair to conclude that adding the use of a PND, or any other mobile
device for that matter, to the highly demanding task of pedestrian navigation could easily
cause cognitive overload, causing a decrease in processing leading to the various dangerous
pedestrian behaviours reported by Schwebel (2012), Hyman (2010), Nasar (2008) and
Neider (2010). It is clear that an effective solution to the problem stated in the introduction
must work to reduce the cognitive load associated with using a PND.

Regardless of the effect constant visual and audio processing has on cognitive load, there
are also other usability issues associated with a heavy reliance on visual and audio senses
that mean mobile devices are not best suited for mobile situations. Touch screen and touch
button interfaces are now common place in mobile devices and some would argue that the
iPhone’s introduction in 2007 paved the way for touch screens to redefine the way we
interact with many everyday products (Fischetti, 2009; Frommer, 2011). Touch screens are
made usable by Graphical User Interfaces (GUIs), a GUI provides the user with access to the
functions of an electronic device through icons and graphical representations of buttons
(Christensson, 2006). However, as the graphical part of GUI implies, these interfaces rely
on visual ability and processing which comes with many associated problems as detailed
below:
**Directed Sense**

As vision is a directed sense, to perceive an object the user is required to direct their eyes towards the product; most PND users will be directing their visual field towards the path ahead making interaction with the product difficult (Brewster, et al., 2003; Lin, et al., 2008; Tsukada & Yasumura, 2004). Brewster (2003) investigates this further by creating multi-modal devices that allow the user to obtain a sense of direction through senses other than vision, he obtains positive results using audio and tactile (undirected senses) icons which he calls ‘earcons’ and ‘tactons’ (Brewster, et al., 2003; Brown, et al., 2005). Various other researchers have used both audio and tactile interfaces to try and counteract the obvious downfalls of using a directed sense. These will be discussed more in chapter 2.4 where a review of existing navigation interfaces takes place.

**Lack of Engagement and Instinct**

Some would argue that the lack of tangibility in visual interfaces creates less engaging products and as humans have a variety of senses and skills, restricting interaction to cognitive processes could cause lesser attachment to the product (Overbeeke, et al., 2004). A lack of physicality to the product could also be said to be less instinctive for use. For some time now researchers have argued that the digitalisation of products and the standardisation of button and icon based interfaces is making electronic devices hard to understand.

“*in the design of micro-electronic black boxes, the form can no longer be determined by the function*”

Bolz (1993)
This is related to Gibson’s (Gibson, 1966), and later Norman’s (Norman, 1988), ideas of affordances.

Overbeeke (Overbeeke, et al., 2004) suggests that with no mechanical components it is hard to judge the use of a product, a flat array of buttons could be applied to any electronic product and does not give any indication of what the function is without visual or verbal icons to aid communication, and relies on language and semiotic understanding which may not be universal. However, as electronics become more ubiquitous certain conceptual frameworks can be applied to particular size and shape buttons. Moggridge (2007) uses the example of a turn dial on an analogue radio where it seems a natural reaction to twist the dial. This example shows the importance of physicality in interface design, a dial could easily be replaced with two buttons (a forwards and backwards/up and down button for example) however this would require icons to convey the function, adding unnecessary cognitive load and a reliance on language and semiotics to the task.

These physical interactions can somewhat be translated to a touch screen interface for example a turn dial is easily replicated in graphical form. However, these translations rely on vision for the user to perceive and make use of them. Ramduny-Ellis, et al. (2009) consider the tactile feeling of use to be very important to product interactions. Along with the various accessibility and usability issues associated with electronic device design, they also believe the subtle physical interactions users have with products could be the key to better electronic device design; they refer to these physical interactions as a product’s ‘physicality’.

This agrees with Overbeeke’s (2007) thoughts stated at the start of this chapter, that the lack of tangibility of touch screens creates less engaging products, and adds to it by arguing that adding physicality to the product could improve ease of learning and use, and so decrease cognitive load.
Inaccessibility

Inaccessibility is prevalent in visually reliant designs. People with visual impairments do not have the ability to interact with these products in the way the designer intended as they cannot locate graphical icons nor have the ability to use visual maps. They therefore must utilise further assistive or adaptive software (Kane, et al., 2008). This issue is set to increase with the aging population furthermore considering that as we age our visual and audio senses deteriorate faster than our other senses (Burnett & Porter, 2001).

Often this issue is addressed by replacing visual interaction with audio as seen in the many ‘talking’ products available which are targeted towards people with visual impairment (e.g. talking watches, talking kitchenware, screen readers). In addition, various attempts have been made both academically and commercially to enhance the accessibility of touch screen technology for people with visual impairments, where these often rely on audio. Apple has very successfully created a usable touch based interface for people with visual impairment using their ‘voiceover’ software (Apple, 2016) making iPhones a common choice for technology users with visual impairments. However, this is still not ideal for ‘on the go’ scenarios, such as the use of a PND, as people with visual impairment rely on audio cues to navigate safely.

Similar issues of accessibility are associated with audio interaction as deaf people cannot fully utilise speech based products. Audio also brings usability issues with social acceptance and security due to the publicity of the interaction form. Many people may not want their interactions announced to everyone in a close proximity. This is especially true in the case of a PND as it broadcasts that the user does not know the area well (Silfverberg, 2003). The alternative, headphones or earplugs, not only block out important navigation cues but can also be socially restrictive, especially if walking with friends (Bornträger, et al., 2003).
2.3.3. Tactile Solution

It seems clear from the previous discussion that the reliance on vision and audio for use in a PND is not ideal. Various solutions are already being researched, some of which have briefly been mentioned already, and many of which utilise the tactile sense. Porter et al. (2005) comments on the use of the tactile sense for in-car control systems,

...the tactile sense is commonly under-used and under-valued. This is despite evidence that tactile-based controls can require minimal use of vision and information processing resources, and offer significant usability benefits in relation to screen-based interfaces.

The design of a PND could be said to be similar to that of in-car control systems as both should avoid the use of vision and audio to allow the user to maintain focus on their primary function (be it driving or walking) whilst using a secondary product.

Touch or tactility is made up of separate systems (Klatzky & Lederman, 2003):

- Cutaneous – related to mechanoreceptors found in the skin that respond to force
- Kinesthetic – related to mechanoreceptors found in the muscles, tendons and joints
- Haptic – combined input from both cutaneous and kinesthetic systems

The skin is the largest sensory organ and as such has large potential for use as an interface mode for mobile devices. A brief search shows various studies have been conducted to
uncover the potential and limits of touch especially in the realm of PNDs, these will be reviewed in more detail in Chapter 2.4: Existing Work on Tactile Navigation.

The tactile sense is very suitable for use in PNDs as it negates many of the usability issues associated with visual and audio interfaces:

- Shows direction without focus – touch allows both a specified direction whilst not having to focus attention towards the stimulus. Tsukada and Yasumura (2004) utilise this effect well in a tactile navigation aid comprised of various vibrotactile patches placed around the body which direct the user leaving vision and audio free (discussed further in chapter 2.4).

- Accessible – though there are instances where a person might lose their sense of touch, for the general population touch is a more accessible sense as it is more resilient to the aging process than vision and audio. (Porter, et al., 2005)

- Social Acceptance – touch is a silent and private way of interfacing with a product, whilst allowing the user to engage their other senses in social responses. An example of this is the Tissot Silen T watch, which allows users to check the time through touch rather than offending their company by potentially looking bored or distracted visually checking the time (Pullin, 2009).

- Cognitive Load – as touch is rarely used in navigation currently it could be hypothesized that presenting at least a proportion of the information through touch, rather than the already heavily utilised vision and audio, could lower the cognitive load; this is referred to as the modality effect (Sweller, 2009).
2.3.4. Conclusion

Many sources indicate that using a mobile device whilst on the move encourages negative pedestrian behaviours (Bungum, et al., 2005; Hyman, et al., 2010; Nasar, et al., 2008; Neider, et al., 2010). Whilst much of this evidence cites the mental demand of interacting with the device as a cause for the negative behaviours, a significant portion of the research also cites visual engagement with the device as a cause. An overloading of already utilised senses alongside a need to focus the visual field on the device itself causes a variety of both dangerous and anti-social outcomes.

The tactile sense is seemingly well suited to the application of mobile devices particularly for PNDs where the user’s engagement with the environment is of particularly high priority and may provide distinct benefits above and beyond visual and audio interfaces.
2.4. EXISTING WORK ON TACTILE NAVIGATION

A literature review was conducted to find PNDs that utilise the tactile sense, these seemed to fall into two categories, ‘designed for people with visual impairments’ and ‘designed for people without visual impairments’. Though some researchers do make reference to the resonance between these two categories, very little work was uncovered which addressed both categories. In the commercial realm, stand-alone devices were also very segregated between devices created for people with visual impairments and devices created for people without impairment, and dedicated pedestrian apps generally relied on visual or audio feedback. This section reviews the existing work, providing comparison between the two usage intentions.

Tactile navigation is not a new concept; most examples rely on vibration feedback, this is for good reason; vibration motors are cheaply attained and easily integrated into electronic circuits, their size and simplicity mean that they are a good choice for commercial exploitation. For these same reasons the focus of the literature review has been mostly on vibro-tactile feedback, however other methods have not been ignored and will appear, if not in depth, in the text.

2.4.1. Background to Navigation

The act of determining and then following a path from a start point to a destination is called either wayfinding or navigation. Whilst the terms are often used interchangeably there is a difference in meaning: navigation is the act of moving from one point to another in open space, wayfinding is the act of selecting a route from a predetermined network of paths in order to travel from one point to another (Golledge, 1999). For the purpose of this thesis
the more common term ‘navigation’ will be used for both activities unless more specificity is required for context.

In order to undertake a navigation activity one must develop an internal representation of an area. These internal representations are called ‘cognitive maps’ which are developed using one or more of the following three methods:

- Exploring the environment
- Exploring secondary information sources such as: maps, books and videos
- Navigating through the environment in a controlled fashion, for example, navigating with a GPS device

(Golledge, 1999)

Whether directly or through a secondary information source an environment can be experienced through either an eye-level, ego-centric “field perspective” or from above in a configuration or layout, allocentric “observer perspective” (Werner, et al., 1997). The three methods to create cognitive maps build upon an individual’s spatial knowledge of the area, there are three types of knowledge:

1. Declarative knowledge – this knowledge type “consists of the inventory of pieces of information contained in long-term memory” (Golledge, 1992). When discussing spatial knowledge and navigation this consists of the unique objects or experiences at fixed locations. This may take the form of a building, a road layout, a smell or a sound as long as it is fixed and consistent.

2. Procedural knowledge – this knowledge type consists of the rules required to “link pieces of information into ordered strings” (Golledge, 1992). When discussing spatial knowledge and navigation this consists of the associations and relationships between points, sequences of locations and rules for navigation.
3. Configurational knowledge - This third type of knowledge is noted by Golledge (1992) who states that theories which rely on declarative and procedural knowledge exclusively fail to account for the complete development of spatial knowledge. Configurational knowledge consists of “an awareness of configurational properties ... of various types of spatial features”. This type of knowledge comes from a more general and comprehensive awareness of spatial systems.

When discussing navigation these types of knowledge are more regularly referred to as Landmark (declarative), Route (procedural) and Survey (configurational) knowledge (Werner, et al., 1997; Meilinger & Knauff, 2008; Krüger, et al., 2004). Whilst landmarks alone (with no spatial context or relationships) feed into navigation activities they are not enough to stimulate navigation therefore route knowledge and survey knowledge are the most commonly discussed.

To undertake a navigation exercise the user requires: a start point, an end point, and the ability to decode directional and distance information between them. When utilising a navigational aid the user will already have a start point and they will be provided with information to decode in order to reach their destination. The prior discussed vocabulary also translates into the route representation that navigational aids will use to provide this information, for example: list of directions consisting of right, left and forward commands in field perspective are route based representations where as an observer perspective map of an area with the route drawn as a line would be a survey representation of navigation information (Meilinger & Knauff, 2008; Werner, et al., 1997).
When building mental models of spatial information individuals show preferences to the representation of the data. Evidence suggests that representing spatial data in line with individual’s preferences results in better navigational performance when presented with the data prior to the navigation task (Pazzaglia & De Beni, 2001). However, the effect of the representation type versus representation preference on navigation performance when presented during use is not well documented (Pazzaglia & De Beni, 2001; Ishikawa, et al., 2008). Noordzij, et al. (2006) studied the effect of representation type on the ability to build spatial models between participants with and without vision, he presented both groups with verbal descriptions of an environment in either a survey (configurational) or a route based (procedural) representation. The results showed that people with visual impairments were better able to construct spatial models utilising route based descriptions whereas people without visual impairments were better with survey descriptions. A possible explanation given for this finding is that the mobility training that people with visual impairments receive is ego-centric due to a lack of visual ability to perceive external cues.

2.4.2. Micro vs Macro

“The traditional white cane is perhaps the simplest example of a visual sensory substitution device”

JOHNSON AND HIGGINS (2006)

The utilisation of the tactile sense is routine in people with visual impairment’s daily navigation. People with visual impairment often receive direct teaching on (or if not learn independently) methods of sensory substitution within the navigation process. Methods
that utilise the tactile sense include: using a cane, a guide dog, and the utilisation of tactile pavements.

Strothotte et al. (1995) and Bradley and Dunlop (2005) (amongst others) recognise the difference between micro-navigation and macro-navigation; micro meaning localised to the immediate surroundings, avoiding obstacles, reacting to different surface textures and moving on a local level. Whereas Macro is concerned with distance, getting from A to B and wayfinding. As this thesis is concerned with the design of PNDs which aid macro-navigation the review focusses on this type of product; however micro-navigation aids such as obstacle avoidance aids may have some relevance in terms of the vibro-tactile interface style and are included.

Often the devices which aid micro-navigation require an active tactile interface. Gustafson-Pearce et al. (2007) distinguish between an active and a passive tactile interface; an active interface “requires the user to engage in information gathering/processing in order to disseminate the information” (for example, the sweep of a cane to find obstacles) whereas a passive interface simply presents the information and the user chooses how to respond. As discussed in chapter 2.3 active information gathering requires activation of the working memory to process the new data arriving, on the other hand a passive interface, once learnt, will rely more on long term memory as reactions to a passive interface can be based on previous use and experience.

2.4.3. Vibro-tactile interfaces for navigational commands

As previously mentioned, many of the reviewed products and research rely on vibro-tactile feedback due to its ease of application and commercial viability. Brewster (2003)
introduces tactons or tactile icons and describes them as “the delivery of structured information through the tactile sense.”

He describes a variety of ways in which information can be encoded into the delivery of tactile messages that could be utilised to create structured commands:

- Frequency
- Amplitude
- Waveform
- Duration
- Rhythm
- Body location
- Spatiotemporal (position and rhythm to ‘draw’ shapes)

On review of the literature discussed further in this chapter the most common delivery methods utilised in navigation aids can be simplified into two categories:

- Direction – utilising body location to indicate direction of travel
- Profiles – creating a language, differentiating commands though:
  - Frequency
  - Duration
  - Rhythm
  - Tempo

A variety of studies have been conducted showing the effectiveness of these interfaces. Gustafson-Pearce et al. (2005, 2007), Pielot and Boll (2010), Johnson and Higgins (2006), Cardin and Thalmann (2008), Heuten et al. (2008) and Tsukada and Yasumura (2004) all take advantage of ‘location’ in their torso based designs. Utilising the user as a central point and vibration locators positioned around the body they conveying route based
representations of navigational information in real time. Like-wise, Peepo GPS (Peepo GPS Ltd, 2014) and Haptic Glove (Zelek, et al., 2003) utilise the position of multiple vibration but in more localised concepts (using the positioning of the motors on the hand). The products that have been reviewed in academic studies have all had successful results, with much of the literature noting the ‘intuitive’ nature of the tactile feedback (Gustafson-Pearce, 2005, 2007, Tsukada and Yasumara, 2004, Pielot and Boll 2010).

In general, the users’ reaction to locational vibrotactile feedback is dependent on whether the device aids micro or macro-navigation. For micro-navigational purposes (object detection devices) the vibration feedback is to indicate the location of an object and so the reaction would be to move away from the feedback. The Haptic Glove (Zelek, et al. 2003) is an early example of this, an assistive macro-navigation aid that that allows the user to ‘look’ at their surroundings through their hand and to determine the position and distance of obstacles. Results of testing the haptic glove show that it is useful in obstacle avoidance, however whether it is more effective than traditional more active tactile methods (the white cane) is not proven, and whether it is more commercially viable is not discussed. The UltraCane (UltraCane, n.d.) is a commercial device which mixes the two feedback types, and provides active kinesthetic feedback through the normal sweeping of a cane and adds another level of passive cutaneous feedback for objects above the cane’s reach through vibration motors.
Macro-navigation on the hand is concerned with wayfinding and communicating a path to walk along. For this, many designers utilise vibration location to communicate the direction that the user should follow. The Tactile User Guidance, (TUGs, Gustafson-Pearce, 2005) is an early example of this, a torso based harness with multiple vibration motors located around the body - the user is meant to walk towards the direction of vibration. Reaction to this simplistic location style feedback has proven to be very instinctive, the TUGs researchers asked the users to ‘react naturally’ to the feedback they receive and achieved positive results with very little training on the device. It could also be argued that because this is not language based, this directional command is likely to be understood on a wider basis than audio/textual directions.

Lin (2008) investigated the use of tactons to provide navigation commands. After conducting questionnaires Lin discovered that the two most important pieces of information in navigational directions for a pedestrian are ‘direction of travel’ and ‘distance to next turn’ and so produced distinct patterns of vibration using a single vibration motor. Both rhythm and tempo were utilised to create understandable profiles. The rhythm indicated the direction of travel (three different rhythms were created which indicated: right, left and stop) and tempo indicated the immediacy of the command (a slower tempo...
for turn at next block and a faster tempo for turn now). In the end five separate profiles were created:

- Turn right now
- Turn right at next block
- Turn left
- Turn left at next block
- Stop

After a short ‘learning’ period Lin achieved positive results for the devised profiles, users were able to discriminate between the different patterns and translate the information received into commands allowing them to navigate along a path. Why Lin chose to use a single motor technique (rather than utilising the location technique) is not clarified within the text, however, it is likely that this system is intended for a use in a mobile phone which would only have a single vibration motor. Though results achieved were positive, due the fact that a learning period was needed it could be argued that this technique is less intuitive than the location technique.

Strength of vibration was only utilised by one product, the Haptic Glove (Zelek, et al., 2003), to help indicate the proximity of an object. Why strength is not considered in other designs was not documented, however a few issues can be considered:

- Soft vibration may be easily missed, especially if on a device that is worn over clothing layers
- Sensitivity to vibration will vary from user to user
- It is slightly more difficult to program strength of vibration rather than a simple on/off
- User preference is prevalent in the strength of vibration, some users may want the option to turn their devices onto a ‘quiet or loud’ mode dependant on
contextual issues such as clothing, whether the journey is new or familiar and whether they are distracted whilst using the device.

Some devices mixed the different styles of vibro-tactile feedback using both location and profile to communicate navigational information. The “Tactile Wayfinder” (Pielot & Boll, 2010) uses location to indicate direction using a torso based design and profiles to communicate a ‘look ahead’ function where the system tells you the direction of not only the immediate turning but also the following turning. Pielot and Boll cite previous tactile navigation work that shows that they accept that vibro-tactile navigation can be successful and are now testing the limits of information that can be communicated. Results were mixed; errors whilst using the tactile system navigation were higher than when using a visual system. Contrasting this, orientation and completion times were similar (slightly better but not significantly so) and amount of ‘near collisions’ were significantly fewer. Pielot refers to the navigation errors as “false interpretation by the user” which could indicate that with a greater learning period and more instructions this error would reduce and considering ‘near collisions’ were significantly less frequent it can be said that, though the device may be harder to learn it is safer once the user is used to it.

Due to the compact size, inbuilt GPS and internet connection, route planning and navigation are becoming a more commonly seen function on mobile phones. This provides
an obvious limitation in vibration motors, allowing only one motor to be utilised, the designers are forced to use some form of profile for navigational information.

Google Maps is a commonly used application for pedestrian navigation on mobile phones – available for free on most smart phones. The app provides mapping in multiple modes, including a specific pedestrian mode. This provides turn-by-turn navigation in the same way as an in-car navigation tool but using pedestrian walking paths. It is available using audio feedback or visual feedback for the main bulk of navigational information, however, vibro-tactile feedback is utilised to prompt the user before an instruction is relayed. This allows the user to divert their attention from the device for the main bulk of the journey and only look at the device when necessary (Thomas, 2010).

PocketNavigator is an app that has been created as part of the ‘Hapti-map’ project, a European funded project that involves many universities and focuses on creating multi-modal mapping and navigation (HaptiMap, 2009). The app utilises the single vibration motor and creates profiles in a similar style to Lin (2008) to direct the user. However, it does not rely on a turn-by-turn navigation system (Pielot, et al., 2010). Instead the user is directed using a compass style direction technique indicating where the next waypoint is, virtually pointing the user in the correct direction. Vibration rhythm and duration create a Tacton used to indicate direction and distance to a waypoint; a long pulse followed by a short pulse shows
that the waypoint is to the right hand side of the walking path; and the length of the longer pulse indicates the distance to the waypoint.

Pielot et al. (2010) achieved positive results using this system as participants managed to navigate to a destination using the tactile representation of a compass bearing alone. Breaking away from the turn-by-turn navigation also allows the user to explore different paths and routes that may be preferred in more leisurely pedestrian journeys. This style of navigation is also seen in Robinson et al.’s (2010) research where audio-bearing based feedback is used to guide the user to their final destination. These devices were designed with sighted participants in mind where specific paths maybe less important. The device was not tested with people with visual impairments.

Further research is needed to understand the full capabilities of vibro-tactile feedback to relay navigation feedback, including its limitations both in a functional sense (what is it possible to communicate) and in a usability sense (what information would users want to be communicated via tactile feedback). However, research conducted so far shows positive results for people with and without visual impairment.

2.4.4. Physical Design

2.4.4.1. For People with Visual Impairments

A variety of designs have been created to allow a passive tactile interface for people with visual impairment. These include:

Academic:

- Waist belts, sometimes alongside a backpack (Johnson & Higgins, 2006)
Harnesses worn on the torso (Gustafson-Pearce, et al., 2005; Gustafson-Pearce, et al., 2007)

Gloves (Zelek, et al., 2003; Ghiani, et al., 2008)

Commercially:

Attachments to a guide dog harness (Peepo GPS Ltd, 2014)

Footwear (Le Chal, 2015)

It is clear from this list that handheld devices are avoided when designing products for people with visual impairment. Various reasons are given for this design decision. Gustafson-Pearce (2005, 2007) created the TUGs system and chose a body harness based on specification requirements of a focus group, the key specifications that led to this design were:

- “The information dissemination devices had to be hidden or as unobtrusive as possible”
- “The devices should not constrict movement and should leave the hands free”
- “Many blind and visually impaired individuals were either suffering from diabetes or age related issues with compromised the tactile or haptic senses in the extremities (hands, feet) therefore the interface should not be Braille of similar”

People with visual impairment often have to utilise their hands when utilising a mobility aid (using a cane or holding a guide dog handle), however, mainstream users in general may have given the same specification as often walkers may be holding a bag or another device.

Though this specification was built from focus group feedback, Pullin (2009) argues that the idea of assistive devices (be it navigation aids, hearing aid, sight aids) being ‘hidden’ is antiquated. He argues that creating hidden assistive devices restricts the design from
mainstream interest as a hidden design has less focus on aesthetics and in-turn less desirability (for specific and mainstream markets). The counter argument is that a “strange” or “outlandish” looking systems “could potentially make one vulnerable” (Gustafson-Pearce, et al., 2005). However, it could be reasoned that the focus on functionality and not aesthetics often seen in assistive products is what would cause a system to be viewed in that way. Gustafson-Pearce et al. (2005) in the same chapter refer to a desire to not ‘stand-out’ from other pedestrians and these specifications were used to come up with a large harness worn on the torso but under the outer layer of clothes, it could be argued that the whole product life-cycle has not been taken into account and that whilst it may hide the device throughout the journey, at the start and end point of the journey it will be very apparent when they have to take off a large torso harness.

Gustafson-Pearce’s (2005, 2007) torso based design does however, have the added positive of intuitive use, as the design provided navigational information in the form of vibro-tactile feedback in a directional capacity, its ego-centric design allows the user to directly relay the direction the vibration on their torso to the direction in which they should be heading. This design decision was also reflected in the tactile navigation aids for people without visual impairments. However, this design decision did bring up some usability problems in regards to wearing it above clothing.
Le Chal (Le Chal, 2015), which began development in 2011, is a commercially available tactile navigation solution built into the sole of a shoe, or an insole. The system places a vibration pod in each shoe. Changes in direction are indicated by activation of a vibration module in a single shoe, for example, should the user have to turn right, the right shoe would vibrate. A simple solution, this provides no movement restraints, but does require the user to always wear the same shoes, or plan ahead and swap insoles from shoe to shoe. The shoes are very stylish and the website shows that the designers paid much attention to making the product as desirable as possible.

Haptic Gloves (Zelek, et al., 2003) and Peepo GPS (Peepo GPS Ltd, 2014), two more vibrotactile based devices, do not avoid the use of the hands. The hands, particularly the fingers, are very receptive to vibro-tactile feedback (Society for Neuroscience, 2012) and so they utilise this to its full potential whilst at the same time creating systems that allow for the hands to be utilised for other purposes. Haptic Gloves (Zelek, et al., 2003) are an object detection device, as the name suggests, the glove design allows movement of the hand (rather than a device design that the user has to actively grip) they also use the dorsal part of the finger rather than the tip and leave the fingertips un-gloved to allow the user to feel Braille. The Peepo (2014) concept device clips onto a guide dog harness; accepting that some people with visual impairments will already have limited use of their left hand and so not impeding their movement any further. The Peepo GPS design has the obvious limitation that if the user is not also a guide dog user it is bulky and uncomfortable to hold.
2.4.4.2. For People without Visual Impairment

The design of tactile devices for people without visual impairment is also varied, however there seems to be significantly less reasoning behind physical design choices for people without visual impairment evident in the literature. Designs include:

- Belts/Torso harness (Tsukada & Yasumura, 2004; Pielot & Boll, 2010; Cardin & Thalmann, 2008)
- Handheld devices (Pielot, et al., 2010; Robinson, et al., 2010; Wang & O'Friel, 2007; Lin, et al., 2008; Pielot, et al., 2012)
- Ear clips (Kojima, et al., 2009)
- Jewellery (IDEO, et al., 2001)
- Shoes (Frey, 2007)

Tsukada and Yasumara (2004) give reasoning for their use of a belt (Activebelt) citing the suitability of an ego-centric design for providing directional feedback, they also rationalise the decision through the prevalence of belts in everyday clothing choices and Pielot and
Boll’s (2010) Tactile Wayfinder simply uses the success of other researcher’s belt-type devices as qualification for their own.

Many of the trials of tactile navigation for people *without* visual impairment use simple handheld devices, and commonly there is no explanation of specific physical device design. It may be assumed that the researchers are simply testing the vibro-tactile interface and have no immediate concern for the device design or it could be that they are basing their ideas around the prospect of utilising the interface style on a mobile phone type device; as Robinson et al. (2010), Lin et al. (2008) and Pielot et al. (2010 and 2012) only use one vibration motor in their interface design this could be a fair assumption.

MOMO (Wang & O’Friel, 2007) is a different type of handheld device, a design concept rather than commercial idea, it takes the form of a large egg which is held in both hands and it simply ‘leans’ in the direction the user is to move. Its organic shape and knitted cover gives this product a fun and friendly aesthetic. Though a fun product it is clear that the current design MOMO has not been optimised for everyday use and is a novel guide rather than a practical PND.

![Figure 12: MOMO guide](image)
GPS toes (IDEO, 2001) a design concept created by IDEO, is a wearable navigation system, two toe rings (one for the left foot one for the right) that vibrate in the direction the user should turn. Whilst there is no reported functional reasoning for the toe rings over any other jewellery style the idea of the projects aim was to “prove that new devices needn’t look alien to your person and that we can make technology adapt to our lifestyles rather that the other way around.” CabBoots (Frey, 2007) by Martin Frey (a senior interaction designer at IDEO) uses the highly sensitive yet underused receptors of the foot. He takes influence from natural trodden paths that form in a slightly concave cross-section, which although may not be noticeable enough to draw a walker’s attention, actually angle the foot in a way that draws the user to the centre of the path; allowing the user to “walk the path blind”. Frey replicates this feeling using pneumatic activators creating the feeling of a path without actually having a path to walk on. This idea means the user has no additional movement restraints but does require the user to strap the device to the sole of their shoes, as the idea evolves it may be possible to miniaturise the technology into shoe inserts similar to the Le Chal (2015) inserts previous discussed.

Alongside the previously discussed tactile devices there are a variety of pedestrian navigation tools that do not utilise tactile feedback. The Garmin eTrex series (Garmin, 2013) are commercial pedestrian PNDs, targeted towards hikers and leisure walkers. Although
this system does not have any tactile feedback there are specific physical design considerations that make it suitable for pedestrian use, these include:

- Sunlight-readable display
- Waterproof
- Clear grip zones
- Durable (drop-proof)
- Dust-proof

These features are marketed in a context specific fashion; as it is marketed towards hikers it advertises hardy features for the harsh, rural, usage environment. However, this style of feature would be useful in any PND product as there is a chance of dropping a device in a puddle or walking in glaring sun in most urban locations.
2.4.5. Comparisons

2.4.5.1. Physical Design

It is interesting to note that reasoning for the physical device design in the research papers aimed towards mainstream users has far less presence in the texts in which the products are presented (when compared to devices designed for people with visual impairments), it could be that:

- The researchers are more interested in testing the interface (be it vibration or pressure or any other tactile method) rather than creating a commercial design
- The designer’s choice of form is more of an aesthetic decision than reliant on usability issues or user specification

Though the functional decisions of device design for people with visual impairment are well documented, there was rarely reference to the aesthetic, with the exception of Le Chal (Le Chal, 2015). This corroborates Pullin’s (Pullin, 2009) theory that design for disability often focuses so highly on functionality and accessibility that the creative, and desire aspects of design are overlooked. In the designs for people without visual impairment it was clear that the more academic solutions focused highly on the interaction style itself and so also overlooked aesthetic, however, designs that were intended for a commercial, or just conceptual audience, were very aesthetically driven. IDEOs GPS toes was, in fact designed to directly show that technology can be beautiful (though the fact that Graham Pullin previously worked at IDEO may mean a more than coincidental link between the work).

Also worth noting is that many of the designs for people with visual impairment are ‘wearable’; however in mainstream design wearable technology is relatively uncommon (with watches being the most obvious exclusion). Designs for people without visual impairment seem more forgiving about using handheld devices.
Belts appeared more than once in both sections and the investigators/designers observed that the design allowed for a very intuitive system, by placing the user in the centre of the feedback; directional information was very easy to communicate. Little feedback was given, or at least reported on a belt design itself in respect to how desirable the product is; though some issues did arise due to ‘fit’ of the belt and the vibro-tactile feedback was difficult to feel through some clothing (Tsukada & Yasumura, 2004).

2.4.5.2. Functionality

Comparisons with other products are essential to the validation of a new product, if a product does not outperform (in some way, be it functional, usability or price) existing products there is little point in realising it onto a commercial market. Some of the papers previously discussed conducted comparative trials: Gustafson-Pearce (2007) tested a vibro-tactile torso-based display against simple left/right audio instructions delivered through an earpiece. Though, in the title of the paper, they clarify the results are intended for people with visual impairment they also test people without visual impairment. In an earlier paper (Gustafson-Pearce et al., 2005) there is a mention of the resonance between people with visual impairment and situationally disabled people and so it may be assumed that they are testing the system for a more general audience. Testing protocols involved users standing still but responding to signals (audio and tactile) whilst ambient street noise is played. In these conditions the tactile interface outperformed (more commands were correctly deciphered by the users) the audio interface for both people with and without visual impairment, within that, people with visual impairment outperformed people without visual impairment. However, this testing protocol could be considered biased, where the audio interface had to compete with background noise the tactile interface was given preferential conditions by not creating realistic tactile noise that would be created whilst
walking outdoors. In fact, in previous testing for the same system it was noted that clothing
moving in the wind affected the performance of the system (Gustafson-Pearce, et al.,
2005).

Pielot and Boll (2010) tested another torso display against a commercial navigation system
(a visual interface). This experiment was more comprehensive, testing in a real world
environment (a busy town centre). Pielot measured the user’s spatial knowledge, the
attention devoted to the task and the performance to create a comparison matrix. Results
showed that the tactile interface did free the user’s attention when compared to the visual
system, this indicates that the cognitive load may be lessened with the tactile interface and
that this interface style may be safer (also shown by a reduction in near collisions when
using the tactile interface). However, based purely on navigational performance, the visual
interface was superior. These tests were conducted exclusively with sighted participants.
Though they do not conduct comparative testing, Tsukada and Yasumura (2004) briefly
discuss the merits and demerits of a tactile system compared to a visual system concluding
that vibro-tactile feedback:

● is intuitive rather than skills based (reading maps or understand language)
● does not occupy other senses
● makes it harder to convey complex layouts
● is more difficult to interact with

Though these papers were the main comparative studies, inevitably more comparisons
were drawn in usability feedback after testing when users compared the tested tactile
experience to their existing visual or audio based experiences.

Robinson’s “I did it my way” (2010) is a tactile system developed to enhance the
recreational aspect of navigation, the system guides the user using vibration but varies as
different route choices become available. In the user feedback related to the tactons some
users commented “they would not use haptics for navigation because they preferred to have constant knowledge of their position and destination”. This view was echoed in the feedback on Pielot and Bolls’ ‘Tactile Wayfinder’ (2010) where it was stated “many participants missed a map to get an overview about their environment”. Whilst the tactile modality performed as well as the visual modality many users were sceptical about its use as it did not provide the survey representation that users expected. This highlights the importance of prior experience when assessing product performance. Many authors have evidenced that prior experience is a key factor in product performance (Blackler, et al., 2009; Langdon, et al., 2010; Hurtienne, et al., 2013). Hurtienne, et al. (2013) discuss the relationship between prior experience and product usability and effectiveness. They discuss that two pre-condition factors of experience: exposure (duration of use, intensity of use and diversity of use) and competence (skills and knowledge for use). They demonstrate that participants who have higher levels of competence and exposure were able to use devices with fewer mistakes and reported higher satisfaction levels. Pielot’s (Pielot, et al., 2011) comparison between a tactile, visual and mixed condition was the only tactile navigation found to reference the effect of prior experience on product use. They report that more prior experience with navigation aids resulted in higher navigation efficiency for both the tactile and visual conditions. However, regardless of product efficacy in feedback on Gustafsons-Pearce’s Tactile User Guidance, (2005 and 2007) users seemed more open to the new experiences noting that although it felt “strange” and “unusual” it was not uncomfortable and with a longer period of use could become very comfortable.

2.4.5.3. Navigation Information Requirements

What information to convey is important in the design of any product, particularly an instructional product such as a PND. Too much information and you will cause frustration
and annoyance to the customer along with a higher cognitive load which may impair the abilities of the user; too little information and you may impair the functionality of the product. To keep device and user performance at its optimum the designer must consider the navigational needs of the users. As discussed in Chapter 2.2.2 when designing an innovative interface the opinions of ‘lead’ or ‘extra-ordinary’ users may be of value and it is suggested that if trying to reduce visual reliance then people with visual impairment, who have had to learn not to rely on vision, may provide greater insight through more experience and a greater ability to communicate their needs (Hannukainen & Holta-Otto, 2006; Pullin & Newell, 2007).

Bradley and Dunlop (2002) conducted a study into the differences of route descriptions when provided by people with and without visual impairment. It could be argued that since people with visual impairment do not use vision in their day-to-day navigation needs the instructions they provide may be more succinct and effective for the development of a non-visual display. To do this Bradley and Dunlop (2002) grouped different route descriptors into categories (for example, directional, environmental, sensory, etc.) and asked people with and without visual impairments to describe routes. They then categorised the directions within the descriptions. The information was then tallied to create two sets of walking instructions, one created using information that a person without visual impairment is more likely to convey and one created using information a person with visual impairment is likely to convey, and tested these to understand the usability implications.

“By using an objective and subjective assessment, it emerged that people with visual impairment rated their mental workload lesser when presented with information from visually impaired participants’ descriptions. This was also reflected in fewer deviations from the route and quicker times to complete those
This showed that information gathered from people with visual impairment could have a direct negative effect on the usability of a PND for mainstream users. However, this study was specific to audio instructions with which both people with and without visual impairments will be accustomed and therefore may not be the same when reviewing tactile navigation aids which will be novel for both users.

Lin (2008) conducted an informative study before designing a PND in which five experienced PND users determined that the most important information for a pedestrian navigator was ‘direction of travel’ and ‘distance to next turn’. It is interesting to note that direction of travel and distance to next turn both fall into instructional categories that Bradley and Dunlop noted were more frequently used by people with visual impairment (directional and numerical). The contrast between these two studies could be used to argue that context must be taken into account as in the previously mentioned study (Bradley & Dunlop, 2002) participant described known routes. For these descriptions of known routes people without visual impairments utilised information described as: textual-structural (shop/building names) and textual area (street names). In the context in which a PND is frequently used (in an unknown city), these information types could be useless even to another sighted person (for example street names may only be useful if the user knows where the street is or can see a street sign, which is not always the case). The fact that Lin (2008) evidence that people with visual impairments and experienced PND users show the
same instructional needs corroborates that there is some level of resonance between people with visual impairment and PND users.

MoBIC (Strothotte, et al., 1995; Petrie, et al., 1997) was a multi-national research project with the aim to develop a navigation aid for people with visual impairment. Though the device was not tactile, a lot of time was spent in creating a specification for a usable system. Innovations that people with visual impairment wanted to see in the device design included:

- Planning a route from home
- The ability to place constraints on a route
- The ability to add personal comments/recordings to specific points along the route
- To control the flow of information (to control whether the device will simply tell you directions or, the other end of the spectrum, every shop name and house number you pass)
- No headphones

However, it is worth noting that MoBIC research was conducted as early as 1995, this is before the mainstream use of internet route planning services which allow any user, whether with or without visual impairment to achieve many of these specifications on their day-to-day devices. It is interesting to note that these navigation needs of people with visual impairment are very similar to the needs of people without visual impairment. Google Maps (or other internet route planning services) allow a user to plan a route from home, and to place a constraint on a route. The control of information was an interesting specification as it came along with the comment,
“The point was made, by one potential user, that people without visual impairment choose what they attend to and that blind and partially people without visual impairment should also have this choice.”

PETRIE ET AL. 1997

It would be interesting to understand what value a sighted person would place on more descriptive information that might be fed to a user with visual impairment. Gustafson-Pearce et al. (2007) touched upon these needs, classifying information into two categories:

- Commands – functional navigational instruction (right, left, forward)
- Conversation – detailed contextual information (shop names, transport issues)

To create a usable system they decided that commands could be displayed through tactile feedback and conversational information is better informed through audio feedback. It may also be interesting to understand what value the ability to add personal notes to a GPS location would have to a sighted user as this is the only specification which has not particularly filtered into mainstream PNDs (it is however, available on the Trekker Breeze and Kapten GPS, two commercial PNDs targeted at people with visual impairment).

2.4.6. Testing techniques

A variety of testing techniques have been utilised to understand the functional appropriateness for the tactile modality within pedestrian navigation. Many studies use early lab based trials to investigate tactons and their deciphered meanings and early stage prototype systems (Cardin & Thalmann, 2008; van Erp, 2001; Gustafson-Pearce, et al.,
However, many of the studies document the requirement for field testing as a vital next stage.

A variety of studies document that walking, particularly in a naturalistic environment affects mobile device performance and subjective ease of use (Barnard, et al., 2007; Mustonen, et al., 2004; Mizobuchi, et al., 2005; Lin, et al., 2007; MacKay, et al., 2005). Whilst these results are all based on visual interfaces, cognitive load is regularly cited as a primary reason for the decrease in performance and ease of use, in which case this requires any navigation product to be tested in a walking scenario. Tscheligi and Sefelin (2006) and Pielot et al. (2012) both highlight the importance of context when testing pedestrian navigation devices. Emphasizing that wayfinding is only one part of the navigation task and in ‘real-life’ scenarios it is likely that the user will have multiple elements competing for their attention.

Field studies then fall into two categories, single condition exploratory studies and comparative studies. Whilst exploratory studies (Gustafson-Pearce, et al., 2005; Lin, et al., 2008; Robinson, et al., 2010) provide evidence that tactile interfaces can direct a user around a route they provide no evidence that the interaction style has any benefits beyond currently available visual or audio devices.

Elliott et al. (2010) addresses both context and comparison. They test a tactile device in a highly demanding military task scenario. Their results are positive indicating that the tactile system, and the mixed system of tactile and visual show significant benefits in the contexts. Soldiers reported an increased ability to identify targets and manoeuvre around navigation obstacles. However, whether these findings can be translated to everyday use where priorities and cognitive load are assumed to be very different is not clear.

Pielot et al.’s (2012) study goes a step beyond the expected in-context study as they distribute a tactile navigation app through the Google play store, in turn over 3000 users
downloaded their device. In order to gather useful data a set of filters was applied on the incoming data and overall 301 trips were recorded. Whilst a large scale study, the lack of control was evident, and many assumptions were made concerning what the actions the user was taking when holding the device in a certain position. The study itself provided very little data into how or why the users implemented the tactile feedback, only that it was used and whether the phone was oriented towards their face (indicating they might be looking at the screen) or the screen was on or off. Pielot et al. (2012) did recognise the limitations of the study, and suggest that it should be viewed in parallel with other work. An earlier study conducted by Pielot and Boll (2010) shows a tactile aid being used in-context, albeit along a predefined path, and in comparison to a visual device, comparing a torso based system with a commercially available visual aid. Results in this study were not entirely positive, whilst the tactile device was able to navigate the users around complex paths it produced more navigation errors. However, the study did show an increased awareness of the user’s environment when using the tactile device as evidenced by a reduction in the amount of near accidents when using the novel system. Pielot and Boll also investigated the system’s ability to aid the user in spatial knowledge acquisition and highlighted this as a key requirement for a well-designed navigation system, the tactile system showed no improvement on the visual system in this area. The study shows interesting results in that the tactile navigation device did allow for fewer near accidents, thus increasing safety of the device. Two issues arise with this metric:

1. There is no control. Near accidents are defined as, “situations where a participant nearly collided with another person or an obstacle”. As the test was conducted in a public pedestrianized area there is no guarantee that the opportunity for near accidents was the same for both conditions.
2. There is no evidence that this could not be achieved using the audio devices currently on the market.

Hyman (2010) uses a unique method for testing a user’s engagement with a mobile device with the environment in their paper “Did you see the unicycling clown?”; in which they inserted unusual and distinctive stimuli, unsurprisingly a unicycling clown, into the testing environment allowing for both controlled and safe investigation into environment engagement. However, it could be argued that this particularly distinctive stimulus is not representative of naturalistic navigation behaviour.

Pielot and Boll’s (2010) study also lacked information provided on the user’s opinion of the device usage, benefits and negatives and so no opportunity to understand expected use scenarios and subjective benefits of either device.

Whilst containing many areas where further research is required, Pielot and Boll’s study is arguably the most comprehensive testing of tactile navigation devices and contains many interesting testing methods.

2.4.7. Conclusion

A variety of products, both commercial and academic, are already available for evaluation. However there seems to be a distinction between two markets, people with visual impairment and people without visual impairment. Although some resonance is mentioned between them, there is no research that fully investigates how a single product may be able to fulfil the needs of both markets. The literature review highlights that products designed for people with visual impairment seem to focus entirely on accessibility and a lack desirability beyond the specific needs of the target audience is noted; products designed for people without visual impairment seem to focus on the functionality of tactile interface as an interaction form and worry little about reasoning for physical design
decisions. This is supported by the types of experiments that have so far been conducted which focus on functionality of the system rather than usability or desirability and lack the appropriate contextual testing alongside comparison to other currently available systems.

Vibro-tactile feedback is a cheap and effective solution to provide navigational information through the haptic sense. However, more research is needed to understand what users need and want to be communicated through tactile means and what information would be best communicated through more traditional interfaces. Both tactile profiles and locational displays have proved effective in basic navigation and show promise for future interaction styles.

Various solutions to personal navigation through a tactile modality have already been investigated. However, the research to date focuses on either the inaccessibility aspect (and tries to create a usable product for people with visual impairment), or on the safety aspect (and tries to create a product which relies less on the visual modality). Few seem to recognise the overlap or connection with each other, as tactility is a recurring theme in both sides of research it seems to be a rational further step to ask whether a PND designed by and for people with visual impairment could actually be a more usable, safer solution for a mainstream market? Will involving people with visual impairment in the design process produce innovations that outperform competing products designed within the mainstream market?
2.5. LITERATURE REVIEW CONCLUSIONS

The literature review explored a variety of design process methods in order to identify those most suitable for working with people with disabilities. Many practitioners suggest that people with disabilities are not only useful in the design process but can provide invaluable insight into different usage styles and stimulate new ideas. Pullin and Newell (2007) suggest that in some scenarios the needs of people with disabilities are ‘resonant’ with the needs of mainstream market users and this could be leveraged as a tool for innovation, they call these users with disabilities “extra-ordinary users”. This resonance was felt to be prevalent in the realm of pedestrian navigation as, people with visual impairment cannot rely on visual interfaces, and people without impairments should not rely on visual interfaces.

Gaining empathy with the end-user is considered vital for designers especially in scenarios where the end-user has very different requirements to a mainstream market. Sanders (Sanders, 2002; Sanders & Brandt, 2010) suggests that the best way of doing so is to encourage user participation in the design process achieved by utilising engaging and interactive creativity tools that prime, probe, identify and generate ideas through uncovering both explicit and latent knowledge. However, there are very few examples of this when working with people with sensory impairments in the literature.

When looking at products currently on the market and in the literature it seems unlikely that participatory engagement with extra-ordinary users has been utilised throughout the design process of tactile PNDs. Whilst many authors discussed resonance few actually evidenced any process or testing strategy that considered this.
Tactile feedback is not new to the field of navigation and many devices are seen in Chapter 2.4 that utilise the tactile sense to deliver messages, these tactile messages are called ‘Tactons’ (Brewster, et al., 2003). A variety of theories have been proposed as to how and why tactile modality is more suited to PNDs than other modalities. However, a lack of: comparative testing, in-situ testing and subjective user feedback means that the current literature fails to identify a viable commercial case for the interaction style. Table 3 summarises the primary sources and gaps in the literature.

Table 3: Gaps in Literature

<table>
<thead>
<tr>
<th>Existing Work</th>
<th>Primary Source</th>
<th>Gaps in research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra-Ordinary Users &amp; Design resonance</td>
<td>Pullin and Newell, 2007</td>
<td>- Examples in mobile device design</td>
</tr>
<tr>
<td>- Theory discussed</td>
<td></td>
<td>- Best practice for integration of extra-ordinary users into a design process</td>
</tr>
<tr>
<td>- Some examples shown of theory</td>
<td></td>
<td>- PND that evidences a process that observes resonance</td>
</tr>
<tr>
<td>- Non-user input created check list for in-car control system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participatory design</td>
<td>Sanders, 2002 &amp; 2010</td>
<td>- Guidelines for inclusion of people with visual impairments in participatory design</td>
</tr>
<tr>
<td>- Toolkits for non-designer inclusion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Examples of participatory design methods</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Frameworks for why, how and when to include methods</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing Products</td>
<td>Pielot, 2012</td>
<td>- Comparative testing of a tactile PND against both visual and audio devices</td>
</tr>
<tr>
<td>- Various tactile based solutions for people with and without visual impairments</td>
<td></td>
<td>- Understanding usability and desirability.</td>
</tr>
<tr>
<td>- Various products functionally approved</td>
<td></td>
<td>- Evidence of design process undertaken</td>
</tr>
<tr>
<td>- Validation measures including: time taken, errors made, walking speed, ability to recall path taken</td>
<td></td>
<td>- Confirmation of hypothesis’ around the benefits of tactile navigation devices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Focus on usability rather than functionality</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- User opinions and expectations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Further research on effect on cognitive load</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Limited in-context testing</td>
</tr>
</tbody>
</table>
3. INITIAL FOCUS GROUPS

After conducting the literature review it was decided that some primary foundation research was required to gather more general knowledge around the technology use and expectations of people with visual impairments as well as establishing connections and experience in working with a potential user-base. The work conducted in this section does not directly contribute to answering the research question but develops a background knowledge of user opinion prior to research question definition.

Initial focus groups were conducted with a selection of people with visual impairments with the aims:

- To aid the understanding the views of people with visual impairments on PNDs and technology in general
- To identify potential 'extra-ordinary' users
- To gain experience of working with people with visual impairments
3.1. STUDY DESIGN

3.1.1. Participant Specification

Three organisations were originally contacted to aid recruitment of participants:

- Cardiff Institute for the Blind (CIB) - part of Royal National Institute for the Blind (RNIB)
- Royal National College for the Blind, Hereford (RNCB), IT department
- Action for Blind People (AfBP), Birmingham, technology department - part of the RNIB

In the critical literature review it was identified that it is important to recognize the diversity within demographics. It was for these reasons that AfBP and RNCB were contacted as it was felt that they may have access to suitable participants with a keen interest and existing experience in the technology already being developed; as any person already involved with a technology or IT department is likely to have relevant experience in handheld electronic devices. Recruitment criteria also must recognise this (without being so prescriptive that opportunities were limited). CIB were also contacted due to their convenient location and a possibility that they would be able to fulfil recruitment requirements. The essential criteria for recruitment were:

- 5-8 participants
- Some level of visual impairment
- Active interest in technology

The preferred criteria for recruitment were:

- Independent in lifestyle
- 18-35
A sample size was chosen in-line, but on the lower end, of recommended sample for focus group scenarios (Krueger & Casey, 2002) to ensure ease of debate management. It was important that participants had some level of visual impairment and an active interest in technology in order to fully discuss research topics. Participants being independent in lifestyle would increase likelihood of experience in navigation systems, however at this stage in the research more general experience of mobile devices and technology was also useful. Finally, a lose age bracket of 18-35 was placed, as well as being pre-determined by the industrial partner as the target audience for the product the age bracket also loosely fitted that of the “digital native” generation (Bennett, et al., 2008). Born between 1980 and 1994, digital natives are the technology generation immersed in digital interfaces and mobile technology and therefore are more likely to have prior experience with a variety of different technology, both in general use and as accessibility and navigation aids.

CIB, as expected, were dubious about their ability to source within the specification; reasons given were that their clients were mostly older and that they were unsure of their interest in technology. This could potentially be due to the lack of schools or colleges dedicated to helping people with visual impairment in the area. AfBP and RNC were both able to readily source participants and so focus groups were conducted at these locations.

3.1.2. Participants

AfBP provided seven participants, six people with visual impairment and one person without visual impairment. The participant with no visual impairment was the contact who organized the groups from AfBP and worked in the technology department aiding people with visual impairment in sourcing new technology to help their lives. He was eager to take part, and as he had good insight into the technology needs and habits of people with visual impairment it was deemed of value. In conversations prior to the focus groups the contact
described the participants as independent and active within the visual impairment community. To protect their identities the participants’ names have been replaced with a number.

Discussed themes in these focus groups were: daily routine, travel routines, product design and specific features of tactile navigation aids (see Appendix II for plan sheets).

Table 4: Action for Blind People Participants

<table>
<thead>
<tr>
<th>Participant Number</th>
<th>Age</th>
<th>Gender</th>
<th>Self-Reported Level of Vision</th>
<th>Hobbies</th>
<th>Regularity of Independent travel</th>
<th>Methods of transport</th>
<th>Aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>32</td>
<td>M</td>
<td>Very limited</td>
<td>Football</td>
<td>Regular</td>
<td>Taxis, walking, busses</td>
<td>Cane</td>
</tr>
<tr>
<td>A2</td>
<td>36</td>
<td>M</td>
<td>Totally blind</td>
<td>Music and Reading</td>
<td>Regularly</td>
<td>Mostly Taxis</td>
<td>Cane</td>
</tr>
<tr>
<td>A3</td>
<td>34</td>
<td>M</td>
<td>Totally blind</td>
<td>Music and Technology</td>
<td>Mostly just around local area</td>
<td>Walking &amp; Taxis</td>
<td>Cane</td>
</tr>
<tr>
<td>A4</td>
<td>35</td>
<td>M</td>
<td>Light perception</td>
<td>IT and Accessibility</td>
<td>Very regularly</td>
<td>busses and trains</td>
<td>Guidedog</td>
</tr>
<tr>
<td>A5</td>
<td>39</td>
<td>M</td>
<td>Registered blind but with some residual vision</td>
<td>IT and football</td>
<td>Very regularly</td>
<td>Taxis &amp; trains</td>
<td>Cane</td>
</tr>
<tr>
<td>A6</td>
<td>30</td>
<td>F</td>
<td>Totally blind</td>
<td>Singing and technology</td>
<td>Very regularly</td>
<td>Busses &amp; trains</td>
<td>Guidedog</td>
</tr>
<tr>
<td>A7</td>
<td>32</td>
<td>M</td>
<td>No visual impairment</td>
<td>Football</td>
<td>Very regularly</td>
<td>Driving</td>
<td>n/a</td>
</tr>
</tbody>
</table>

RNC provided seven participants, all with some level of visual impairment. In conversations with the contact at RNC it became clear that most participants would be living with their parents and their level of independent travel was limited. For these reasons discussion
subjects focussed around their technology usage rather than their regularity of independent travel.

Themes discussed in these focus groups were: technology use, branding, product design and features. (See Appendix II or plans)

Table 5: Royal National College for the Blind Participants

<table>
<thead>
<tr>
<th>Participant Number</th>
<th>Age</th>
<th>Sex</th>
<th>Self reported level of vision</th>
<th>Studies</th>
<th>Technology</th>
<th>Mobility aid</th>
<th>Group Attended</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>18</td>
<td>M</td>
<td>Registered blind – some residual</td>
<td>Radio production</td>
<td>Very Confident. iPhone 4s user</td>
<td>Guidedog</td>
<td>First</td>
</tr>
<tr>
<td>B2</td>
<td>20</td>
<td>M</td>
<td>Totally blind</td>
<td>IT</td>
<td>Somewhat confident. Jaws &amp; guide on PC, Oasis 220</td>
<td>Cane</td>
<td>Both</td>
</tr>
<tr>
<td>B3</td>
<td>18</td>
<td>F</td>
<td>Totally blind</td>
<td>IT</td>
<td>Very confident. Various apple products, Nokia e71, Trekker Breeze, GPS apps</td>
<td>Cane</td>
<td>First</td>
</tr>
<tr>
<td>B4</td>
<td>20</td>
<td>F</td>
<td>Registered blind some residual</td>
<td>Music Tech</td>
<td>Confident. Various apple products, Trekker Breeze, Zen Stone</td>
<td>Guidedog</td>
<td>First</td>
</tr>
<tr>
<td>B5</td>
<td>19</td>
<td>M</td>
<td>Totally blind (sudden and recent onset)</td>
<td>IT</td>
<td>Somewhat confident. Nokia CS, NVDA, iPod</td>
<td>Cane</td>
<td>Both</td>
</tr>
<tr>
<td>B6</td>
<td>42</td>
<td>M</td>
<td>Totally blind</td>
<td>IT</td>
<td>Somewhat confident</td>
<td>Cane</td>
<td>Second</td>
</tr>
<tr>
<td>B8</td>
<td>18</td>
<td>M</td>
<td>Totally blind</td>
<td>IT</td>
<td>Very confident Samsung Galaxy S2</td>
<td>Cane</td>
<td>Second</td>
</tr>
</tbody>
</table>
3.1.3. Logistics

Focus groups were conducted in 2011 and two were held at each location. The AfBP groups were located at the headquarters in Birmingham. Meeting rooms were organised by AfBP contacts and lunch was provided. Any travel expenses for the participants were reimbursed but no monetary incentive was given.

The RNC groups were located at the college site in Hereford. Meeting rooms were organized by RNC contacts. No monetary incentive was given, participants were students and groups were arranged within their free periods, for this reason no travel or lunch expenses were required.

3.1.4. Ethical Approval

Ethical approval was obtained from Cardiff Metropolitan University.

Where possible information sheets were sent ahead of the groups so a screen reader could be utilised by the participants. For the RNC groups this was not possible and therefore the information was read aloud prior to group commencement.

Participants were asked to sign or stamp consent forms in the presence of a trusted, familiar person with no visual impairments.

3.1.5. Data Capture and Analysis

Data was captured using video and audio, and transcribed after the event. Transcriptions were thematically coded and analysed using N-Vivo qualitative analysis software (QSR-International, 2015).
3.2. RESULTS

After initial review four key themes were identified:

1. Price – the cost of assistive products in comparison to mainstream design
2. Brands – which brands provide the most accessible products and what are the social perceptions of them
3. Navigation – Strategies currently used for navigation
4. Interaction with technology – General opinions and engagement with technology, particularly mobile devices.

NVivo software (QSR-International, 2015) was utilised to group comments from the transcripts under these themes. Results presented are a descriptive overview of the data found against the nodes.

3.2.1. Price

Price was a key issue that was brought up multiple times in all discussions (and also in much of the later stage research).

There was a clear inequality felt between perceived ‘accessible’ and ‘mainstream’ devices reflected in the price.

A2: ... taking things into account, a sighted person, take GPS for example, could go and buy a GPS for what £90 or something =

[agreement – crosstalk]

A3: = and we’re expected to pay hundreds=

[agreement – repeated ‘hundreds’]

A3: //and I find that discriminatory
Whilst the participants were happy to pay extra for added functionality it was felt that products designed for access had less functionality than standard products but charged a higher price. This was a topic that the AfBP staff member had a good insight on,

_A7: ... so to offer them a product that stores 20 numbers, has big buttons, is frankly patronising, then to ask them to pay £89.99 for the privilege is rubbing it in._

Though cost was the easily verbalised issue it was implied that this was not the real problem. The real problem stemmed from making people with visual impairment feel different, and that they somehow deserve lesser or different treatment as a result of their disability.

_A7: the problem is you have product which is adapted to suit a certain percent of the market._

[annoyed utterances]

A3 – _I’ve heard this argument before._

A7 – _Of course you have._

A3 – _I didn’t buy it then and I don’t buy it now. 25 million blindies [sic] across the globe is not a niche market!_

This was reflected in participant’s opinions on brands where participants regularly held Apple as their brand of choice. Whilst Apple products generally have a more expensive upfront cost their integrated, hassle-free accessibility features were deemed of high value, not only did participants end up saving money by not having to pay for extra software but they also paid the same price as people without visual impairment.
B1: We as blind people use iPhones because we have found our own touchscreen, we want to be like everyone else, we want to be like sighted people, and we feel very frustrated that we can’t be the same as them “ahh they’ve got a touchscreen why can’t we do that?” Apple, have turned round and said, well you can now.

B2: and we’ll charge you 700 pounds for it/

B1: //yes! We’ll charge you the same as what we charge everyone else!

3.2.2. Brands

When discussing brands of handheld devices two names dominated the conversation, Apple and Nokia. Decisions to purchase is based largely on accessibility, with these two brands really pushing forward with their speech control software (Siri for Apple and Talks for Nokia). However, whilst the phones were bought for functionality, they were loved for their label and Apple clearly instilled a sense of pride in its owners.

B1: Yeah, I mean, when I got my iPhone it feels quite good like, “yeah! I’ve got an iPhone!”

Overall, those participants who owned Apple products (often multiple products) were more excitable about the prospect of technology and showed more engagement in the greater conversation about good and bad products.

Whilst Nokia received less excitement about the brand it was recognized for its functional ability and its physical buttons were seen as a benefit to many:
A6: ...my main one is an iPhone but I have Nokia if I want to text really quick.

Traditional assistive brands such as ‘Oasis’ and ‘Doro’ received a unanimously negative reaction.

A3 – [the price] wouldn’t be so bad. It would still be extortionate, if it had some of these other features that the Nokias and iPhone have but it’s just a phone! Without a screen

A1 – to be honest I wouldn’t even touch it...

3.2.3. Navigation

When discussing navigation it was clear that a vast amount of planning happens prior to the event. This planning was not limited to the route but instead to prepare for all situations. A particular focus of the discussion was investigating and preparing for the weather.

When describing a route, the participants tended to use directional information and road layouts as their primary identifiers. Bradley and Dunlop’s (2002) comparative research into the route descriptions provided by people with and without visual impairments also saw a very high level of directional and “structural” instructions (e.g. roads, architecture, built landscape). Bradley and Dunlop also documented a high level of “descriptive” instructions such as ‘steep’ and ‘tall’ however this was not corroborated throughout the initial focus groups. Road names and distance estimations played a very small part in the participant’s day-to-day navigation descriptions, though participants agreed that with more regular use of GPS navigation tools their estimation of distance has improved.
...it might say 50 yards, 150 yards whatever, but you soon get used to that because it repeats. It doesn't just say 200 yards then never says anything again it says left, 200, 100, 50, you start to build up this judgement of distance.

In a later paper, Bradley and Dunlop (2005) confirm that people with visual impairments feel less frustration, and a lower cognitive load and perform better when responding to directions if they are in-keeping with the type of journey descriptions given by people with visual impairments. However, they also document that, whilst performing similarly, people without visual impairments perceive a higher level of workload and frustration when receiving those same instructions, when compared to receiving instruction based on journey description from other people without visual impairment.

3.2.4. Interaction with Technology

Participant’s opinions on methods of interaction with technology was largely based on previous experience and currently owned products. Participants across both groups had a broad range of experience, with some using tactile keypads and some using touchscreen devices. Users of both tactile keypads and touchscreens stated that layout and consistency was of very high importance when using the product.

So it’s quite easy to use the thing with touch screen is, yeah it’s touch screen, but it’s just the same way of learning as a touch phone because it’s all about spatial awareness, it’s about how that phone is layout, where things are on the screen, the screen is flat you haven’t got any buttons but it doesn’t matter, you’ll get to know it eventually.

Only one participant regularly used voice commands, he was also the only participant who used an Android based smart phone. Whilst enthusiastic about the prospect of voice
recognition it limited his interactions with the phone, not allowing him to access the full functionality.

*B6 – what do you actually use to help you access the phone...*

*B8 – it's an app with voice recognition. And it talks to me when I talk to it...*

*B6– yeah but how do you use the screen? Do you have any sort of way...*

*B8 – it reads it out for me. Like my messages*

*B6 – oh I see – so it’s all using voice recognition?*

*B8 – I can’t add new contacts*

Participants were nervous but excited about the prospect of tactile output for a PND. Initially it met a sceptical response, theorising that it would be complicated to learn a new interaction technique but with more conversation participants grew to like the idea.

*B6 – It’d be like learning a new language which is hard, but once you’ve learnt it, well then it would be pretty easy I reckon.*

No participant expected to rely wholly on the tactile sense and instead they envisaged it to augment their current product usage. Audio blocking important navigation cues was identified clearly as a problem and so the use of tactile for simple navigation information was considered to be of value to people with visual impairments.
3.3. FOCUS GROUP CONCLUSIONS

Early stage focus groups with people with visual impairments indicated some prevalent issues that people with visual impairments consider including:

- **Overpricing of access market products**

  Price is a contentious issue for people with visual impairment; the pricing of any new product should be a fair reflection of the function and desirability. Importantly, the product must not denote people with visual impairments as ‘different’ from other users. There is a strong desire to use mainstream products and as such, even if it requires extra learning time, the product should be usable and desirable by all.

- **A desire to use inclusive devices as opposed to products targeted towards people with visual impairments**

  Whilst accessibility is the driving function for purchase, brand perceptions are of the utmost importance. Even though physical buttons were agreed upon as easier to use, participants were willing to invest time into using new, harder, interface systems to benefit from the esteem associated with the brand name.

- **A preliminary product specification**

  Direction and structural data concerned with road layout were the primary documented methods of navigation description. This should be taken into consideration when designing the command structure for a navigation device, however, it may be a hurdle in the acceptance of the product for a mainstream audience.
Participants largely relied on experience to form opinions about interaction styles therefore their initial response to a tactile navigation showed trepidation. However, the potential benefits were agreed and as discussion grew participants warmed to the concept.
4. REVISED RESEARCH QUESTION

A research objective to uncover strategies and techniques around navigation and handheld device usage unique to people with visual impairments in order to further develop a concept tactile navigation aid led to two stages of initial research:

1. A critical literature review
2. Initial focus groups

The literature review identified three primary themes (see Table 3, Page 87): extra-ordinary users and design resonance, participatory design with people with sensory impairments and the efficacy of tactile navigation aids. Gaps in the literature were identified which resulted in the following research question:

*How might the employment of theories of resonance and extraordinary users in the collaborative design process result in better design outputs?*

In order to provide a response to both the research question and the gaps in the literature around the three themes the following objectives were devised:

1. Research and design a tactile PND with people with visual impairments acting as design informants
2. Explore and document the use of people with visual impairment, within a participatory design process for a PND.
3. Assess the output of this process, a tactile PND, in order to identify any benefits against traditional navigation aids.
5. METHODOLOGY

5.1. INTRODUCTION

This chapter details and qualifies the methodology designed to provide an answer to the research question:

How might the employment of theories of resonance and extraordinary users in the collaborative design process result in better design outputs?

Utilising the design of a tactile navigation aid as vehicle for investigation this chapter details a double-phase approach covering both the process and the design outputs. As such, specific study details (such as: logistics, specific methods and analysis techniques) will not be documented in this chapter and instead will be described later in the thesis in the chapters related to the phase of research and directly before their respective results sections.

5.2. DOUBLE-PHASE RESEARCH DESIGN

The research question and objectives require both investigation into the design process and evaluation of the outcome. The research question is complex, investigating values, methods and subjective opinion alongside functional benefits that may be acquired from the use of people with visual impairments as design informants. When attempting to break down the complexity of the project, two strands of research emerged to be conducted consecutively; first an investigation into the process and development of the product and secondly testing the output of this process. These two strands of research determined the use of a double-phase research design (Saunders, et al., 2012).
The first phase (described in more detail in the following sub-chapter 5.3) uses a practice-led methodology to take a purely qualitative multi-method approach to undertake, document and assess a participatory design process with people with visual impairments, this section forms the “design process”.

The second phase (described in more detail in the following sub-chapter 5.4) uses an experiment strategy, in the form of a comparative study and takes a fully integrated mixed-method approach to data collection in order to evaluate the outcome in a holistic manner (Saunders et al. 2012). This section forms the “design evaluation”.

Figure 14 (below) shows a summary of the research methods undertaken in each chapter of the thesis.

![Figure 14: Thesis Structure](image)
5.3. PRACTICE-LED RESEARCH USING A PARTICIPATORY DESIGN STRATEGY

5.3.1. Introduction

To understand how innovations drawn from people with visual impairment could add value for users without impairment, a product must be developed for evaluation. A tactile PND was chosen and the process and product was scrutinized in an attempt to uncover any innovations that have value to a mainstream market. Participatory Design (PD) and extra-ordinary users as design informants are two strategies that have been identified in the literature review to help aid designers in gaining empathy with their users and developing innovative and desirable solutions (Sanders, 2002; Pullin & Newell, 2007). However, both strategies are lacking in documentation and examples within the field of study. Participatory Design in particular presents a selection of problems in the integration of people with visual impairments into the, largely visual, design process.

For these reasons the first section of this research will look at the process itself, exploring and documenting the integration of people with visual impairments, within a participatory design process for a PND and to reflect upon input from extra-ordinary users in order to develop the product. The research will look to draw not just product specific findings but address the more general questions:

- How can people with visual impairments collaborate in what is traditionally a visual process?
  - What methods can be used?
- Do people with visual impairments augment the largely visual design process?
  - And if so how?
5.3.2. Why Participatory Design?

During the literature review, Participatory Design (PD) and the use of extraordinary users as design informants were identified as strategies to create successful design solutions when resonance has been identified (see chapter 2.2.2). Further to this, a review conducted by Steen et al. (2007) supports the application of these strategies in this context. Steen et al. (2007) reviewed six design strategies in an attempt to identify which techniques would be most appropriate for certain project types. He recognised that the separation of these design strategies is artificial and that in practice a designer would likely combine multiple strategies to achieve the desired outcome. However, this artificial divide aids analysis and understanding of the techniques. The six strategies are:

1. Participatory Design – as discussed in chapter 2.2.4
2. Lead User Approach – as discussed in chapter 2.2.2 (note: extra-ordinary users is a derivative of the lead user approach)
3. Co-Design – Workshops that utilise tools allowing non-designer stakeholders to articulate ideas and develop concepts, also known as generative tools. When previously discussed in Chapter 2.2.4 these were categorised as PD methods.
4. Ethnographic Field Work – where designers/researchers go “into the field” in order to become immersed in the culture and gain a greater level of understanding in the field of study with a descriptive output.
5. Contextual Design – the observation of users in the context of the field of study and the application of the insights to the design of the system
6. Empathic Design – where designers/researchers aim to experience what the user experiences to empathise emotionally with the user.
In order to assess these methods for practical application, Steen asked two questions; both questions recognise that designers and users bring a unique knowledge to the process and they recognise that different emphasis will correspond with different outputs. Steen asked:

1. Whose knowledge is privileged? Questioning who is leading the project and whether the user is pro-actively engaged in decision making (meaning the user has privileged knowledge), or whether they are reactively confirming the designer’s knowledge (meaning the designer’s knowledge is privileged).

2. Which knowledge is privileged? Questioning the knowledge that generated the brief, whether the project is a reaction to a problem or an opportunity identified.

When reviewing these questions against the research and design of a tactile PND ideally the knowledge of the user should be most privileged, as current mainstream solutions and the authors knowledge (as designer-researcher) is heavily biased towards the visual modality. People with visual impairments will have a unique perspective and expert knowledge that should take priority over the designer-researcher’s assertions. However, the answer to the second question “which knowledge is privileged?” is not so immediately apparent as it could be considered that the initial concept is a reaction to problems noted by the original designer, that people with visual impairments find current navigation solutions inaccessible, or, that it reacts to an opportunity that tactile navigation could have potential successful application in certain contexts of use for people with no impairment.
Figure 15 visualises Steen’s analysis of the six systems. When applied to this project an emphasis on end-user’s knowledge is desired meaning that: Participatory Design, Lead User approach and Co-designing would be the recommended options. Steen (2007) also discovered that the prior discussed confusion between whether the brief stems from a problem or opportunity can actually be harnessed in the lead user approach as they have “knowledge about a current product or practice, and they develop and articulate knowledge about a future product or practice” and that this simultaneous mixing of the two types of knowledge is the most pragmatic approach to new product innovation.

This information confirms that the strategies identified in the literature review are suitable for application within this research project.
5.3.3. Practice-Led Research and Reflective Practice

Many elements of the research to be conducted are consistent with the definitions provided for ‘Action Research’ in that it:

- Generates knowledge based on practical contexts and enquiries
- The role of the researcher and practitioner are merged
- Is participatory
- Aims to inform future practice

(Koshy, 2010; Avison, et al., 1999)

However, due to the timelines identified at the start of the process there was very little opportunity for iteration of methods in order to affect and reflect upon change in practice. These iterations of process are vital in a true Action Research methodology as evidenced by the cyclic nature of many practitioner’s models of Action Research (Kemmis and McTaggart, 2000. Ellis, 1991. O’Leary, 2004. all cited by Koshy et al. 2010). Instead a more generalized term is used, “Practice-Led Research”, defined by Candy (2006) as;

“...concerned with the nature of practice and leads to new knowledge that has operational significance for that practice”

A distinction is made between practice-based research and practice-led research; the former, practice-based, relies on the creative artefact as the contribution to knowledge where-as the later, practice-led, is a reflection on the process itself and recognises its relationships to Action Research.

Candy (2006) reflects on the differences between both practice-based and practice-led research against the general product research a practitioner may conduct on a day-to-day basis stating that:
“[practice-led] research aims generate culturally novel apprehensions that are not just novel to the creator or individual observers of an artefact”

In order to achieve these “culturally novel apprehensions” the researcher must critically reflect on the actions and outcomes of the process; not simply drawing specifications and guidelines from the process but understanding the impact of the process itself. Finlay (2008) describes reflective practice as,

“the process of learning through and from experience towards gaining new insights of self and/or practice”

In order to provide structure to the reflection, a framework was sought, and many frameworks were reviewed (Gibbs, 1988; Pee, et al., 2002; John, 2000). Rolfe’s (Rolfe, et al., 2001) reflective model was chosen, the simple model asks three questions:

1. **What?** A description of the situation, the task, the emotions and problems.
2. **So What?** Scrutiny of the situation, what was learnt and what is the new understanding of the situation.
3. **Now What?** Construction of knowledge through suggestions for future implementation and iteration.

Rolfe’s reflective model was chosen as it was felt to be in-keeping with practice-led research in that it has a firm focus on outwards reflection and construction of knowledge beyond what is novel to the researcher, or specific to the design. It was perceived to be appropriate for the commercial process that, due to the timelines involved, did not allow for multiple iterations on the same research method.

Finally, it was in keeping with the three-fold contributions to knowledge expected in this chapter:
1. Asking “what?” provides a description of the situation and documents novel methods for non-visual inclusion in the design process.

2. Asking “so what?” scrutinises the situation and what was learnt assesses how these methods and the participants generate new knowledge in the specific realm of PNDs.

3. Asking “now what?” proposes how this new knowledge may be useful for practitioners in general.

5.3.4. Analysis

As discussed in the previous section, reflective analysis of both the process and the outcomes is used to gather insights. Rolfe’s (2001) reflective model is chosen for its simplicity and suitability to the fast paced commercial design development process. Two frameworks were identified to aid the analysis of the methods and their positioning against current practice and literature. The first is Sanders’ (2010) “Framework for Organizing the Tools and Techniques of Participatory Design” (first discussed in the literature review, Chapter 2.2.4) which analyses and organises the tools by purpose using the categories:

1. **Probe** - “stimulate the informant to produce more information” (Bernard, 2011)

2. **Prime** – immersing the participants in the domain of interest

3. **Understand** – gaining a better understanding of the participant’s current experience

4. **Generate** – ideas or design concepts for the future

(This framework is illustrated in the literature review, chapter 2.2.4)

The second is the framework developed by Kaulio (1998) in order to review methods and methodologies on two dimensions: the level of involvement of the participants and the phase of the process at which the method would be most useful; as illustrated below.
These frameworks will be considered throughout the reflective analysis and following discussion.

5.3.5. Limitations of the research

Due to the tight timescales involved in the process, little time was available for iterative attempts at the same research method. It is for this reason that the research has not been referred to as “Action Research” as it shows no level of the iterative development involved in the practice.

As participants were located around 100 miles from the research base integration was limited. However, trips were made on a regular basis and all decision points throughout the development process were made alongside an open dialogue through social media.
channels. On reflection social media could have been better utilised to facilitate design decisions and provide more structured regular feedback.

5.4. COMPARATIVE STUDY

5.4.1. Introduction

A final assessment of the product is vital not only for validating the product itself but also in the evaluation of the process involved. The literature review discussed the theory of resonance (Pullin & Newell, 2007) in which the design of products for extra-ordinary users may have additional benefits for ordinary users. In the development of a tactile navigation aid intended to aid access for people with visual impairments this theory of design resonance is supported as many practitioners theorise around the benefits of ‘tactons’ (Brewster, et al., 2003) in the communication of navigational data when compared against visual and audio devices. Both the theory of design resonance and the proposed theories relating to the benefit of tactons have provided direction for the research project, however, there is currently a lack of compelling documentation within the literature that actually evidences either of these assertions. As such, testing is required of the final product to confirm or disprove the theories that have provided both commercial and academic motivation.

A comparative study was devised to investigate and assess how the tactile navigation aid, developed by and for extra-ordinary users, may benefit ordinary users. In turn, this will also provide an assessment of the assertions around the benefits of tactons provided in the literature which include: enhanced safety, better engagement with the surrounding areas
and a more intuitive interaction. Comparative studies test hypotheses by identifying changes in action or behaviour which correlate with study variables (Saunders, et al. 2012). The study investigated the use of the device designed in 'Phase One' of the research study against two commonplace modality specific (audio and visual), commercially available navigation devices. Testing with people without visual impairments allowed an assessment design resonance and a mixed-method approach tested for both subjective and objective benefits.

5.4.2. Mixed-Method Approach
A mixed method approach was taken to generate a holistic understanding of how the product performs, targeting function, usability and the pleasure derived. Due to the study’s multiple facets a mixed methods approach was desirable as it is used for “obtaining a fuller picture and deeper understanding of a phenomenon” (Johnson & Onwuegbuzie, 2004). The study was “fully integrated mixed method” (Saunders, et al., 2012) due to the complex demands of the data, assessing both objective and subjective elements of product use through qualitative and quantitative research methods. During the analysis stages quantitative analysis provided a more easily comparable data set and therefore basic quantitative techniques were applied after an initial qualitative analysis. Saunders et al. (2012) recognise a variety of different benefits to mixed method studies. Those appropriate to this study are:

- Complementary

  The methods enhance, elaborate and confirm each other.

- Generalizability
The methods produce a more complete knowledge of the system assessing both functional metrics and user opinion

- Triangulation
  
  Data can be combined to corroborate findings

- Confidence
  
  In order to overcome the method effect

As the product is developed with people with visual impairments, the research conditions were instead focused on fully sighted participants in order to aid the assessment of the resonance of needs between the two user groups; thus addressing the research question, "How might the employment of theories of resonance and extraordinary users in the collaborative design process result in better design outputs?"
5.5. METHODOLOGY SUMMARY

This chapter described the methodological approach to responding to a research question of:

*How might the employment of theories of resonance and extraordinary users in the collaborative design process result in better design outputs?*

The chapter detailed a double-phase approach.

The first phase of research takes a practice-led approach to the design process, investigating collaborative participatory design with people with visual impairments and the use of extra-ordinary users as design informants. As well as documenting the output reflective practise will be utilised to analyse methods and their success.

The second phase of research undertakes a comparative study investigating and assessing the output of the design process. This phase is focussed on the assessment of design resonance and therefore investigates the use of a product designed for and by people *with* visual impairments when used by people *without* visual impairments. This will allow for the empirical assessment of the value added by the novel device to the ordinary user.
6. PHASE 1.A: GENERATIVE RESEARCH

6.1. INTRODUCTION

As discussed in the previous chapter (Chapter 5: Methodology) a two phase research methodology was taken in order to answer the research question:

_How might the employment of theories of resonance and extraordinary users in the collaborative design process result in better design outputs?_

The first phase of research takes a practice-led approach to explore and document the integration of people with visual impairments within a participatory design process for a PND and to reflect upon input from extra-ordinary users. This chapter details the first stage of the practice-led research undertaken in which the author conducts a variety of participatory design techniques with a group of participants with visual impairments. Utilising Sanders’ (2010) framework of participatory design techniques, a selection of techniques were chosen to generate initial ideas and inspiration for the future product as well as exploring current habits and coping mechanisms.
The objectives of this research are:

- To build the specification for a novel tactile navigation aid to improve on current designs for both people with and without visual impairments
- To gain an improved understanding of the modifications required to participatory design techniques in order to engage people with visual impairments
- Reflect on the output of these techniques for potential future use beyond the specific design

The literature review has argued the case to engage people with visual impairments, as experts in tactile product interfaces. In order to achieve empathy with the users and experts, a participatory process is recommended where users become creative in their own right and input into the design process (Sanders, 2002). Kaulio (1998) defines three levels of user engagement:

1. Design for customers
2. Design with customers
3. Design by customers

Methods with which to achieve the integration of, specifically, people with visual impairments into the (largely visual) design process are not well documented. The limitations in current documented methods are recognised by Hussain et al. (2012) who, when investigating participatory design in developing countries, states;

> It is almost taken for granted that participants are available, have the skills for contributing to the design process and will be able to work together in an egalitarian manner.

(HUSSAIN ET AL., 2012)
Whilst a selection of practitioners lay out useful guidelines and hints for designing for users with visual impairments (Gerber, 2002; Henry, 2007; Kroll, et al., 2007) examples of designing with and by users with visual impairments are extremely limited. This chapter examines the methods of engagement to encourage design with and by users utilising the generative research techniques as suggested by Sanders (2002) as a starting point.

Furthermore, the literature review reflected on the difference between accessibility, creating a product that people can use, and usability, creating a product that people both can and, importantly, want to use (Pullin & Newell, 2007). This is equally true when undertaking the creative process. This philosophy is relevant for two stakeholders of this PD process:

1. The Participants (i.e. People with Visual Impairments)

Whilst the PD activity might be accessible for people with visual impairments, without creating an activity that participants want to take part in, their engagement and in-turn the quality of the output, will be lacking.

2. The Practitioners (i.e. Designers)

An accessible PD process for people with visual impairment will be useful to a few designers in very specific circumstances, those who may be designing products with this intended market in mind; simply detailing the steps taken will mean practitioners can use these methods. What may make practitioners want to use this process is an understanding of the unique perspective that a non-visual point of view may bring to their design.

It is important that both accessibility and usability of the selected techniques are analysed within the text.
6.2. STUDY DESIGN

6.2.1. Methods Utilised

Sanders’ (2010) framework of participatory practice clearly defines different methods for user involvement but these are largely visual-based processes and so adaption will be required to make these activities accessible. A variety of methods were used throughout the process, these methods were derived from those described by Sanders (2010) as:

- 2-D collages
- Modelling
- Card sorting
- Storytelling

How the methods were edited to provide access and to engage people with visual impairments is one of the outcomes of the research project and therefore will be described in the body of text relating to results (Chapter 6.3 Results and Analysis).

6.2.2. Participants

Participants were selected from the initial exploratory focus groups conducted detailed in Chapter 3. The participants of the Birmingham Action for Blind group were utilized as these users provided the best fit to the recruitment criteria (detailed in Chapter 3.1.1). Table 6 displays the demographic information for the participants involved (this table is also seen in the Initial Focus Groups chapter 3.1.2).
Table 6: Generative Research Participants

<table>
<thead>
<tr>
<th>Participant Number</th>
<th>Age</th>
<th>Gender</th>
<th>Self-Reported Level of Vision</th>
<th>Hobbies</th>
<th>Regularity of Independent travel</th>
<th>Methods of transport</th>
<th>Aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>32</td>
<td>M</td>
<td>Very limited</td>
<td>Football</td>
<td>Regular</td>
<td>Taxis, walking, busses</td>
<td>Cane</td>
</tr>
<tr>
<td>A2</td>
<td>36</td>
<td>M</td>
<td>Totally blind</td>
<td>Music and Reading</td>
<td>Regularly</td>
<td>Mostly Taxis</td>
<td>Cane</td>
</tr>
<tr>
<td>A3</td>
<td>34</td>
<td>M</td>
<td>Totally blind</td>
<td>Music and Technology</td>
<td>Mostly just around local area</td>
<td>Walking Taxis</td>
<td>Cane</td>
</tr>
<tr>
<td>A4</td>
<td>35</td>
<td>M</td>
<td>Light perception</td>
<td>IT and Accessibility</td>
<td>Very regularly</td>
<td>Busses and trains</td>
<td>Guide dog</td>
</tr>
<tr>
<td>A5</td>
<td>39</td>
<td>M</td>
<td>Registered blind but with some residual vision</td>
<td>IT and football</td>
<td>Very regularly</td>
<td>Taxis and trains</td>
<td>Cane</td>
</tr>
<tr>
<td>A6</td>
<td>30</td>
<td>F</td>
<td>Totally blind</td>
<td>Singing and technology</td>
<td>Very regularly</td>
<td>Busses and trains</td>
<td>Guide dog</td>
</tr>
<tr>
<td>A7</td>
<td>32</td>
<td>M</td>
<td>No visual impairment</td>
<td>Football</td>
<td>Very regularly</td>
<td>Driving</td>
<td>n/a</td>
</tr>
</tbody>
</table>

As detailed in Chapter 3.1 the essential criteria for recruitment were:

- Some level of visual impairment
- Active interest in technology

The preferred criteria for recruitment were:

- Independent in lifestyle
- 18-35

6.2.3. Presentation of Results

The results presented in this section reflect the three-question analysis strategy laid out in the methodology chapter (Chapter 5.2.4) Using Rolfe’s (2001) reflective model which asks three questions “*What? So What? And Now What?*” three levels of results are presented for each method:
1. **What? = Practice Instrument**

   The first level of results details the changes required to make the method accessible to the participants. It starts with an overview of the method and goes on to describe how it was applied in this specific scenario.

2. **So What? = Results**

   The second level details the design output of the technique, reflecting on the results that further the design project.

3. **Now What? = Reflection and Analysis**

   Finally, the third level of results reflect on the success of the method and potentially the future use. This level uses both Sanders’ (2010) and Kaulio’s (1998) frameworks to aid the placement of the newly developed method against current literature.

Alongside the three level reflective Practice structure a fourth section has been added entitled “**Summary and Recommendations**” to draw together and present the findings in a concise fashion.
6.2.4. Location

The majority of the studies took place at the Action for Blind People headquarters in Birmingham. In the later stages of the design process sessions took place at one of the participant’s home address. This was offered by the participant as the residential address was more convenient for all participants. All travel expenses were reimbursed.

6.2.5. Ethical Approval

All activities were approved by the PDR, Cardiff Metropolitan Ethics committee. Participants were given information sheets detailing the study, data collection and storage measures and their right to withdrawal. As many of the participants had visual impairments, where possible these forms were sent beforehand via email so participants could utilize screen readers in their own time; if this was not possible the information and consent forms were read aloud. Signatures or stamps were gathered with a (fully sighted) supervisor, trusted by the participants present. The information sheet and consent form are viewable in Appendices III and IV.
6.3. RESULTS AND ANALYSIS

6.3.1. Mood board / Free Listing

Practice Instrument

Sanders (2010) describes the use of collages in participatory design: to probe for existing knowledge, to prime participants in the area of interest, to understand viewpoints, motivations and emotions and to generate ideas. In this project, collages, in the form of mood boards, were chosen as an early stage method to aid understanding of products and product features that may be inspirational for the design of a tactile navigation aid. Mood boards are a well accepted method to: improve communication between stakeholders, provide inspiration to the designer and understand the product context (McDonagh & Storer, 2004). To ensure physical form is informed by the end-user it is essential that these boards are created by the users and not the researcher’s assumption of what the users would enjoy, and so the traditional process of mood board creation was not accessible for the participants.

When creating a version of mood boarding that would engage people with visual impairments it was vital the some key elements of the task were preserved: free flow of ideas, no criticism of ideas, rapid output and identification of overall themes.

Four participants took part in the task, they were introduced to the aim of mood boards in general and the aim of this specific mood board, to investigate the form of electronic devices and their appeal to people with visual impairments. In order to gather output in a non-visual manner the verbal method of Free Listings as discussed by Bernard (1995) and Colucci (2007) was utilised, where participants are asked to list preferred products, or product features, by loudly calling out. The calling out was intended to produce
unrestricted rapid flow of ideas and leave little time for criticism or cognitive assessment of the output. Responses were recorded in field notes and through video recording of the session. After the session the responses were translated into a visual mood board to provide the stimulation and discussion resource to aid design.

Results

![Mood board results](image)

Figure 17: Output of collage activity

(Field notes available in Appendix V)

The mood board results were limited to products very obviously related to that being designed. Of the results that were produced button layout was the first item to be mentioned with the Nokia keypad taking prime position as the first mentioned product.
Products that were cited for stylistic reasons included the iPhone, HTC phones and Creative Zen Stone, all three of these devices have similar stylistic traits in that they are all rectangular with rounded corners.

Three products from the assistive technology market were cited, Trekker Breeze, Daisy Milestone and the Daisy booksense (shown in Figure 18). Trekker breeze was mentioned multiple times (each by different participants) as a variety of its features appealed to the participants these were: button layout, button tactility and materials. The Daisy Milestone was mentioned by one participant as he liked both the size and shape and the tactile buttons. The Daisy booksense was also cited for its button differentiation technique as the keypad uses both raised and indented keys to aid differentiation. All three assistive products were received with agreement by the participants who did not cite them.

Participants very quickly ran out of ideas, so they were prompted to consider input techniques and other devices. Volume dials and sliders were cited as preferential input methods and pin chargers rather than USB as they do not require a specific orientation:

*Figure 18: (From left to right) Trekker Breeze, Daisy Milestone, Daisy Booksense*
Reflection and Analysis

Creating mood boards through verbal descriptors could be conducted through traditional focus group style discussion however as previously stated it was deemed important to facilitate some key features of the mood board technique: free flow of ideas, no criticism of ideas, rapid output and identification of overall themes. Alongside this traditional focus group discussion lacks the creative ethos of PD that engages and inspires participants. Asking participants to call out responses added an element of chaos that in-turn increased engagement, thus overcoming one of the main challenges of PD, engagement and involvement (Sanders, 2010). This is in keeping with Collucci (2007) and Bernards’s (1995) explanation of free listing as a method to “make focus groups more fun” (Collucci, 2007) thus improving outcomes.

Costa et al. (2003) when describing negative factors of normal verbo-centric methods discusses user’s inability to describe in detail why they may or may not like a feature or product. The mood board (or free listing) method described focusses on quantity of responses rather than in-depth product analysis which helps overcome Costa’s (2003) stated negative factor. However, participant’s creativity and idea generation quickly depleted and the facilitator (the author) had to stimulate thought by prompting for examples of different features.
The task asked participants to generate ideas of preferred products, however on occasion participants would focus on elements that they did not like; an example is that of USB chargers which resulted in a requirement to probe for an alternative preferred solution.

Much of the benefit of mood boards created through visual imagery is that little prior knowledge is required, a participant can simply be given a magazine and asked to cut out inspiring or relevant imagery. In this adjusted scenario there was a strong reliance on prior knowledge, for this reason it was necessary to promote out of context examples to encourage creative and abstract thinking. This was not entirely successful and on review a more abstract aim alongside less primed participants may have been more effective, as, in this scenario participants were well aware of the design project in hand and so answers revolved around the subject. It was interesting to note the use of visual terminology when discussing products. Phrases such as “it looks beautiful” were not rare as a descriptor of a reason to like a product. Care must be taken to understand what is meant when a person with visual impairment makes this statement, in these scenarios it was usually related to the overall shape, curvature and material quality of a product.

...the original iPod because it looks beautiful

The verbal *free listing* technique was not an adequate replacement for traditional mood board techniques. However, when reviewing *free listing* against mood boards as described in Sander’s framework of participatory design techniques it does adhere to similar purposes:

- To Probe
- To Prime
To Aid Understanding

The major difference noted was in the final purpose field of the framework “to generate” – “the generation of new ideas or design concepts for the future”. The lack of visual collages resulted in it being difficult to reflect on overall themes immediately as there was no method for concurrent presentation of the output. Verbal output isolated the responses and in turn lacked the development of the ‘mood’ element of mood boards. Instead, the output had to be translated into a visual collage at a later date in order to provide prompts for design features and idea generation. Whilst useful for the designer it did not fit into the ethos of Participatory Design as (if being used as a tool for idea generation) it did not allow the participants themselves to act as creative partners within the design process.

Whilst not a particularly apt activity to encourage “design by users” (Kaulio, 1998), Free Listing in general was well received by participants with visual impairments, it stimulated responses quickly and concisely in a more engaging fashion than a traditional discursive task, fulfilling the expected outcomes as described by Bernard (1995) and Colucci (2007). It has value in the early phases on the design process aiding data collection as a “design for users” method for building a product specification, however the task did not yield a great variety of results nor did it provide a particularly stimulating design resource.

Summary and Recommendations

Conducting mood boards by employing a free listing (Colucci, 2007) strategy as a Practice technique with people with visual impairments proved to stimulate multiple ideas around form and function for the device under-study. The results were unique to participants with visual impairments due to their heightened knowledge on the tactile product interactions and greater knowledge around products where tactile engagement has been well considered. It is recommended that creating moodboards with people with visual
impairments would be valuable in the design of a product that requires minimal visual engagement. The output however, is dissimilar to traditional mood boards in that the results were more specific and less evocative of mood, character and ambiance.

Suggestions for Practice are laid out below.

<table>
<thead>
<tr>
<th>MOODBOARDS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Participants to ‘shout out’ examples of products (or services, or materials, or sounds etc.) that respond to a particular statement e.g. “items that are stylish”. These suggestions are documented then post-hoc a collage is made by the researcher.</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Recommendations</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Be sure to recruit participants who have an active interest in the areas</td>
<td>A verbal based task it is difficult to provide stimulus material without leading. This results in answers that rely heavily on prior knowledge.</td>
</tr>
<tr>
<td>Start with an abstract aim e.g. “items that are beautiful / items that are comfortable” then gradually refine to specific focus</td>
<td>Avoiding leading the subject through verbal prompts by starting with an abstract approach.</td>
</tr>
<tr>
<td>Conduct the moodboard task prior to priming the participants.</td>
<td>Participants struggled to consider items outside the particular focus of the project. Conducting the task prior to the participants knowing the specific project aims will produced more generalised results.</td>
</tr>
<tr>
<td>Prepare verbal stimulus material prior to session</td>
<td>Due to lack of stimulus material participants are quick to run out of ideas</td>
</tr>
<tr>
<td>If possible have a note taker create a moodboard by image searching and collaging then and there</td>
<td>To assist the researcher in identifying themes whilst undertaking the research. This will help identify if the research is meeting the aim.</td>
</tr>
<tr>
<td>Encourage rapid flow of ideas by ‘shouting out’ answers</td>
<td>To avoid the activity becoming standard ‘focus group’ style discussion and encourage</td>
</tr>
<tr>
<td>Expect visual terminology</td>
<td>Visual terminology such as ‘it looks...’, ‘I can see it has...’ was used throughout</td>
</tr>
<tr>
<td>Be conscientious of every participant having a voice</td>
<td>Visual cues associated with a person waiting to speak are unavailable to the participants</td>
</tr>
<tr>
<td>Consider a ‘negative’ mood board also</td>
<td>Participants struggled to only consider positive elements. Allow them the freedom to discuss negative features in order to more easily move forward.</td>
</tr>
</tbody>
</table>
6.3.2. Storytelling

Practice Instrument

Storytelling as a design research technique can be used at a variety of stages within the design process. It allows the researcher a depth of understanding into the users’ experiences that aids development of empathy and an understanding of common ground (Vink, n.d.).

Sanders (2010) suggests storytelling as a participatory activity. This is regularly a verbal activity (but can be achieved through other methods such as storyboarding or acting) and so no changes were required to allow access.

Five of the participants with visual impairment and one member of staff from AfBP who had no visual impairment were asked “Talk us through a journey that you regularly make”. The aim of the task was to generate an understanding of the user’s navigational abilities and to uncover the types of navigational cues that people with visual impairments notice along a route. Field notes were taken and the stories were video recorded and transcribed soon after the session.

Results

People with visual impairment used no unique storytelling techniques; responses to the initial question were given as a verbal narrative.

Journey stories detail simplistic navigational commands with all five participants with visual impairments using “straight on”, “turn right” and “turn left” as the most common descriptors. However, whilst the commands themselves were very simplistic there was evidence of a high level of granularity in the descriptions as every change in direction was noted. For example, one participant describes moving through an indented road crossing:
When I get to a certain part of the side road I’d do an indented crossing, I’d turn right and go into the road, then cross over, I’d turn left, go back on myself, turn right, carry straight on, and when I come to the second indented crossing I’d do the same thing.

Participant A2

Road layouts provided the primary physical reference point for navigation however this was not connected with the use of road names as only one participant used a street name within their journey. The two participants utilised “structural” (Bradley & Dunlop, 2002) information in their journeys:

*Carry on straight to locate the gates then turn right into the car park* 

Participant A2

*...you’ve got a fence, you basically follow that round and eventually you get to the shop*

Participant A3

Unlike the other participants who, whilst being classed as ‘legally blind’, had some level of residual vision, these two participants were completely blind, and both used a cane as a navigational aid.

Throughout the stories told by people *without* visual impairment (the author and a representative of AfBP) participants with visual impairments interjected with requests for more detail in order to gather enough information to imagine the journey themselves.
Insight was drawn not only from the stories but also from the participant’s interjections to others’ stories where participants requested more detail in order to imagine the journey themselves.

*Author – follow the road around cross the crossing go up the street and it’s on your left.*

*A4 – now you say follow the road around does the road go left of the road go right?*

*INTERJECTION BY PARTICIPANT A4*

*AfBP staff member – I come out of my drive turn left, walk 400m roughly straight crossing a few minor roads//*

*A3 - //that’s a big ruler//*

*INTERJECTION BY PARTICIPANT A3*

**Reflection and Analysis**

In the described context storytelling was conducted as a verbal activity. Differences are seen in a verbal approach as opposed to visual storyboarding in that the viewpoint is cumulative, rather than a summary view of the story. In practice, this means that extra data can only be added as the story is built, there is little opportunity to ‘go back’ and add more in a coherent manner; this means the researcher must be clear on what they hope to gather from the story process prior to starting the research as they cannot change it once it has happened, of course, this issue is not unique to people with visual impairments.

Storytelling is not included in the ‘purpose’ section of the Sanders (2010) Framework for participatory design. On review it was an effective tool for probing, priming and understanding current experience, as the participants were required to think and talk about their current solutions. By describing the seemingly mundane it provided an insight
into every day thought process and life of a person with visual impairment. The Practice instrument could be utilised for idea generation; a suggestion for extension of this activity is to describe a new product and work through each section of the story asking how the user would envisage they would interact with the product at these stages.

It was notable that the participants who utilised “structural” (Bradley & Dunlop, 2002) data in their journey stories were those who were completely blind and both utilised a cane as a navigational aid. The use of a cane requires active tactile exploration of the surroundings and therefore the presence of physical structures in the environment is much more likely to be identified and significant in these user’s journeys.

In a scenario where resonance has been recognised, storytelling was an effective tool to generate a greater understanding of extra-ordinary users’ ordinary experiences. These can be used in turn to inform ordinary user’s extra-ordinary experiences. Particularly useful was the addition of the sighted participant’s and the authors story where insight was drawn from from the participants interjections. These interjections highlighted that the navigational requirements for those without visual impairment vary from those with as people with visual impairments required a greater level of direction data and a lack of need for distance information. The distinct differences between the two contexts can then be transposed into a product specification. This idea of the presentation of stories to different (resonant) user groups would be a useful tool to reflect upon variation of product use in assorted usage contexts. That being said, in the current usage context the tool was a “design for users” method as it simply helped to gain insight into the lives and actions of the audience.
Summary and Recommendations

When conducted with people with visual impairments the verbal storytelling technique identified particular navigation strategies useful for the participants. In isolation the stories aided understanding of the users particular needs and requirements. The addition of stories from other user groups proved to be a useful tool in highlighting differences between the experiences and requirements for specific user groups. This is useful for scenarios in which resonance has been identified as it provides clarity on the differences in experience and actions for the two user groups.

Suggestions for Practice are laid out below

<table>
<thead>
<tr>
<th>STORYTELLING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants are asked to tell a story about a particular event or occurrence in their lives.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spend some time considering exactly what output you desire.</th>
<th>Due to the cumulative nature of verbal storytelling it is not easy to go back and add more</th>
</tr>
</thead>
<tbody>
<tr>
<td>Be clear with the participants about what you’d like to achieve</td>
<td>Once a participant starts story telling there is no way of correcting without interrupting the flow of the story</td>
</tr>
<tr>
<td>Embrace the mundane</td>
<td>Whilst the story may seem dull, viewing ordinary experiences from extra-ordinary people gave an interesting perspective.</td>
</tr>
<tr>
<td>Present stories to different user groups and allow commentary</td>
<td>Insight was derived from the participant’s responses and questions about stories from a different user group with different engagements and navigation styles.</td>
</tr>
<tr>
<td>Consider recording the story and playing it back to add more details</td>
<td>Allows the facilitator to probe for more information without disrupting initial story flow</td>
</tr>
<tr>
<td>Ask participants to retell the story as if they were using the proposed product</td>
<td>Shifting the activity from a ‘design for users’ activity to a ‘design by activity’ by asking them to describe how they imagine the product would work.</td>
</tr>
</tbody>
</table>
6.3.3. Card Sorting

**Practice Instrument**

Valued by designers for its low cost, ease and speed of implementation, *Card Sorting* is well suited for the early stages of the design process (Vredenburg, et al., 2002). More routinely seen as a categorization process for website design (Spencer and Warfel, 2004) it can have a variety of outcomes; Sanders (2010) states that it aids the designer to “separate, categorise and prioritise” concepts, ideas and features and she categorizes its use as a tool to aid understanding and generate new ideas.

Current examples of card sorting detail the creation of physical cards and a task set to the participants to complete (Spencer & Warfel, 2004). Cards could be displayed in a braille format for people with visual impairments however this requires extensive preparation which negates the main benefits of the method that it is rapid and low cost to implement. For this reason it was decided that presentation of cards for this activity would be verbal to be more in-keeping with the original benefits of the method. The verbal method therefore fits with Bernard’s (1995) description of “Ranking” where participants are presented with concepts and asked to discuss the order.

Card sorting was used to aid resolution for decisions and create a priority list for features and functions of the device. Features, function and qualities were identified and listed, these items became the *cards*. The cards were presented verbally to a group of four participants who were asked to immediately and instinctively respond to the conflict, for example: “features or price?” or “tactile, visual or audio?”. The aim of this technique was to provided conflict resolution through the use of single questions and when viewed cumulatively a priority order of features.
Responses were recorded through a reorganisation of typed lists on a laptop word processor as well as through the audio recording of the session.

**Results**

The task achieved the goal of creating a priority order for features and providing conflict resolution.

When discussing the device output/input priority order was placed as outputs:

1. Audio output
2. Tactile output
3. Visual output

And inputs:

1. Mobile phone keypad
2. QWERTY keypad
3. Voice Recognition

Qualities were ordered as:

1. Cost
2. Functionality (navigational ability)
3. Ease of data input
4. Customisable output
5. Comfortable
6. Material Choice
7. Button Size
8. Button tactility
9. Pocket Sized
10. Having two hands free
11. Single Component
12. Multi-functional
13. Brand
14. Colour
15. Screen Interface
16. Desirability
The number one priority was cost as it was noted that if the device was too expensive it would prohibit the access to any other quality regardless of the importance. The highest ranking qualities all related to the device’s usability as opposed to its form with the most important quality (after cost) being the ability to do its job well.

It was noted that overall comfort was more important than button size or tactility as it was envisaged that the majority of usage would be merely holding the device and buttons would only be utilised in the initial set up period.

Desirability was placed as the least important quality for the device, whilst this was in-keeping with the overall attitudes of the participants in that good functionality was of high importance it was juxtaposed by earlier focus group outcomes where the brand and desirability of Apple products were key motivators for purchase.

**Reflection and Analysis**

The results were unsurprising, as noted in the initial focus groups, opinions on device interfaces seem largely bias towards current experience and this is reflected in the priority order. It is important in the design of a navigation aid that the tactile display builds upon the positive qualities that people with visual impairments gain from using audio output interfaces.

During the initial focus group sessions (Chapter 3) it became clear that there were many conflicts between user needs and desires and device costs. Facilitation was, at times, difficult and effort was made to prevent the focus group becoming too fixed on negative perceptions of the cost of current technology and drive the conversation towards desires for future technology. As is true in many focus group situations, dominating participants were present, but when conducting a focus group with people with visual impairments this
proved to be a heightened issue; potentially due to the participants being unable to recognize the usual visual prompts associated with an individual waiting for their turn to speak. This task overcame these issues by adding urgency to the discussion, leaving little room for debate or thought. Participants were asked to order the cards immediately and concurrently, meaning that all participants expressed their view. Short discussion periods followed each conflict but urgency to move onto the next remained high priority.

The cards were presented verbally to the participants. To aid facilitation cards were viewed on a laptop computer. This acted as the script for tasks, then the cards were copied and pasted within a word-processor into the correct order. In hindsight, physical cards might be been quicker and less obtrusive as the clattering of a keyboard or clicking of a mouse can be distracting for the participants.

The primary difference between this task and visual based card sorting activities was in the lack of a cumulative view of the cards. The organisation of multiple cards required the presentation of cards in batches, with only limited amounts (maximum three) presented at any one time. The facilitator cannot rely on the memory of the participants as only through extended discussion would it be uncovered that the participant has forgotten a card, which is contrary to the fast paced style of the activity. The task took longer than visual based card sorting tasks, and while it required less preparation in that physical cards were not required, this was mitigated by the extra time spent considering the order of the questions to achieve the desired results.

A useful task for engagement of people with visual impairments, the application of this task for participants without visual impairments is limited. It could be useful to break up otherwise structured focus groups as cards and conflicts could be generated by a note taker throughout a focus group discussion in order to conduct the activity then and there, as
proposed by Bernard (1995) and Collucci (2007). Otherwise, if the participants have the ability, the visual task is a more appropriate and effective way of gaining the same type of data.

When reviewing against Sanders’ framework, she suggests that card sorting’s purpose is to “understand” and “generate”. This is corroborated by this study as it allowed the researcher to understand user’s priorities and requirements whilst it generated a specification for the product being designed. The exercise could be utilised as a priming exercise in order to start users thinking about their priorities and then revisit after discussion to see if any differences are evident. The “generate” element indicates that it is useful as a ‘design by users’ method providing that the ranking order produced is utilised within the final design.

Summary and Recommendations

The verbal card sorting technique aided production of design specification in a ‘design by users’ fashion and the participants responses were useful for the particular design project being undertaken. However, the activity was less effective than the visual counterpart and therefore it is not advised that the verbal technique is used where avoidable. An exception to this may be to break up otherwise stagnant focus groups as suggested by Bernard (1995) and Collucci (2007).

Suggestions for Practice are laid out on the following page.
### CARD-SORTING

*Product features and functions are identified and each constitutes a ‘card’. Participants are presented with these cards and are asked to prioritise or categorise e.g. “price or functionality?” or “tactile or audio?”*

| Undertake the activity with physical cards (facilitating the participants answers) | Avoidance of audio noise from a laptop. Easier to order cards. |
| Present a maximum of three cards at once | The verbal version of this activity relies on memory of the cards presented |
| Maintain urgency in the response | Documents participants initial reaction as opposed to being drawn into conversations about benefits / negatives |
| Create a script or plan prior to the event detailing the ordering of the questions to attain the best information in the quickest fashion | As presenting cards must be conducted in ‘batches’ a script or plan avoids repetition |
| Consider utilising card-sorting to break up otherwise structured focus groups by creating cards ‘on-the-go’ | Focus group participants (with and without impairments) can get distracted by tangential issues or absorbed in debate. This task resolves conflicts quickly and effectively. |

### 6.3.4. Existing Product Feedback

#### Practice Instrument

Evaluation of existing products is a common activity in the product design process. In this scenario existing products were scrutinized in order to gain feedback on aesthetic and ergonomic form. The products interrogated were not necessarily navigation aids, but merely products with similar features: handheld, electronic products.

This work was an extension on the mood board activity (Chapter 6.3.1) in order to uncover insights around product form for those who cannot visually engage with products. As the activity is not reliant on any one modality the activity is suitable for people with visual impairments.

A selection of products were given to the five participants with visual impairments and a member of AfBP staff without visual impairment, these products were:
Participants were asked to feedback on various physical elements of the devices such as: overall form, button size, weight and material.

Results
The majority of the feedback focussed on the interface mechanisms. Strong preferences were seen around devices that had fewer and larger buttons. As well as button size, button depth was highlighted as deeper buttons were easier to distinguish than shallow or flat buttons. The games controller, the DVD player remote control, the Nokia 5110 and the Motorola M3188 were all mentioned for their clear button layout. One participant noted that the buttons on both the games controller and the Nokia 5110 were all reachable by the thumb and felt that this was a positive. All participants felt that the clear 'select' button of the Virgin Media remote control was a benefit however many felt that the other buttons on the remote were not easily tactiley perceivable.
Out of the mobile phones both the Motorola and the Samsung phone received positive feedback around the buttons covers. The Samsung phone received particularly good feedback in its button cover mechanism as the ‘swivel’ was seen to be fun. However the flat and very small button layout beneath quickly diminished the excitement of the swivel mechanism.

Product orientation proved to be an issue, two participants struggled to decipher the orientation of the Sony Ericsson phone and one participant held the games controller in an orientation different to that intended.
Very little feedback was received on overall form or material of the objects, even when prompted. The material on the HTC phone was noted as it was felt that the rubberised plastic made it seem durable compared to the other similar devices:

“it feels like it might take a few more bangs than my iPhone”

PARTICIPANT A4

Participants were asked to reflect upon their preferred design of TV remote control between the two designs featured in Figure 21. Participants unanimously preferred the Alba DVD remote for various reasons including: button layout, button depth and product size.

The AfBP staff member who did not have a visual impairment gave slightly different feedback to the participants with visual impairments, where participants with visual impairment mainly focused on the interaction elements such as buttons, the sighted participant looked at overall form, for example, two initial feedback statements on the same product (a games controller):
I think the buttons are large, some of them are quite easy to feel, good grip, good shape – a few of the buttons here are quite small, so someone with less sensitivity in their fingers would need larger buttons than this. The wiring doesn’t look the easiest to get into.

Participant A1 (person with visual impairments)

The basic ergonomics of it are quite good, the triggers and everything, the button positioning is quite good. It feels quite robust, like it could take a few losing battles, it feels like it’s got quality.

Participant A7 (person without visual impairments)

Reflection and Analysis

Overall a well-received activity, participants were happy to take part and feedback on the products. Whilst an easy task to undertake, two particular points of interest were highlighted in the performance of this activity with people with visual impairments:

1. Clarification of the products use

The participants took some time to discover what product they were interacting with and in a few cases this was not recognised at all. Care was taken to avoid the notion of ‘testing’ the users on their product knowledge as it is understandable that unless a person with visual impairment has had direct interaction with a product they may have no experience to draw upon which would identify the product. On the other hand, this lack of context is
desirable in this style of product test and can help the designer to understand how quickly a product is recognised through tactility alone, what features are quickly identifiable, and, without visual cues, what is the most intuitive way to hold and interact with the product? In this situation due to the tactile sense requiring a few moments to build up enough data to generate a full mental image of the product the amount of time was enough to gather initial insight prior to the participants enquiring into product use.

2. Avoidance of tactile cues

The initial exploration of the product is one of the main elements of interrogation and identification of intuitive grip styles and hand positioning; for this reason the facilitator must make an effort to avoid tactile cues. Simple interactions, such as passing the object to the user or referring to a button by the finger by which it is intended to be used (e.g. “the thumb button”) would coach the user on interaction intention.

Interesting insights were uncovered showing tactile preferences for product design that would not be expected to marry up to visual preferences. A particular example was that of two remote controls, one which came with an inexpensive DVD-player and had a very simplistic visual design, and one Virgin media remote control, which was far more stylized;
the participants unanimously preferred the less stylized controls for various reasons including, button layout, button depth and product size.

The visually impaired participant’s greater expertise in requirements for purely tactile interfaces was also particularly evident in this task. Very specific responses were given in reference to the button size and style, which may have been overlooked by a participant without visual impairment.

*I prefer this one, the reason being is, it’s got larger buttons, the select button is highlighted as well and I like the size of it as well, the reason why I wouldn’t prefer it is that the select button on this one is smaller.*

**Participant A2**

Interesting to note was the use of visual terminology within the task for example “*the wiring doesn’t look the easiest to get into*”. It is important that these statements are carefully considered by the researcher to ensure that the point is clear, in this circumstance the participant was talking in respect to how the connection socket on the attached lead was not very distinctly shaped, therefore it may be difficult to identify the correct orientation for the plug.

People with visual impairment are in an apt position to give detailed and unbiased feedback on ergonomics and form. Not only are they uninfluenced by graphical cues that may indicate usage style or orientation but, as tactile product exploration takes some moments to build up a cognitive image of the product, for the first few seconds they are also uninfluenced by recognizing it as a particular product. Whilst arguably this could be reproduced by using ‘empathic user testing’ (Lin and Seepersad, 2007) where a sighted
participant is blindfolded the outcome would unlikely be the same. A factor that informs this hypothesis was the surprise that such little feedback was received on overall form. People with visual impairments explore products starting with the details and work towards overall form (detail-up exploration), and so would naturally feedback on detail first, regularly they’d find an element of the detail to dwell on rather than moving on to overall form, it is likely that blindfolded participants would make an assumption that the graphical cues on an interface would aid them to control the product and so would focus more on overall form. Nevertheless, many practitioners suggest “blind test” of products, where blindfolding the participants offers interesting results particularly around orientation, comfort and brand recognition (Knight, 2006; David, 2006; Coughlan & Sklar, 2005).

The participants with visual impairments gave a unique perspective on products that they had no experience with. This was exemplified well during the study when discussing a games controller, a participant with visual impairments who had never used a controller before held it in a unique style which, on reflection, the products form affords; the user held the product so the majority of the buttons landed where the majority of their fingers laid, and vice versa, where there was only one button they controlled it with only their thumb (see figure 20 page 143). These controllers are common place in media and so for people without visual impairments even having never used the controller before, would understand the intended grip ergonomics and would probably never have discovered this new interaction style, blindfold or not.

Overall, this was deemed to be a successful task and it would be interesting to carry out this task in other product contexts. The literature review discussed Burnett and Porter’s
(2001) utilization of non-users in the design process and this task evidenced the unique and
effective outcome that came of it. Whilst Burnett and Porter’s solution reflected directly
on a resonant scenario between people with and without visual impairments this study
would be of benefit to any designer looking to make an intuitive tactile interface. On the
other hand the lack of feedback on overall form and stylistic choices such as sculpting or
material selection does support the statement that a heavy focus on usability for
marginalized communities may compromise on stylistic elements of the product (Pullin and
Newell, 2007).

The method could be used as a tool to ‘probe’, ‘prime’ or ‘understand’ and whilst it did not
generate new concepts, it did identify key features for consideration in the final product.
In this example existing products were used, however, examples of similar activities in the
literature (conducted with participants without visual impairments) show the activity used
to interrogate product concepts utilising low-fidelity prototypes (Knight, 2006) and
therefore evidences that the technique can be successfully applied throughout the product
design process.

Summary and Recommendations
Gathering feedback on existing products was shown to be an effective and enjoyable
participatory tool.

The results of the activity highlighted people with visual impairments unique approach to
product exploration and how this can be utilised to provide an insight into product form
dissimilar to the likely feedback from those without visual impairment.

Suggestions for practice are laid out on the following page.
### EXISTING PRODUCT FEEDBACK

<table>
<thead>
<tr>
<th>Do not ‘test’ the participants on their product knowledge. If a participant asks what a product is</th>
<th>Some participants may not have engaged with a product before and without being able to visually perceive any usage cues participants may struggle to identify products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do not immediately explain product usage</td>
<td>Allow the participants to first explore the product, providing insight into how recognisable the form of the product is.</td>
</tr>
<tr>
<td>Do not indicate grip orientation by handing the product to the participant. Instead place the product on the table in front of them.</td>
<td>Provides insight into how intuitive a product's grip orientation is based on form alone.</td>
</tr>
<tr>
<td>Do not provide verbal cues as to a feature's intended use e.g. “what do you think of the thumb button”</td>
<td>Avoiding instructions on how to use/hold a product tests the intuitiveness of form</td>
</tr>
<tr>
<td>If filming, ensure the camera is directed towards the participants hands not their faces</td>
<td>Aids proper data capture</td>
</tr>
<tr>
<td>Expect feedback on product detail, such as buttons layouts, depths and tactile noise</td>
<td>Due to the product exploration techniques of people with visual impairments initial engagement is with product detail</td>
</tr>
<tr>
<td>Probe for feedback on overall shape and materials</td>
<td></td>
</tr>
</tbody>
</table>

### 6.3.5. Modelling

**Practice Instrument**

Models and prototypes are a commonplace tool within the design process. They allow the designer to explore solutions, understand problems, study how users interact with the concept, alongside testing functionality (Hallgrímsson, 2012). Within Sanders’ (2010) participatory framework, 3D mock-ups are stated to aid in the understanding of current experience and in the generation of new ideas. They allow for a sharing of ideas and discussion of form and feature placement in a manner that would be difficult to accomplish verbally. These tasks are a particular challenge within this project as model making is a very visually reliant process.
A large number of ‘blank shapes’ were created in Styrofoam. These shapes drew inspiration from the outcomes of the previous activities and through conversation with the participants. Five participants with visual impairments were then asked to explore the models and indicate where they would envisage key features of the product, which would then be drawn onto the models.

Results

As well as placement of key features on the models, the exercise also helped clarify the features and functions envisaged to be on different parts of the device. A general consensus was reached that the device would have two components, one ‘computer’ component which handled the input of destination and one ‘command’ device which would be used to issue the tactile commands as it was felt that the ‘command’ device should be
free from tactile noise. This division of functionality meant that there was also a division of features to be placed on the devices, the agreed units and their functions are described below:

- **Computer unit:**
  - Mobile phone style keypad
  - Menu button
  - Speaker
  - USB port
  - Headphone port
  - SD card slot
  - Power Button
  - Volume dial

- **Command Device:**
  - Tactile feedback areas
  - Pin charging socket
  - Power Button

Preferred models for these components are seen in figure 24 and 25. The preferred forms for the command device all took a more organic form with a focus on being comfortable to
hold in the hand. This reflects the sentiment seen in the card sorting task where participants felt that being comfortable to hold had a high priority. The preferred forms for the computer device took forms that were more similar to that of mobile devices, in that they tended to be based on a rectangular shape, however shapes with curved or rounded edges were chosen over more simple rectangular forms.

Figure 25: Preferred forms for the command device
Reflection and Analysis

Participants enjoyed this task as it allowed them to add something tangible to the design process. The task itself took a reverse perspective on product exploration; as people with visual impairment will first explore detail then build up a mental model of the product, this task required that they first explore overall shape before they develop detail. For this reason it was vital that a full explanation of the prototype stage was provided as participants did not have access to the usual visual cues to indicate that stage of development which would usually be used to explain the lack of detail. In turn, material selection must be appropriate for the stage of development. Styrofoam worked well as a modelling material as it allowed the participants to fully explore form whilst also editing design details using pressure from their fingers or a pen, this also required a certain level of detachment from the painstakingly hand carved and sanded models as they very quickly became tatty and dishevelled. Initial exploration through touch required a higher level of robustness in the models as, with no visual prompts to indicate delicate areas, the initial tactile exploration could easily break fragile models.

An engaging and enjoyable activity, model making brought a new dimension to the design process for the participants, many of which had partaken in focus groups, interviews or testing activities previously. Outcomes included: the preferred forms for further development; feedback on pros and cons of forms; and generation of an understanding of where expected features should lie.

Feedback on form was well articulated and explicit. A particular benefit of this feedback was in the placement of key features. Regularly these placements did not marry up with where how the sketches had envisioned the features, this indicates that the placement, when driven by tactile requirements may be different to the placement when driven by
visual discernment. This could have significant impact on a product’s ease of use, as visual
discernment is dictated by the designer’s taste, for example a like or dislike of symmetry
could have huge impact on a product’s design, where tactile requirements are more
functionally based with a focus on anthropometrics and ergonomics. Further iterations
would include similar studies with higher fidelity models, more lifelike materials and
different weights. Quick responses, in an almost stream of consciousness approach to the
prototypes, suggested that there was less judgment of the fidelity, feedback was more a
direct response to the form rather than an aesthetic judgment of it.
Suitable for use in the early to middle stages of the design process this method was a useful
“design by users’ tool to aid ‘understanding’ and ‘generating’ new concepts. It allowed for
both development and refinement of product concepts.

Summary and Recommendations

Model making with people with visual impairment proved to be an effective design tool as
well as an enjoyable experience for the participants.
The results of the activity showed a sensitivity towards feature placement concerning the
practicalities, ergonomic and tactile aesthetic which at times did not marry up with the
authors expectations of feature placement from a visual perspective. It is recommended
that model making with people with visual impairments would be valuable in the design of
a product that requires tactile engagement, particularly products in which visual
engagement is undesired. Feedback showed very little judgement of fidelity or expectation
of graphical cues.

Suggestions for practise are laid out on the following page.
**MODELLING**

*Participants are presented with solid, rough forms for the proposed product and asked to add expected features and feedback on form preferences.*

<table>
<thead>
<tr>
<th>Explain the fidelity of the models</th>
<th>Participants may not have access to the (visual) cues required to appreciate its stage of fidelity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use a malleable material and ask participants to add their own features and give the participants simple tools to add their own features</td>
<td>Engage participants in the placement of features, overall form and detailing of the product.</td>
</tr>
<tr>
<td>Ensure the models are sturdy</td>
<td>Participants may not have access to the visual cues of a delicate model. Simple tactile exploration of a product can be violent enough to break delicate prototypes.</td>
</tr>
<tr>
<td>Use Styrofoam</td>
<td>Styrofoam proved to be an apt material for modelling with people with visual impairments. Sturdy enough to hold overall form, but malleable enough to add tactilely perceivable features.</td>
</tr>
<tr>
<td>Consider creating a list of initial features to consider</td>
<td>Participants started the task slowly but once they had got used to the task embraced it. Proving a few examples allowed users to understand the task better.</td>
</tr>
</tbody>
</table>
6.4. SUMMARY

This section has documented and reflected upon a selection of design activities conducted with people with visual impairments. The activities conducted varied in terms of design output from probing and priming participants around the research area to generating design concepts. The success of the activities overall was mixed, those activities more similar to ‘word games’ relied heavily on prior knowledge which limited the scope of the output. The feedback on physical items (products and models) was more enjoyable for the participants and led to some interesting design concepts.

Overall the process was considered a success as it provided a good foundation, direction and inspiration for the development of the tactile navigation aid going forward. “Engagement and involvement” are the two major challenges in a participatory design process (Sanders, 2002). For researchers with little experience of working with people with sensory impairments this challenge is considerably more prevalent. The participants of this study had no experience of the design process, they had undertaken various focus groups and feedback sessions before, however, they had never been asked to ‘help design’ a product in the way that these tasks did. The act of co-creation itself was engaging for the participants.

The participatory tasks attempted were relatively easy to translate to a non-visual form however varying success was found across the methods. Generalizable findings across the methods include a need for clarity and honesty, the requirement to focus on methods which exploit the skill sets of the participants, and that there will be a heavier reliance on prior knowledge. Also important to note is the value of finding participants who are invested and interested in the product development, not only does this mean they are
more likely to become engaged with the process but it also means their prior knowledge will be more applicable and relevant. The participatory process itself has been developed to help the researcher gain empathy with the user. As with the design of products it is expected that, as the researcher’s empathy with the user group grows, so too will the ability to successfully design techniques to enhance the product design process through better accessibility, engagement and involvement of people with sensory impairments.

6.4.1. Design Outcomes

Design outcomes at the end of this stage of research included:

- Button layouts should be consistent with conventions
- Fewer, multi-functional buttons are better than many single button functions
- Soft shapes with curved corners were preferred
- Desire to use with mainstream products
- Contrast in material has importance:
  - Soft rubberised indicates buttons or grip zones
  - Hard smooth surfaces indicate body
- Raised keys and buttons help differentiation more than large surface areas
- Dials and sliders should be used where possible
- Power inputs which allow for insertion in any orientation are preferable to USB
- High level of granularity required for directions
- Distance measurements require context:
  - E.g. a ‘count-down’ whilst approaching a turn
  - Providing an estimated time may have more value
- Audio output is seen as having high value – tactile should augment audio output rather than replace
- Mobile phone keypads are the preferred data entry method
- Function is more important than form
- Having two hands free is less important than previously expected
- There is a high expectation to be able to customise the output
• Buttons should be reachable from the ‘normal’ holding position
• A clear ‘select’ or central button helps users navigate devices and memorise layouts
• Button covers have value
• Novel interactions are desirable
• Rubberised materials increase perception of durability
• Two components are expected:
  o A computation unit
  o A command unit
• The computation unit should be where most buttons and interface mechanisms are homed
• The command unit should be free from tactile noise
• The command unit should have a minimum of three tactile feedback areas
• The command unit should be organic in shape and comfortable to hold
• The computation unit should resemble common consumer devices (e.g. a mobile phone)
7. PHASE 1.B: DESIGN DEVELOPMENT

7.1. INTRODUCTION

The research question asks:

How might the employment of theories of resonance and extraordinary users in the collaborative design process result in better design outputs?

The research methodology designed to respond to this question details a two phase approach: ‘Phase One’, a practice-led research approach to the design process and ‘Phase Two’, a comparative study to assess the output.

Phase One investigates the engagement of people with visual impairments in the design process and is split into two sections: generative research and design development. The generative exercises described in the previous chapter provided direction for the design and an initial specification of requirements for a tactile navigation device. This chapter details the development of that design, alongside two extra-ordinary users. It documents the engagements with the extra-ordinary users and the decision making processes taken in the development of the tactile navigation aid. This allowed for further reflection on their contribution and the impact it may had on the design output.
7.2. STUDY DESIGN

7.2.1. Participants

Each “extra-ordinary user” should not be considered as representing a specific disability, but should be considered as an individual person who happens to have a specific disability as well as a range of other characteristics which are important for defining them as a person, but may not be related to their disabilities.

Pullin and Newell (2007)

As discussed in the literature review a person with visual impairment would likely provide some expert insight into tactile interface systems due to their heightened use of the touch in their day-to-day life (see Chapter 2.2.2). However, as emphasized by Pullin and Newell (2007), it is important to recognize the diversity within the demographic, and that the chosen people with visual impairment have a range of other characteristics that make them suitable for the research. Two focus group participants in particular were chosen to be ‘extra-ordinary’ users and the go-to informants throughout the design process. Participants agreed to have their first names provided in the thesis. Pullin and Newell (2007) recommend working with very small groups or even individual people in order to create designs that are truly user centred and entirely meet the needs of the very select extra-ordinary user. They also suggest these small sample sizes will produce more radical solutions as they decisions will not be compromised to meet the needs of many separate individuals.
Tony and Quizzie

Tony is 35 and lives in Birmingham, Quizzie is his guide dog. He is interested in IT and accessibility.

Tony is a self-confessed mac lover and owns an iPod, an iPhone and an iPad alongside various other handheld technologies.

Tony studied IT and electronics at Queen Alexander College. Tony and Quizzie regularly make independent local journeys and sometimes make independent national journeys to visit family.

Tony has Albinism resulting in his eyesight being limited to very basic light perception, he is registered ‘legally blind’.

Andrea and Zeta

Andrea is 30, lives in Birmingham and Zeta is her guide dog. Andrea has been completely blind since birth.

She loves music and studied it at the Royal National College for the Blind and currently sings with her local choir. She has a passion for technology particularly that which aids independence, and her favourite brands are Apple and Humanware.

Andrea and Zeta have lived in various cities around the country and are used to travelling independently both in known and unknown areas.

Tony and Andrea were chosen as extra-ordinary users as throughout the initial stage of focus groups they showed an advanced level of knowledge about electronic devices (both assistive and mainstream) that clearly indicated a passion for the subject beyond what would be a useful aid for themselves.
7.2.2. Methods Utilised

Throughout the design process Andrea and Tony had significant involvement in design decisions. This took the form of multiple unstructured conversations, semi-structured interviews, feedback on prototypes and casual testing with prototypes. Andrea, Tony and the author became the design team, with the extra-ordinary users making the design decisions and the author facilitating these decisions. These decisions covered all elements of the product: overall form, material selection, method for providing the tactons, the command tactons themselves and the programming method. As such, their design involvement cannot be detailed as a set of methods as seen in the previous chapter and therefore will be discussed in a narrative format.

7.2.3. Data Capture

Where possible these design sessions were audio recorded. However, due to the length of some sessions and the interactive nature this was not always possible. Field notes were taken throughout and immediately after the sessions if recording was not possible, enabling the documentation of decisions made and the rationale behind them.

7.2.4. Ethical Approval

Tony and Andrea’s further engagement in the process was covered under the ethical approval sought at the start of the research project.

This chapter also details research engagement with new participants, for these engagement the standard Cardiff Metropolitan ethical approval process was taken, including a risk assessment, and the gathering of informed consent for each participant.
7.2.5. Research Conducted Beyond the Scope of the Thesis

Whilst the study itself focuses on the input of people with visual impairments on the design process, a variety of other development studies took place with people without visual impairment that informed the development of the prototype. In Von Hippel’s (1986) seminal paper ‘Lead Users’ (of which Extra-Ordinary users is a development) he discusses the requirement to “project lead user data onto the general market of interest” in order to assess the application for typical users. In this project the product was also tested on users without visual impairment, this was for two primary reasons:

- To test the applicability to the typical user needs
  
  Any feedback gathered was then presented back to the extra-ordinary users as further discussion points.

- To test minor design iterations with an easier to recruit market segment
  
  As the extra-ordinary users were some distance from the research base items such as the device programming were tested with participants more local to the research base. This decreased cost and timelines as appropriate for a commercial development process.

This chapter will reference these studies in the required detail to contextualise and clarify the product development narrative, however the focus of the chapter will remain on those informants with visual impairments.
7.3. CONTEXTUAL INQUIRY WITH EXTRA-ORDINARY USERS

Contextual Inquiry was utilized to investigate current navigation technology for people with visual impairments and usage patterns, and benefits associated with specific PNDs designed for non-visual engagement.

Raven and Flanders (1996) lay out the three principles on which contextual inquiry is based:

1. Data gathering must take place in the context of the users work
2. The data gatherer and the user form a partnership to explore issues together
3. The inquiry is based on a focus

This approach was chosen over an ethnographic approach due to the very focused requirement of the research at this stage in the process (Dourish, 2006). It was also felt to fit well into the research as the ‘partnership’ between researcher and users to explore issues resonates well with the participatory approach taken.

Each extra-ordinary user was observed on a short (roughly ten minutes) journey with a commercial available navigation aid aimed at the access market, ‘the Trekker Breeze’ (Humanware, 2016). The Trekker Breeze was the most commonly cited navigation aid throughout the early stages of the research process and is manufactured by ‘Humanware’ a well-known brand in the assistive technology sector. Users were filmed at all stages of the journey, from getting ready (and getting their guide dog ready), to arrival. Both Andrea and Tony were made clear of the aims of the research and after a short demonstration of the key features used a “think-aloud” protocol (Nielsen, 2012) to explain their interaction with the product.
The product is clearly designed for accessibility as when assessing against inclusive design recommendations (Gill, 2000) a high number of suggested design features are visible. The design utilizes hotkeys and multiple button presses revealing different features and functions, and, whilst not in the expected square layout the buttons act as a 1-9 keypad, with the arrow keys providing a central point of reference. On route, it provided audio instructions navigating the user along a path. Users can also mark their own waypoints and audio record a name that will also be announced as they pass the marked area.

7.3.1. Results and Scrutiny

The two participants were keen to demonstrate their devices, both to celebrate technology usage and to identify usability issues that may aid product development.

The task highlighted the necessity for simplicity in the device, as for people with visual impairments the ‘getting-ready’ routine is already lengthy. Both participants complained about the amount of time the device took to identify GPS location, and Tony compared it against his iPhone,

...I don’t know why it takes so long, this [iPhone] can do it in half the time.
When further probed about the possibility of using his iPhone he indicated that he would prefer it, but as of yet the apps are not as easy to use as the Trekker.

![Figure 27: The two components of the Trekker Breeze system](image)

The product comprised of two components, the control unit and a speaker/microphone unit worn on a harness around the body; an earphone unit could be connected but both participants chose to use the speaker unit instead stating that headphones block other important navigational cues. This was highlighted whilst walking with Andrea where she noted the noise of car engine parked nearby prior to a road crossing, which would have been unlikely heard with an earphone in place, supporting the hypothesis that audio devices are not apt for navigation purposes.

Prior to setting off the users demonstrated the use of the control system. This system relied heavily on softkeys where each button provided many different functions, the primary
function of the keys was to access the device menu system. One of the secondary functions of the keys was that of a 0-9 keypad, which was interesting as the layout did not reflect the rigidity usually seen in this style of keypad however the users showed no difficulty in using it.

Also interesting was the change of the orientation of the device whilst in use; when initially programming the device it was held with the logo in the correct orientation. However once clipped to the travel harness the logo was upside down, this meant that the hand sat on the device in the same position when attached to the harness; a sensible solution though one not regularly seen in mainstream devices which require you to bring the device back to a horizontal position in order to view the controls system.

Throughout the walk the device was very loud, often uncomfortably so. Andrea rushed to turn the speaker system down whilst walking through a quiet residential area, particularly
when her own recorded voice was being projected. Although she did not state it explicitly, the reason for this seemed to be both an awareness that it might disturb other walkers and embarrassment at hearing her own voice projected so loudly. Both Andrea and Tony showed signs of frustration when the audio interrupted conversation flow especially on areas of the route local to the starting point (where they already knew the direction in which to travel).

When walking through busy areas loud audio was required to clearly understand the devices directions, however this drew a lot of attention towards Andrea and Tony. Andrea and Tony were unaware of it themselves but passing pedestrians were sometimes surprised by the device’s outburst and regularly stopped to have a look at what was creating the noise. It was very clear to anyone within earshot of the participants that they were following directional instructions and so labelled them as vulnerable. It is these mundane direction commands that it was felt that tactility would augment, the simple directional information that can be simply encoded, which would reduce the audio feedback that was both an annoyance and risk. Whereas, more contextual data like details of landmarks that would be difficult to encode and less regularly utilised, and more easily forgotten, could remain an audio output.

Trekker successfully guided the participants to their destination. At one stage in the journey, Andrea walked slightly off route, this was caused by Zeta attempting to avoid a crowd of people. Andrea identified within (an estimated) 5-10 meters that she was walking the incorrect direction due to an awareness that she was walking away from the noise of the main road (and prior knowledge that her destination required her to follow the road), the device however did not rectify the incorrect turn, raising the question, how far would she need to walk before the device corrected her?
Neither participant removed the harness once at their destination, though Andrea commented that had she had her handbag on her she would usually have taken it off. Whilst keen to present the technology, neither participant seemed enthusiastic about either the design or the functional ability. Tony regularly compared it to his phone stating that a well-designed app would benefit him just as much. Andrea was slightly more positive than Tony and clearly valued the accessibility features of the physical design, but gave mostly running commentary on the device as opposed to enthusing about features and benefits.
7.4. DEVELOPMENT OF INITIAL FORM

Initial ideas on overall form were constructed through participatory tasks with multiple participants (as detailed in Chapter 6.3.5). Semi-structured interviews took place with Andrea and Tony to explore other opportunities that may not have presented themselves in the initial task.

The framework of themes discussed in the initial interview included:

- **Review of the 3D sketch models after the initial group feedback task (Chapter 6.3.5)**
  
  After conducting the modelling task with a larger group of users a smaller selection was presented to Tony and Andrea for further development.

- **Review of the device supplied by the original commercial partner**
  
  The initial group feedback task had not identified any solutions similar to the device, which attached to a guide dog harness. In order to present a full range of ideas and to provide inspiration the existing product was presented for feedback.

- **Discussion of potential for wearable solutions**
  
  Similarly to above, the initial ideas had not diversified into wearable devices. This was likely due to the discussed high reliance on existing product knowledge recognised throughout the tasks. In order to stimulate further ideas and to investigate other possibilities the prospect of ‘wearables’ was investigated.

The sessions ran smoothly and Andrea and Tony both engaged well with the design discussion. They had clear ideas on how they envisaged the product to work but were open to new opportunities and suggestions.
7.4.1. Review of Sketch Models
Of the initial ideas developed from the group task Andrea and Tony both preferred an organic form for the command unit and a more standard ‘device’ form for the programming unit, which could then be kept in a pocket or bag throughout the navigation task whilst the command unit provided the directional information. However, both participants agreed that they would prefer to programme the device using their smartphones and were particularly enthused about this prospect.

Yeah that’d be cool! It could be like, an add-on thing

ANDREA

On further discussion they felt that a programming device would still be of value to those users who didn’t have smartphones but this should be an optional extra as opposed to the standard method of programming. That it was preferred for a smartphone to programme the device confirms the sentiment expressed in the initial research focus groups that there is a strong desire amongst people with visual impairments to use mainstream devices. The prospect that the navigation device could be part of a mainstream system rather than a separate system designed for people with visual impairments was attractive to the participants. Both participants felt that the prototypes could be made slightly larger to fit more comfortably into the hand. Andrea and Tony envisaged the computer unit to be utilised similarly to the Trekker Breeze and as such would attach to a strap or belt buckle. On investigation it was felt that a bulbous back end provided a comfortable hand rest on the device. This echoes the findings of Porter et al. (2005) who described a “hand control reference point” as a physical landmark to aid product navigation.
On investigation of the command unit participants struggled to understand in which direction and orientation to hold the object and requested further sculpting to help identify the grip orientation.

7.4.2. Review of Existing Tactile Navigation Aid

A prototype of Peepo GPS (Peepo GPS Ltd, 2014) milled from model-board was shown to Andrea and Tony, the prototype was low fidelity and simple allowing them to explore the intended form.

Both participants felt strongly that the device was not comfortable or intuitive to hold and both were very negative towards attaching to the guide-dog harness; Andrea was worried about the wellbeing of the guide dog and Tony did not want to exclude non guide dog users from using the device.

Tony – what about Syed? He doesn’t have a dog

Discussion on this subject was curt as the users, particularly Andrea, were very dismissive of the product stating that she would not be interested in trying a higher fidelity version of the device.
Figure 29: Peepo PGS Existing system

Figure 30: Peepo GPS prototype
7.4.3. Potential for Wearable Solution

The participants discussed the prospect of a wearable device including: a glove, a belt, a watch or integrated as an app on a smartphone as these are items commonly seen in the literature.

Both participants were very negative towards the idea of a belt.

*I wouldn’t wear that. It’s hard enough finding a decent outfit in the first place without having to colour co-ordinate an electronic belt*

ANDREA

Two key factors informed this. Firstly, that people with visual impairments already struggle with clothing selection and this was perceived to make this more difficult, secondly, they discussed that many people with severe visual impairments struggle to maintain a healthy weight as good exercise routines can be difficult to achieve, a belted product was felt to emphasize this and was not desirable.

The prospect of a tactile glove was agreed as an interesting potential solution and both participants recalled having heard about a solution similar to this having been trialled in the past.

7.4.4. Actions

The goal of this initial semi-structured interview was to provide direction development of product form. As such actions generated through this discussion were:

- Refine the current designs in line with the specifications laid out by the users:
  - Make the design slightly larger
  - Add sculpting to indicate grip direction
- Use different materials to differentiate between product body and tactile zones
- Prototype a glove/watch command design to stimulate more discussion
7.5. INITIAL IDEAS FOR TACTON

Another key area in need of development was that of the tactons. These tactons were intended to communicate the navigation directions in a manner that was unobtrusive and allowed the audio modality (and when being used by people without visual impairments, visual) freedom to undertake safety and social roles. The contextual inquiry previously undertaken (Chapter 7.3) identified that mundane directional information (e.g. turn left, keep walking, etc.) had the greatest potential for tactile communication as opposed to contextual data such as identification of landmarks.

Initial ideas for Tactons were developed through semi-structured interviews with Andrea and Tony, this discussion was conducted after the contextual inquiry described in Chapter 7.3 in which the participants were observed individually using the Trekker Breeze. This was helpful as many of the key insights, such as preparing the dog for an upcoming turning and the necessity for regular reassurance provided points for discussion. After an initial exploration of form, that helped to ground the idea of tactile output within potential physical objects (which at this stage was either going to be a handheld device or wearable watch like-solution), two topics were planned for discussion:

- Which navigation commands are required?
- How might these commands be displayed?

7.5.1. Command Requirements

Seven different navigation commands were identified by Tony and Andrea as vital for a complete journey:

1. Go forwards
2. Prepare to turn (left/right)
3. Bear (left/right)
4. Turn (left/right)
5. Turn around
6. Arrived
7. Warning

As discussed, ‘prepare to turn’ was considered a very important requirement as it relates to the command system that is used with Guide Dogs where an owner will tell their dog to “look left” when an upcoming turn is expected.

A dog doesn’t just know [that he needs to turn] he needs to be told and if you just start turning then that’s gonna upset it.

ANDREA

The warning signal was discussed at some length, whilst initially it seemed useful, as the conversation continued, Andrea and Tony started to question whether it would detract from the skills of the user and cause a dangerous reliance on the device, particularly for cane users.

Andrea - Be careful of that, that you’re not taking away//

Tony - //you know you don’t want the person to rely on the GPS, it’s there as a guidance, you know there could be an object in the middle of the road no GPS is going to be able to tell you that, but you’re talking detection... that it’s going to get too expensive if you have things that are object detection

Overall, it was felt that a warning signal would cause an over-reliance on the system replacing those navigational prompts that are provided by white canes and Guide Dogs such as: road crossings, stairs, and inclines and this was not desirable for either participant.
However, due to the lengthy discussion around the command for the time being it was kept on the short list of ideas.

Andrea was keen to implement a compass direction based system, in which she was able to stand still and the device will indicate the correct direction. She commented that many people with visual impairments, particularly completely blind users (like herself) get easily disoriented, which correlated with the noted disorientation when observing her use the Trekker Breeze (Chapter 7.3). A compass based system would allow her to orient herself prior to setting off, avoiding walking in the incorrect direction prior to the initial instruction as she suggested that she regularly does when using the Trekker Breeze.

7.5.2. Command Display

The interviews continued to discuss potential tactile methods in which to convey these seven different types of commands. Two methods had been briefly discussed in group conversations earlier in the development process (during the modelling exercise detailed in Chapter 6.3.5) which were vibration profiles and a pin array system. To facilitate the discussion, two props were utilised: a small electronic system containing three vibration motors and a remote to control them, and, a selection of wooden pegs. This allowed for on-the-spot trials of proposed tactons, both vibrotactile and pin array.

The list of commands was utilised and Tony and Andrea were asked to discuss ideas of how these would be presented in vibration, pin array, or through other tactile means.

The outcome of the interview was 25 different potential Tactons utilizing either vibrotactile or pin arrays (15 vibration and 10 pin array listed in Appendix VI). Many of the seven commands have multiple suggestions for potential tactons, as well as many tactons being
suggested for multiple commands and so further testing was required to identify which would be the most effective and intuitive for each command.

7.5.3. Actions

The aim of this semi-structured interview was to generate ideas for which tactons should be communicated to the user and how that may happen. As such, actions for the next stage of the development process were:

- Understand which profiles offer the most intuitive interaction
- Use the data generated to refine the profiles
- Create a prototype system utilising refined profiles for field trials
7.6. REFINEMENT OF TACTONS

In the previous section, a selection of 25 different potential tactons was generated which covered 7 commands. A rapid formative study was devised in order to refine the commands and identify which tactons most intuitively fitted with the command structure. As the study was intended to be a quick decision aid, as opposed to actually generating new knowledge, it was felt that users without visual impairments could be recruited for this study as they were easier to recruit in higher numbers, required less admin to gather consent (as participants with visual impairments required a trusted supervisor in presence for any signatures gained) and were able to be recruited closer to the research base. This also aided the assessment of applicability for mainstream users at an early stage of development as suggested by Von Hippel (1986) ensuring that whilst the product was developed by people with visual impairment a recognition of the resonance took place in order to keep market opportunities broad. The only criteria for participation was that participants must have no sensory issues in their hands to ensure they could feel the tactons being displayed.

7.6.1. Study Overview

17 participants took part in the study. Participants were given a list of the potential 7 potential commands and were then asked to lay out their dominant hand palm upwards. The list of commands was located on the opposite side to their dominant hand and participants were asked to keep their visual engagement on the list of commands to ensure results were not biased by being able to see the presentation of the 25 profiles. Vibro-tactile profiles were simulated using an Arduino and vibration motors which were attached to the participant’s finger tips using sellotape. Pin array profiles were simulated
by pressing wooden pegs on the palm in the correct position. Figure 32 (below and continued on next page) shows the profiles that were presented.

<table>
<thead>
<tr>
<th>Vib. motor</th>
<th>Time passing in seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1s</td>
</tr>
<tr>
<td>1</td>
<td>Left</td>
</tr>
<tr>
<td>2</td>
<td>Left</td>
</tr>
<tr>
<td>3</td>
<td>Left</td>
</tr>
<tr>
<td>4</td>
<td>Left</td>
</tr>
<tr>
<td>5</td>
<td>Left</td>
</tr>
<tr>
<td>6</td>
<td>Left</td>
</tr>
<tr>
<td>7</td>
<td>Left</td>
</tr>
<tr>
<td>8</td>
<td>Left</td>
</tr>
<tr>
<td>9</td>
<td>Left</td>
</tr>
<tr>
<td>10</td>
<td>Left</td>
</tr>
<tr>
<td>11</td>
<td>Left</td>
</tr>
<tr>
<td>12</td>
<td>Left</td>
</tr>
</tbody>
</table>
Figure 32: 25 Tactile profiles
The profiles were presented in two batches: vibro-tactile and pin array, as an initial set-up period was required for the vibro-tactile profiles. Presentation of the batches alternated on every participant and the presentation of each profile within these batches was rotated. After each profile the participant was asked to indicate which of the 7 commands they felt it would be trying to communicate; only one command was to be chosen for each tactile profile but each command could have many potential tactile profiles. Once results had been collected the mode was used to determine which tacton was the most commonly selected for each command.

*Figure 33: Presentation of Profile 20 (pin array)*
7.6.2. Results

The tables below show the results of the study with the mode for each command highlighted (vibration and pin array separately).

Table 7: Results detailing participant reaction to vibro-tactile profiles

<table>
<thead>
<tr>
<th>Command</th>
<th>Vibration Profiles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Go Forwards</td>
<td>16</td>
</tr>
<tr>
<td>Prepare to turn</td>
<td></td>
</tr>
<tr>
<td>Bear</td>
<td></td>
</tr>
<tr>
<td>Turn</td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>2</td>
</tr>
<tr>
<td>Arrived</td>
<td>1</td>
</tr>
<tr>
<td>Warning</td>
<td></td>
</tr>
<tr>
<td>Don't know</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
</tr>
</tbody>
</table>

Table 8: Results detailing participant reaction to pin array profiles

<table>
<thead>
<tr>
<th>Command</th>
<th>Pin Array</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16</td>
</tr>
<tr>
<td>Go Forwards</td>
<td>17</td>
</tr>
<tr>
<td>Prepare to turn</td>
<td>2</td>
</tr>
<tr>
<td>Bear</td>
<td>8</td>
</tr>
<tr>
<td>Turn</td>
<td>6</td>
</tr>
<tr>
<td>180</td>
<td>7</td>
</tr>
<tr>
<td>Arrived</td>
<td>10</td>
</tr>
<tr>
<td>Warning</td>
<td></td>
</tr>
<tr>
<td>Don't know</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
</tr>
</tbody>
</table>
To aid the decision between vibro-tactile and pin array the frequency of each mode was converted into a percentage and averaged over the 7 commands for both the vibro-tactile and the pin array. Vibro-tactile had on average, a 71% consensus of the mode and Pin Array scored a 66% consensus of the mode. Bosman et al. (2003) found that pressure based tactons (as opposed to vibration based tactons) can be ignored after the initial stimulus, so based on the slightly higher consensus of opinion on vibro-tactile feedback, the fact that pin/pressure based tactons are more easily ignored, and the availability of vibration motors, the decision was made to use vibro-tactile feedback.

Figure 34 displays the final seven tactons chosen at this stage that were then taken back to the extra-ordinary users for further review and refinement. Each profile is demonstrated using a grey highlight to indicate when the vibration motor is active against a timeline in seconds, initial ‘centre’ vibration has been removed for clarity of instruction.

<table>
<thead>
<tr>
<th>Command</th>
<th>Vib. motor</th>
<th>Time passing in seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1s</td>
</tr>
<tr>
<td>Forwards</td>
<td>Left</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Centre</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td></td>
</tr>
<tr>
<td>Bear (left)</td>
<td>Left</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Centre</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td></td>
</tr>
<tr>
<td>Prepare to turn (left)</td>
<td>Left</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Centre</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td></td>
</tr>
<tr>
<td>Turn (left)</td>
<td>Left</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Centre</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>Left</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Centre</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td></td>
</tr>
<tr>
<td>Arrived</td>
<td>Left</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Centre</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td></td>
</tr>
<tr>
<td>Warning</td>
<td>Left</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Centre</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 34: Refined taction selection*
7.6.3. Actions

The aim of this study was to uncover which of the tactons developed by the extra-ordinary users would be the most intuitive for use in a tactile navigation aid and to make a decision on the use of vibro-tactile or pin array tactons. Actions following this study were:

- To integrate the chosen tactons into prototypes suitable for field testing
- To test these tactons with a pedestrian navigation algorithm
7.7. NAVIGATION SOFTWARE DEVELOPMENT

Concurrent to the design decisions being made by extra-ordinary users around physical form and tactons a third party developer undertook the software design for the mapping system. A number of iterative field trials took place over the course of the product’s development and one such study which utilised Lin and Seepersad’s ‘empathic user testing’ (Lin and Seepersad, 2007) is overviewed here to contextualise the product development process undertaken and for reflection on the success of the method.

7.7.1. Study Overview

The navigation software app was installed on a Samsung phone, which communicated via Bluetooth to the Arduino board (Arduino, 2016) system utilized in the prior study. The prototype was attached to an elastic strap and placed on the users arm and the vibration motors attached to their fingertips.

![Figure 35: Prototype system](image)
Utilizing the markers of a rugby pitch and an AstroTurf pitch two short virtual paths were programmed into the app (initially only the rugby pitch was created, but weather conditions meant that the trials got moved to the AstroTurf pitch). The paths were not marked on the ground so no visual or tactile cues indicated the correct path. Three participants were then blindfolded and asked to follow the directions provided by the vibro-tactile feedback. Recruitment criteria specified that participants must be comfortable walking unaided for at least 30 minutes, and must have no sensory issues in their hands in order to feel the tactons. The participants’ walked paths were recorded on the app using their GPS location.

Figure 36: Participant two walks a digital path whilst blindfolded
7.7.2. Results

All participants had three attempts to navigate the path.

Their most successful attempts are detailed below.

Participant 1:

<table>
<thead>
<tr>
<th>Participant 1 data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
</tr>
<tr>
<td>Start time (hr excluded)</td>
</tr>
<tr>
<td>End time (hr excluded)</td>
</tr>
<tr>
<td>Time taken</td>
</tr>
<tr>
<td>Time taken (s)</td>
</tr>
<tr>
<td>Meters per second</td>
</tr>
</tbody>
</table>
Participant 2 (tactile):

Participant 2 (Visual):

<table>
<thead>
<tr>
<th></th>
<th>Participant 2 tactile data</th>
<th>Participant 2 visual data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>210</td>
<td>190</td>
</tr>
<tr>
<td>Start time (hr excluded)</td>
<td>14:27.7</td>
<td>25:23.0</td>
</tr>
<tr>
<td>End time (hr excluded)</td>
<td>17:37.8</td>
<td>27:54.0</td>
</tr>
<tr>
<td>Time taken</td>
<td>3m 10s</td>
<td>2m 31s</td>
</tr>
<tr>
<td>Time taken (s)</td>
<td>190</td>
<td>151</td>
</tr>
<tr>
<td>Meters per second</td>
<td>1.11</td>
<td>1.26</td>
</tr>
</tbody>
</table>
Participant 3:

<table>
<thead>
<tr>
<th>Participant 3 data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
</tr>
<tr>
<td>Start time (hr excluded)</td>
</tr>
<tr>
<td>End time (hr excluded)</td>
</tr>
<tr>
<td>Time taken</td>
</tr>
<tr>
<td>Time taken (s)</td>
</tr>
<tr>
<td>Meters per second</td>
</tr>
</tbody>
</table>

Average walking speed between the participants was 0.88m/s, more than a third lower than the average walking speed of young adult 1.47m/s (Carey, 2005), however this was not unexpected as the simulated impairment clearly made participants particularly cautious when walking, even when being guided to the starting location by the test facilitators.

Whilst not part of the testing protocol, the facilitators (the author and the app developer) also observed Participant 2 complete the task with a visual interface (at the request of the
participant who was interested to see/feel the difference). A visual interface had not been fully developed but the participant was able to view themselves as a ‘dot’ travelling around a path similar to what is seen in the above results diagrams. Interestingly, the results were not dissimilar and on discussion with the participant it was noted that a high level of concentration was required to map the very basic visual display to the surrounding areas with no visual landmarks from which to navigate.

7.7.3. Actions

Problems identified and their associated actions were:

- Commands queuing caused a delay in information
  - Remove queue function
- Mapping correction caused an on-going error
  - Experiment with other mapping correction options
- Seemingly opposing feedback due to ‘bear’ and ‘turn’ commands being close together*
  - Reassess algorithm which currently directs from point to point rather than along paths
- Connection between phone and Arduino
  - Ensure wired connections on final prototype are secure
- Computing device must face torso direction in order to provide correct compass directions*
  - Either, create harness/clip for device holding it in the correct orientation, or, develop software solution that computes direction based on prior movement.
*Feedback elements concerned with usability (as opposed to back-end programming) which required further interrogation with extra-ordinary users.

7.7.4. Other Software Studies

The system was regularly tested through casual field trials similar to that described utilising myself, or small groups of people without visual impairments, as participants and the developer as the facilitator in order to ensure system functionality. No further software errors were identified.

7.8. FURTHER DEVELOPMENT OF FORM

Chapter 6.3.5 investigated potential options for initial form. Actions from this stage included the development of two prototypes: one developing the designs as developed by people with visual impairments throughout the process and one to investigate the
possibility of a wearable device for the wrist. These two prototypes were created and were taken to Tony and Andrea for further feedback. Figure 38 shows the organic palm held device, which took on the working name of “The Stone” created from: two different densities of model-board, to allow differentiation between body and vibration zones and utilising Xbee radios (Digi, 2016), an Arduino mini (Arduino, 2016), three vibration motors and a lithium-ion battery, to create the tactile feedback required.

A rough and ready glove prototype was also made. Figure 39 (next page) shows both the glove prototype and the Wizard of Oz Control system that was used to control both the glove and the stone. This prototype utilised a full size Arduino that was sewn to the palm of the glove and vibration motors that slipped into slits on the middle phalanges of the thumb, forefinger and little finger.
Whilst the glove provided a basic prototype for testing, another option was discussed in which the vibration motors would be attached to a watch and clipped onto the fingers as shown in Figure 40.

When discussing a wearable option at this stage this watch style was the preferred option as:

- Wearing a single glove would appear strange
- A glove would not be suitable in the summer
However, Andrea and Tony decided that “The Stone” was the preferred option. The key reasons behind this were:

- Having to remove the device for tasks that require better dexterity would be an annoyance (for example, using a phone)
- When in a handbag or rucksack, a greater physical presence makes it easier to find for people with visual impairments
- It was perceived to be fragile and may easily be broken when storing or using the device

[the watch concept is] like headphones I can’t find them then in my bag and they get all tangled

ANDREA

More changes were discussed for the next iteration of “The Stone” prototype; firstly it was now felt that the device was too big. Whilst it was comfortable to hold it was very conspicuous and would not easily fit into even a coat pocket. The location of the vibration zones on this device showed that the “forward” and “right” tactile zones were positioned too close together and instead the right zone should be moved further down to the base of the hand in order to create three separate tactile zones. When faced with the issue of ‘full-hands’, as one hand would be using the device and one hand would be holding the dog harness, participants chose a lanyard to wrap around their wrist allowing them to drop the device at any point. A minimal amount of detail was wanted on the device, this was deemed stylish and contemporary by Andrea and Tony. This is in line with expectations for a design created by people with visual impairments as tactile noise may be confusing on initial
product exploration. The right hand was preferred as all guide dog users hold the harness in the left hand, when probed into left handed use it was suggested that the control software could ‘switch’ the side of use. They chose a smooth plastic finish with rubberized tactile zones to help with indication of where the tactile commands would be located, again this corroborated outputs of earlier research such as the existing product feedback (Chapter 6.3.4) and the mood board (Chapter 6.3.1)

7.8.1. Actions
After further consultation with Tony and Andrea actions to further product development were:

- Decrease the size of device
- Add a wrist lanyard
- Move the ‘right’ vibration zone further towards the base of the hand
- Replicate in a smooth plastic body with rubberised vibration zones
7.9. FIELD TRIAL OF TACTONS

The preceding research developed a refined set of tactons with which basic navigational information could be communicated alongside an initial device form. These refined tactons and prototype form were trialled by Tony to refine elements such as regularity and distance prior to turn, and to investigate the possibility of encoding distance data into the tactons. Utilising the modelboard prototype (described in the previous section 7.4) and a ‘Wizard of Oz’ (Usability First, 2016) interface meaning the device mimicked actual functionality but was controlled by the facilitator using a remote control, Tony was guided around a short path (seen in Figure 41). During and after the event, field notes were taken documenting Tony’s recommendations for the Tactons.

Figure 41: Area walked during trial
The following information details the field notes, and any changes made to each command:

1. **Forwards**

<table>
<thead>
<tr>
<th>Forwards before field test</th>
<th>1s</th>
<th>2s</th>
<th>3s</th>
<th>4s</th>
<th>5s</th>
<th>6s</th>
<th>7s</th>
<th>8s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centre</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Forwards after field test</th>
<th>1s</th>
<th>2s</th>
<th>3s</th>
<th>4s</th>
<th>5s</th>
<th>6s</th>
<th>7s</th>
<th>8s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(repeat every 10 seconds)</td>
<td></td>
</tr>
<tr>
<td>Centre</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Initially a 1.5s vibration every three seconds was trialled. This was felt to be both too long and too regular and would annoy the users. After some attempts at different paces it was decided that every 10 seconds would be an ideal starting point. However, Tony stated that depending on his route knowledge he would likely want to decrease it further.

2. **Bear left/right**

<table>
<thead>
<tr>
<th>Bear left before field test</th>
<th>1s</th>
<th>2s</th>
<th>3s</th>
<th>4s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centre</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bear left after field test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centre</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Whilst Tony felt comfortable with the command he highlighted that when walking on a pavement it had little value as Quizzie naturally followed the path of the pavement. However, when asked if he would remove it he felt that it’s value in open areas such as parks and along wide paved areas would be lost; he also indicated that it would be useful for cane users to understand the change in
direction passively (through tactons) rather than ‘discovering’ it through active
tactile exploration (through the sweep of a cane). Overall he felt the command was
too long as he moved a significant distance by the time the command finished.

3. **Prepare to turn left/right**

<table>
<thead>
<tr>
<th>Prepare turn to left</th>
</tr>
</thead>
<tbody>
<tr>
<td>before field test</td>
</tr>
<tr>
<td>Left</td>
</tr>
<tr>
<td>Centre</td>
</tr>
<tr>
<td>Right</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prepare turn left after</th>
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<tbody>
<tr>
<td>field test</td>
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<td>Centre</td>
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</table>

To identify the optimum time for a “prepare left/right” signal Tony was asked to
walk a path that he regularly followed with his dog Quizzie. Roughly 3-5 meters prior
to the turn Tony would ask Quizzie to look for the turn. Due to the length of the
tacton it was decided that it should begin actuating at roughly 6 meters from a turn.
It was also suggested that the space between the two actuators (left/right and
forwards) should become shorter to leave no time to react to the direction actuator
prior to receiving the forwards actuator, this avoids users initially mistaking the
tacton for a “turn left/right” command and prematurely turning.

4. **Turn left/right**

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<td>field test</td>
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<table>
<thead>
<tr>
<th>Turn left after</th>
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<tbody>
<tr>
<td>field test</td>
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Initially it was expected that the “turn” signal should be slightly prior to the turn itself but due to the “prepare to turn” signal being relatively close to the turn itself the signal was relayed at the point of direction change.

5. You have arrived

<table>
<thead>
<tr>
<th>Arrived before field test</th>
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<th>2s</th>
<th>3s</th>
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<table>
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<th>Arrived after field test</th>
<th>1s</th>
<th>2s</th>
<th>3s</th>
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</table>

Was easy and clear to understand.

6. Turn around

<table>
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<tr>
<th>Turn Around before field test</th>
<th>1s</th>
<th>2s</th>
<th>3s</th>
<th>4s</th>
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</table>

<table>
<thead>
<tr>
<th>Turn Around after field test</th>
<th>1s</th>
<th>2s</th>
<th>3s</th>
<th>4s</th>
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As this command required a more urgent response Tony suggest that the rhythm should be more distinct with a faster pace.

Encryption of distance was trialled by decreasing the time interval of the “forwards” command in line with the decreasing proximity to the turn. However this was felt to make the commands feel cluttered and unnecessary as long as an indication of total journey length was given in the programming stages of the system.
7.9.1. Actions

With refined rules for when and how to actuate commands the final steps to create a testable device were:

- Programme the Tactons onto a micro-controller
- Embed the micro-controller into the prototype
- Give specification of when Tactons should be displayed to the software programmer to integrate into test app
7.10. SUMMARY

This section has reviewed the design process and decisions made in collaboration with two extra-ordinary users. Tony and Andrea were asked to be involved in the project as they had a good working knowledge of the product landscape and their impairments meant that they are experts in tactile product interfaces. The research process was not as clearly defined as in the previous section, as rather than working through specific methods the development dialogue took and iterative cycle of semi-structured sessions. This process worked well, Tony and Andrea stayed engaged in the process and were eager to participate. No significant problems were uncovered in Tony and Andrea’s participation with the traditionally visual process, as whilst they may not have been able to sketch or model their design ideas the iterative sessions allowed for ideas to be discussed and developed over time.

The next steps are to assess the design output of the research by creating a prototype product which can then be studied to investigate whether the product design by these extra-ordinary users:

7.10.1. Design Output

A list of 29 key insights were identified which informed the design of the tactile navigation aid for the extra-ordinary users:

1. Vibration is best utilised to replace generic, and regularly used commands
   a. Rather than specific contextual data
2. Simplicity is of vital importance due to an already extended routine when leaving the house
3. Preference leans towards utilising the computational power and interfaces of existing devices
4. Headphones/earphones were dismissed by users
5. A lack of visual reliance leant itself to unique product usage. This was exemplified by the use of the Trekker Breeze in multiple orientations depending on the context of use.

6. Use of audio should be restricted to irregular commands in order to limit perceived vulnerability.

7. If the user turns off route the system should inform them as soon as it is recognised.

8. The device should be easily stored when not in use, even when at a destination which is not the home.


10. Smaller is not always better
    a. Devices should be comfortable to grip
    b. Devices should be large enough to be easy to find when stored in a handbag/backpack.

11. Bigger is not always better
    a. Devices should be small enough to be used discretely to avoid risk
    b. Devices should be small enough to fit in a coat pocket.

12. Physical prompts should be provided in order to help identify grip orientation.

13. Wearable devices should take into consideration:
    a. Their impact on outfit selection
    b. Their ‘fit’ requirements for users of different sizes
       i. Avoid systems the user could ‘grow out of’
       ii. Avoid systems that draw attention to undesired physical traits.

14. Tactile command systems should fit with currently used command systems for guide dog users.

15. Regular unobtrusive reassurance should be provided.

16. Primary commands should include:
    a. Go forwards
    b. Prepare to turn
    c. Bear
    d. Turn
    e. Turn around.
f. Arrived

17. The use of a warning command should be avoided as it may cause an over reliance on the technology and detract from existing, known to be reliable, micro navigation aids

18. Compass based orientation systems will reduce user frustration

19. Vibro-tactile tactons showed a very slightly higher consensus on use than pin-array

20. Tactile zones should be spread across as large an area as possible to aid differentiation

21. Handheld devices should consider a wrist lanyard or similar mechanism to allow the user to quickly drop the item should they require use of their hands

22. Handheld devices should be rugged and be able to withstand being dropped

23. The product should avoid tactile noise

24. Tactons should consider the speed at which the user is walking

25. Route reassurance commands should be limited to a minimum of once every ten seconds

26. A ‘bear right/left’ command will help those who use a white cane to identify subtle changes in direction in a passive manner

27. ‘Prepare to turn’ should activate roughly 6 meters prior to turn

   a. This is in keeping with the ‘look right/left’ command which would be issued to a guide dog

28. If used alongside a ‘prepare to turn’ command, ‘turn’ should activate directly on the turning point

29. ‘Turn Around’ should be distinct and urgent.

These insights were the primary considerations for the prototype system developed for testing against mainstream navigation solutions.
7.10.2. Prototype System

The prototype system is an organically shaped handheld device. A computer component was designed to provide access for those without smartphones however the primary envisaged control mechanism is that of a smart phone app. The prototype was named “Touchstone”.

Figure 42: Touchstone sketches
Touchstone has three vibration ‘zones’ indicated by coloured rubberised plastic on an otherwise smooth plastic product; these zones vibrate to provide the tactons. It fits comfortably into the average palm with a lanyard which can be tightened around the wrist allowing it to be dropped when the hand is needed.

The commands chosen were:

- Walk forward – a 1.5s vibration on the ‘forwards’ motor
- Prepare to turn left/right – a 0.5s vibration on the correlating (left/right) motor followed by a 1s vibration on the forwards motor
- Turn left/Turn right - a 1.5s vibration on the correlating (left/right) motor
- Bear left/right – a 1.5s vibration on both the forwards and the correlating (left/right) motor
- Turn around – two 1s vibrations on both left and right motors twice
- Arrival – three 0.5s vibrations on the forward motor

As a reassurance measure ‘walk forwards’ actuates immediately after a correct change in direction is recognised and repeated approximately every 15 meters beyond that (or every 10s if the user is still but facing in the correct direction). Turn around actuates as soon as the system recognises an incorrect turn has been made and repeats every 5s (or 10s if the user is standing still). The prototype was 3D printed, the rubberised sections were created using “Sugru” a mouldable glue which dries into a rubberised silicone. Inside the prototype was a Bluetooth chip, battery and three vibration motors, and a microcontroller (mini
Arduino board), converting incoming Bluetooth signals into the Tactons required for navigation (for code see Appendix VII).

The Bluetooth signals are sent by a smartphone app called “Gallivant” created by a third party programmer to adhere to the specification developed throughout the process.

Figure 43: Prototype internals without battery
8. PHASE 2 – DESIGN EVALUATION

8.1. INTRODUCTION

In ‘Chapter 5: Methodology’ a double-phased research process was detailed to address the research question:

*How might the employment of theories of resonance and extraordinary users in the collaborative design process result in better design outputs?*

‘Phase One’ (detailed in the previous two chapters) centred on the design process and took a practice-led approach using a participatory design strategy in which extraordinary users were employed as design consultants on a project developing a tactile navigation aid.

This chapter details ‘Phase Two’ of the research process, an assessment of the outcome. A comparative study was devised to investigate and assess how the tactile navigation aid, developed by and for extra-ordinary users, may benefit ordinary users. By testing the output of ‘Phase One’ with people *without* visual impairment the study allowed for an empirical assessment the value added by the extraordinary users to the ordinary user. This assessment examines the theory of resonance and extraordinary users by providing insight...
into whether functional, usability or experiential benefits are evidenced in the design output.

8.1.1. Literature Summary

The utilisation of tactons by mainstream users to display navigational data is not new in the literature. Benefits are stated to be:

**Shows direction without focus**

Where vision requires focus in the direction of the stimulus, and to provide directed audio cues would require headphones (which would prohibit any other audio stimulation); touch allows both a specified direction whilst not having to focus attention towards the stimulus.

**Allows Better Engagement with Surroundings**

Related to the above statement, the removal of focussed attention allows users to engage in their surroundings more effectively, allowing for safer and more social pedestrian practices.

**Accessible**

Though there are instances where a person might lose their sense of touch, for the general population touch is a more accessible sense as it is more resilient to the aging process than vision and audio (Burnett & Porter, 2001).

**Social Acceptance**

Touch is a silent and private way of interfacing with a product as opposed to auditory commands which can be perceived as embarrassing or annoying when used in public. (Poupyrev, et al., 2002)
Language requirements

Audio commands rely on the user understanding the language they are relayed in.

The Modality Effect

A reason for heightened cognitive load, the ‘modality effect’ indicates that presenting information to users through an already utilised modality will decrease working memory capacity (Sweller, 2009). Decreasing cognitive load aims to make products more intuitive allowing for both better navigation performances and an increase in engagement with the environment.

Many researchers have already conducted research into the potential of using tactons and cite one or more of the benefits to qualify their research. The majority of research tends to be aimed at either, people with visual impairments (to make the navigation device accessible) (Ghiani, et al., 2008; Gustafson-Pearce, et al., 2007; Johnson & Higgins, 2006), or, people without visual impairments (to decrease cognitive load) (Bosman, et al., 2003; Lin, et al., 2008; Pielot & Boll, 2010) with only a few studies showing recognition of the resonance between the two (van Erp, 2001; Gustafson-Pearce, et al., 2009).

And in turn, the studies currently presented in the literature have proven that:

• You can direct a person with visual impairments around a path using the tactile sense (Gustafson-Pearce, et al., 2005; Ghiani, et al., 2008; Gustafson-Pearce, et al., 2007)

• You can direct a person without visual impairments around a path using the tactile sense (Cardin & Thalmann, 2008; van Erp, 2001; Pielot & Boll, 2010)
• You can direct people with and without visual impairments around a path using the same system. (Gustafson-Pearce, et al., 2009)

On review of the literature there is little data proving the theorised benefits of tactons against already commercially available systems. This is evidenced by three factors: minimal baseline comparisons, a lack of realistic contextual settings and a lack of end-user feedback. As discussed in the literature review, Pielot et al. (2010) and Elliott et al. (2010) go some way to addressing the issues but are limited by, in Elliott’s case a very specific usage context, and in Pielot’s case, a lack of comparison against audio, and a minimal amount of user opinion discussed. Also, neither of these cited examples detail their development process and so to state that these innovations have been drawn from the needs of people with visual impairments would at best be assumptive and at worst inaccurate. Therefore, the comparison of the output of ‘Phase One’ of the research, a tactile navigation aid called Touchstone against two competitor products in-context would address two gaps in the literature:

1. An in-context comparison of a tactile navigation aid against both audio and visual competitors. Comparison by both functional metrics and qualitative user feedback
2. The assessment of how a system developed for people with visual impairments may bring value to a user without visual impairments.
8.2. PILOT STUDY ONE

An initial comparative study was conducted, this section summarises this study to contextualise and qualify the final study design which is presented in the Chapter 8.4: Final Study Design.

This study was intended to be the pilot to the final study (Rubin & Chisnell, 2008), conducted whilst the third-party app being developed was undergoing some essential changes. However, the study outcomes revealed many changes that had to be made to the study design and therefore this study was the first of two pilot studies. This section details the initial study and the impact on final study design. It does not detail the results of the study as too few participants undertook the study to draw conclusions.

8.2.1. Pilot Study Design

This study took a within subject approach and tested both the tacton commands and a visual feedback device.

The tactile commands were displayed through a glove based prototype. This was not the prototype intended for the final study (for which this was a pilot) which was currently in the development stage. It did however utilise the internals of the final system. The visual feedback was provided through the use of an app (OSMand, 2015) on a Samsung smartphone.
Four short routes were devised in a residential area, each around 350 meters long. The participant was asked to use the devices to navigate the routes. The participant completed all four routes with both navigation aids. The routes were counterbalanced to avoid carryover effect (Rubin and Chisnell, 2008).

Testing metrics were:

- Completion time
- Walking speed
- Engagement with surroundings
- Confusion time

Figure 45: 4 short routes
The journeys were video recorded and the testing metrics extrapolated using Nvivo software (QSR-International, 2015) alongside qualitative data captured in the form of field notes and a questionnaire completed after the navigation task (see Appendix XII for questionnaire).

8.2.2. Recruitment

A single participant took part in the study. More had been intended however after the first participant the study design was clearly flawed and therefore further studies were called off.

Participant specification was:

1. **Experienced in smartphone use**
   
   The technology under investigation is the use of context-aware mapping applications commonly seen on smartphones and dedicated GPS systems. Specifying that participants had experience in smartphones ensured a minimum level of technology competency which would be required in the utilisation of context-aware mapping applications.

2. **18-35 years old**
   
   As well as being pre-determined by the industrial partner as the target audience for the Touchstone product, the age bracket fits that of the “digital native” generation (Bennett, et al., 2008). And therefore addresses similar issues of ensuring a minimum level of technology competency to specification one.

3. **Has the ability to walk independently for at least 30 minutes**
   
   This specification ensured that the participant could safely and comfortably complete the walking task that was fundamental to study design.
4. **Must not have any form of impairment concerning visual, audio or tactile sense**

As the intention of the study was to test a tactile aid against visual and audio counterparts the participant must have the ability to use any of the prescribed wayfinding devices.

*Figure 46: Participant walking with tactile navigation aid*
8.2.3. Outcomes for Final Study Design

The study itself took a considerable amount of time, around 2 hours (when including: pre-test instructions, test time and post-test questionnaire), fatigue was evident by the study completion. This had worrying implications on the final study considering it would also compare against an audio device and entail a post-test interview to gather more in-depth data regarding the users’ opinion. Fewer test routes could be used but the risk of carryover effect was high and could have significant impact on the results.

For this reason a between subjects study was utilised in the final study design which would lead to a decrease in study length and fatigue; a higher number of participants was required, but with a shorter overall study time. This eased the overall recruitment difficulty.

When analysing the metrics taken: task completion, time to complete, walking speed, eyes-on-device and disorientation other issues also arose.
**Task completion:** The study raised the question of what is considered task completion. The participant did not complete two routes when using the visual device as she stopped early. However, in a real navigation situation this is still within sight of the final destination and so the device would have been successful.

**Disorientation:** Disorientation proved difficult to codify using the video analysis system. A more specific description of the visual cues for disorientation was required.

**Time to complete and walking speed:** Whilst time to complete and walking speed showed a slightly lower performance level the participant preferred using the vibration device. This highlighted the issue that the aim of the walking task dictates the importance of this metric. Albert and Tullis (2013) highlight that in scenarios where the ‘experience’ is as important as efficiency, time to complete may have less relevance.

**Noticing surroundings:** Similar to disorientation, “noticing surrounding” proved difficult to codify. In some scenarios the user would specifically turn their head to investigate something within their environment and these items were coded, but beyond this there was no way to identify how much the user engaged with their surroundings.
8.3. PILOT STUDY TWO

8.3.1. Introduction
As the within-subject study in the previous section proved to be inappropriate a between-subjects study was devised. Prior to undertaking the full study which is detailed in the following section (Chapter 8.4 “Final Study Design”) three participants were recruited using the same criteria evidenced in the previous pilot study (see Chapter 8.2.2) to test the study materials and wayfinding devices utilised for each condition (tactile, visual and audio).

A summary of the study structure is as follows:

1. Pre-study questionnaire
2. Navigation task
3. Watch back the video taken whilst navigating to provide commentary on thoughts at the time
4. Post-study questionnaire

More details on the components of the study can be found in the following section (Chapter 8.3 “Final Study Design”).

8.3.2. Outcomes for Study Design
Two fundamental changes were conceived through the second pilot test.

Firstly, one participant who undertook the study had very good knowledge of the test facility having worked there previously. This effected both her navigational ability as she felt more confident of the routes available, and her ability to recall the path that she had
taken. For this reason, it was added to the recruitment criteria that the participants should not have good knowledge of the area.

Secondly, study task 3 asked the participants to watch back a video of themselves to provide commentary of their thoughts, feelings and actions. This added significant length to the study time, and very little insight was drawn from the responses; overall it was not felt that the length of time this added to the study was worth the outcome and it was removed from the study protocol.
8.4. **FINAL STUDY DESIGN**

After conducting the pilot studies documented in the previous sections the final study design was developed. In order to fully assess the value of the participatory process documented in the previous chapter, and in-turn, extra-ordinary users design input, a comparative study was conducted in which Touchstone, was evaluated against two modality specific (one audio and one visual) commercial counterparts. The study was conducted with participants who did not have any visual impairment in order to assess the applicability of the research outcomes to a wider audience.

The studies took place in September 2013, each study took around 30 minutes to complete.

8.4.1. **Study Structure**

The study contained three main elements:

1. Pre-task questionnaire
2. The task
3. Post-task questionnaire and interview

8.4.1.1. **Pre-Task Questionnaire**

Each participant completed a short questionnaire prior to the study, which collected demographic data alongside experience levels and qualitative data on pre-test preferences (viewable in Appendix VIII).
8.4.1.2. The Task

Each participant was randomly allocated one of three navigation devices (audio, visual or tactile). Participants were each given a short tutorial on their allocated device and instructed to follow a pre-defined path as directed by their device. The walk was approximately six minutes long and video recorded. For approximately one minute of the walk the participant was engaged in conversation, this was intended to add to the participant’s cognitive load and to replicate real-world use where distractions are prevalent. Participants were pre-warned that this would take place and asked to engage in conversation in a ‘normal’ manner. Outside of the allocated ‘conversation’ zone participants were not informed as to whether they should or should not converse with the facilitator, this was intended to encourage natural engagement with the device. If the participant chose to speak to the facilitator the facilitator would respond in a normal manner. A variety of data was extracted from the video in post-study evaluation:

- Error rate – defined by the user ‘striding’ along an incorrect path. One count was made per incorrect path taken.
- Confusion time – defined by the user stopping, turning on the spot, uncertainly stepping along a path (but not decisively taking it) or verbally announcing confusion. Data was collected as duration in seconds.
- Eye down time – defined by the user visually focusing on the device. Data was collected as duration in seconds in order to assess the impact of eyes-down time on environment engagement.
- Completion time in seconds.
8.4.1.3. Post-Task Questionnaire and Interview

After task completion the participants were asked to complete a questionnaire and take part in a one-on-one interview about their experience.

The post-task questionnaire was designed to uncover the users’ subjective opinion of the device in a way that allowed for comparative analysis of the design alternatives. As such, the majority of the questions took the form of Likert Type Scales (Albert & Tullis, 2013). Likert items use a mix of positive and negative statements to avoid pattern answering (Brace, 2008).

Open-ended questions were also used to gather additional feedback on the product and were analysed alongside the interview data (as detailed in section 10.3.8).

To view the questionnaire, please see Appendix IX.

The questionnaire included:

- A photo recall test – a method designed by Pielot et al. (2010) to test route recall, and in turn, engagement with surroundings. It presents the participants with a photo of various on-route intersections and asks them to recall the direction that was taken.
- Route Drawing – another method designed by Pielot et al (2010) to test spatial knowledge acquisition. The participants are given a blank map of the general area and asked to draw the route they had just walked.
- Likert Scale-Type usability ratings of the system as a whole, as well as specific elements under investigation.
- Open-ended questions seeking to investigate their feelings towards the system they had just used.
The interview was semi-structured in nature, aiming to further investigate the subjective experience of using the device. The framework of themes to be explored further was made up of the following topics:

- General comments
- Interrogation of usability with high cognitive load (when engaged in conversation)
- Any unique or notable usage strategies utilised throughout the task
- Posing usage contexts for comment:
  - Using whilst navigating with friends in a leisure environment (no time constraints)
  - Using whilst in a city, navigating alone (time constrained)
  - Using at night time
- Physical form

8.4.2. The Route

The studies took place at St Fagans National History Museum in Cardiff. St Fagans Museum was chosen as a testing area as it replicated well day-to-day pedestrian navigation without the risk factors associated with road crossings. Permission was gained prior to conducting the study from St Fagans Museum management.

The specification for the route was drawn up to ensure thorough testing of the devices command systems; it included:

- At least one left turn decision point
- At least one right turn decision point
- At least one ‘bear left/right’ decision point
- At least one extended ‘forwards’ stretch
- At least one area of multiple turns in quick succession
The term ‘decision point’ was used to indicate that there should be another path available to follow, ensuring the participant has to make the active decision to take the turning.

Figure 48 shows the devised route.

8.4.3. Prototypes

Three different sensory navigation systems were used in the trial. The specification for selection of the audio and visual app was as follows:

- Recognisable display mechanisms; in-keeping with industry standards
- The ability to display data in a single modality
- Correct functionality around the chosen test area
- The ability to create self-generated routes (as opposed to a device that computes the shortest path between two points)
For these reasons, OSMAnd (OSMand, 2015) was chosen as the navigation system for both the audio and visual navigation conditions. OSMAnd is an open source navigation app which was presented on a Samsung Galaxy smartphone. In the audio condition an earpiece was provided to ensure that all participant could clearly hear the instructions regardless of ambient noise. OSMAnd conformed to all the specifications laid down as well as being freely available for use within the study. A GPS tracker was used to log the chosen route; this was then saved as a “.gpx” file and loaded onto the OSMAnd system.

The previously described prototype tactile device, Touchstone, and associated Android app was used as the tactile condition prototype (see Chapter 7.10.2 for description).

Extensive testing prior to the event ensured all three prototypes supplied the correct navigational commands to guide the user around the chosen path.
8.4.4. Data Capture

The navigation task was recorded using a video camera. The functional metrics: error rate, eyes on device, confusion time and task completion were extrapolated post-hoc from the video documentation using Observer XT behavioural analysis software (Noldus, 2015). Field notes were documented immediately after the study.

The semi-structured interview was audio recorded and transcribed for analysis. The questionnaire and post-task tests were completed on paper and digitalised for analysis after the event.

8.4.5. Recruitment Criteria

The study sample was representative of the intended and likely end users. Participant specification was similar to that seen in the pilot studies (see sections 8.3 and 8.4) and was as follows:

1. Experienced in smartphone use
   To ensure a minimum competency in appropriate technology.

2. 18-35 years old
   Pre-determined by the industrial partner as target audience as well as fitting the “digital native” (Bennett, et al., 2008) age bracket and addressing similar issues of ensuring a minimum level of technology competency to recruitment specification one.

3. Has the ability to walk independently for at least 30 minutes
   This specification ensured that the participant could safely and comfortably complete the walking task that was fundamental to study design.

4. Must not have any form of impairment concerning visual, audio or tactile sense
In order to be truly random in the participant’s allocation of condition (audio, visual or tactile), all participants had to have the ability to use any of the prototypes.

5. **Participants should not have good knowledge of the area**

As evidenced in Pilot Study Two (8.3) participants should not have good knowledge of the testing area to ensure that the navigation task is not biased by prior knowledge.

The study required a minimum of eight users per condition with an aim of between 10-12 per condition, as recommended by Macefield (2009) as an appropriate size for a comparative study, as it is likely to identify any statistically significant differences whilst at the same time allowing to scope the project both financially and logistically.
8.4.6. Sample

Sample size was 38 and condition assignment was random resulting in the following distributions:

- Visual – 14
- Audio – 13
- Tactile – 11

Note: Due to technical failure the interview results of one participant in the visual condition are not presented. However, all other data from this participant is still valid and presented within the results.

The following charts show the breakdown of participants:

![Figure 50: Participant’s Gender Distribution](image-url)
8.4.7. Quantitative Analysis Techniques

Quantitative results were analysed using SPSS software (IBM, 2015) using techniques appropriate to the data type. Multiple data types were used throughout the study therefore the specific techniques will be described alongside the relevant results.
8.4.8. Qualitative Analysis Technique

After each day of the study the interviews and open-ended questionnaire responses were transcribed. A clear comparative dataset assessing the positive and negative elements of the three conditions was the desired output of the qualitative data and therefore a framework analysis was utilised (Smith & Firth, 2011). This allowed for a systematic thematic analysis across both: the key features of the conditions and the envisaged usage scenarios whilst retaining the case-by-case data.

Some key areas of investigation highlighted in the literature review were: whether the user felt that they could engage with their surroundings, whether the users felt that the device would encourage negative pedestrian behaviours, and which usage scenarios the user imagined the devices may be most useful. Alongside these themes the transcripts were read and selection of other themes arose, these were: communication and how users interpreted the data they were provided with, whether the users enjoyed the experience or not, physical form and the users subjective opinion on it, including their feeling about how others would perceive them and, finally, navigation technology in general particularly their relationship and trust of GPS and smart devices. These themes were used to develop coding nodes (summarised in table 9, next page). Two framework matrices utilising these themes were then created using NVivo software (QSR-International, 2015), one pertaining to positive feedback and the other to negative. Each transcript was then reviewed and any statements relating to the determined themes was summarised in the frameworks and linked back to the original data set.
<table>
<thead>
<tr>
<th>Theme</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attention</td>
<td>A participant discusses their ability to engage with their surroundings, either through conversation with other people or engagement with their environment.</td>
</tr>
<tr>
<td>Fun</td>
<td>A participant discusses their enjoyment (or lack of) in using the device.</td>
</tr>
<tr>
<td>Communication</td>
<td>A participant discusses the manner in which the device communicated navigational information to the user.</td>
</tr>
<tr>
<td>Physical</td>
<td>A participant discusses the physical form of the device.</td>
</tr>
<tr>
<td>Safety</td>
<td>A participant discusses the impact the device would have on the user’s safety and security, perceived or actual.</td>
</tr>
<tr>
<td>Technical</td>
<td>A participant discusses any matter generically technological, not specific to the condition.</td>
</tr>
<tr>
<td>Other</td>
<td>A participant made a relevant statement that fell outside the existing coding structure.</td>
</tr>
<tr>
<td>Usage scenarios</td>
<td>A participant discusses potential envisaged usage scenarios.</td>
</tr>
</tbody>
</table>

After the frameworks were completed these were transferred to Microsoft Excel (Microsoft, 2016). A count was conducted of the fields that contained data allowing for a numerical overview of the percentage of participants who discussed each theme in a
positive and in a negative light. The quantity of data coded to each theme was not taken into account, simply whether or not it was cited. This allowed an, albeit very simplistic, comparison of qualitative opinion to be presented. Once this task had been achieved the frameworks were then integrated, presenting both the positive and negative data concurrently and so allowing for deeper case analysis.

8.4.9. Triangulation
In a further attempt to confirm the validity of findings and draw conclusions, the data was triangulated through “methodological triangulation” using a between-method analysis investigation (Denzin, 2009). Many different methods will investigate similar or overlapping issues, providing different perspectives around the same area for example, ease of use will be investigated through observational research, semi-structured interview and Likert Type Scales.

8.4.10. Ethical Approval
An ethics application separate to that completed for the prior work stage was completed to aid clarity of application. All activities were approved by the PDR, Cardiff Metropolitan University Ethics committee.

Participants were given information sheets detailing the study, data collection and storage measures and their right to withdrawal (information sheets and consent forms viewable in Appendices X and XI).
8.5. RESULTS

This section displays the results of the study. Discussion will be provided in the following chapter.

8.5.1. Initial Preferences for a Pedestrian Navigation System

Prior to completing the task, when asked "If you were able to choose, which device would use and why?" the majority of participants (19/38) stated that they prefer a visual device to guide them around a 5 minute leisurely walk.

Qualitative responses were reviewed and themes created using a grounded theory approach. Figure 54 displays the coding of responses to the themes created, in some scenarios participants gave multiple reasons for their selection resulting in 48 statements coded.

Figure 53: Which sensory navigation aid would people prefer to use?
As seen in the chart the most regularly cited reason for this visual preference is related to expected levels of performance.

Many participants felt that the ability to visualise their path would help both improve performance whilst navigating and data retention prior to the task.

*...seeing your route helps you to understand the direction you have to walk in and helps you remember for future journeys*

Seemingly, the two following most cited reasons (previous experiences and learning style) are also related to performance in that, whilst not explicitly stated, it is likely that users believe that having previous experience, or the fact that it suits their learning style, will in turn lead to a better performance.
32% (12/38) of the participants stated that they would prefer to use the tactile device, unlike visual the reasons given for this selection are mostly unrelated to performance, instead they cited enjoyment and new experiences. One participant explicitly stated that in this context they are not worried about performance;

...because it sounds funner, and it’s only 5 minutes so if you got lost it wouldn’t be for too long!

PARTICIPANT 11

Only 4 out of 38 chose audio as their device of preference. Responses were varied concerning reasons given for this decision with no one element of the system being a particular motivation. Those who chose more than one method stated that they would chose a visual interface with a supplementary aid. These participants commented on elements of visual devices that they do not feel comfortable using and so a supplementary aid is required.

Figure 55: Which device do you expect to be more fun?
Prior to use, the tactile device was expected to be the most enjoyable to use device, this was closely followed by the visual device. However, the majority of people felt that the visual device would be the most functionally effective.

![Figure 56: Which device do you expect perform best?](image)

**8.5.2. System’s Ability to Navigate User around a Path**

**8.5.2.1. Task Completion**

![Figure 57: Navigation task completion rate](image)
3 of the 38 participants (8%) failed the navigation task, in all of these cases the participant reached the intended destination but did not follow the path communicated by the device as instructed. This shows that all devices have the fundamental capability of directing a user from one location to another around a complex path with multiple decision points.

8.5.2.2. Error Rate

![Figure 58: Errors made per condition](image)

Figure 58 shows the number of errors made per condition. Errors were not counted for participants who failed the navigation task meaning that only 11 visual participants are shown in the analysis. No participant made more than three navigation errors, and 37% (14) completed the route with no errors at all.

A Kruskal Wallis H test was run (with a significance level of .05). The mean rank showed no significant difference in the results $\chi^2 (2) = 3.197$, ($p = .202$) indicating that devices are functionally equivalent in their ability to keep the user on a specific path.
8.5.2.3. Route Drawing

Participants were asked to draw the route they had taken on a map immediately after walking it, this was to judge whether any condition afforded better route recall and thus developed the users survey knowledge of the area. All participants were included in analysis; the results of those who took a different route to that intended were compared against their actual route. Only 7 of the 38 participants were able to correctly draw the route taken immediately after walking it.

Pairwise Fisher’s Exact tests (with a significance level of .05) were run between conditions with two-tailed P values as follows:

- Visual and Audio: p = 0.04
- Visual and Tactile: p = 0.41
- Audio and Tactile: p = 0.13

The results indicate a significant difference between the visual and audio devices (p=0.04), on review of the results it shows that the visual condition aided users to gain a more survey knowledge of the area walked. The tactile device did not perform significantly better or
worse than either other condition but the trend indicates that it performs better than the
audio condition in this area.

8.5.2.4. Photo Recall

Figure 60: Participants ability to recall the correct turns at key decision points on route

Directly after the navigation task, participants were shown four photos of major route
decision points and asked to identify the direction in which they travelled. Figure 60 shows
an overview of the amount of correct answers given across the conditions. The results
exclude the three participants who took a different path to that prescribed. All participants
answered at least one correctly.

A Kruskal Wallis H test was run (with a significance level of .05). The mean rank showed no
significant difference in the results $x^2 (2) = 4.119, p = .128$. This indicates that there are no
differences in the amount that each condition allowed users to recall their decision points
from photos.
8.5.2.5. Confused Time

Figure 61 shows the amount of time spent confused in seconds for each condition. A Kruskal Wallis H test was run (with a significance level of .05). The mean rank showed no significant difference in the results $x^2 (2) = 802, p = .670$.

The outlier in the tactile condition indicates a participant spent a larger amount of time confused than others in the condition. The number shown relates to the entry number of the participant on SPSS software and on review it is participant 25. Throughout the video data on two occasions the participant had to stop consider the tactons he was receiving. This was reflected in the qualitative data for that participant which indicated that the vibration zones were not clear enough to navigate confidently. The participant utilised the ‘turn around’ command by pivoting on the spot and waiting for the ‘turn around’ command then walking in the opposite direction to the command.
8.5.2.6. Eyes-on-Device Time

Figure 62 shows the amount of time, in percentage of total time, participants spent with their visual field directed towards the device in use.

A Kruskal Wallis H test was run (with a significance level of .05). The mean rank showed a significant difference in the results $\chi^2 (2) = 28.739$, $p = .000$.

Pairwise comparisons were performed using Dunn’s (1964) procedure with a Bonferroni correction for multiple comparisons that revealed there was a statistically significant difference in eyes-down time between visual (31.50) and audio (13.69)($p = .000$) and visual and tactile (11.09)($p = .000$), but not between audio and tactile. This shows that the visual device does require a higher level of eyes-on-device time that the other conditions.

Outliers are shown in both the audio and tactile condition (labelling indicates participant number), however, since the majority of participant did not visually engage with the
devices at all any participant who looked at the device even for a minimal amount of time is presented as an outlier.

Table 10 shows the descriptive statistics indicating how long users of each condition spend with their eyes on the device.

<table>
<thead>
<tr>
<th>Device</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual</td>
<td>14</td>
<td>11.33%</td>
<td>68.01%</td>
<td>45.25%</td>
<td>16.42</td>
</tr>
<tr>
<td>Audio</td>
<td>13</td>
<td>0.00%</td>
<td>3.56%</td>
<td>0.44%</td>
<td>0.99</td>
</tr>
<tr>
<td>Tactile</td>
<td>11</td>
<td>0.00%</td>
<td>2.31%</td>
<td>0.22%</td>
<td>0.69</td>
</tr>
</tbody>
</table>

Visual inspection of a scatter plot shows no correlation between eyes-on-device time and the photo recall test results. This indicates that whilst the user’s visual capacity is free to explore the environment this does not mean that they will engage with, or remember what they have seen.
8.5.2.7. Summary of Functional Metrics

Functional metrics indicate an equivalent performance across the conditions. No significant differences were seen in:

- Task Completion – the ability to guide the user from one location to another
- Error Rate – the clarity of communication of directions at decision points
- Photo Recall Test – the ability to engage and recall the environment
- Confused Time – how clearly the information is relayed

A significant difference was noted in route drawing, thus the device’s assistance in spatial knowledge acquisition, where the visual device outperformed the audio device. However, the tactile results sat in the middle of the two conditions and showed no significant difference with either.

Unsurprisingly, a significant difference was seen in the amount of ‘eyes-on-device’ time across conditions with participants of the visual condition spending an average of 45.25% of their journey with their eyes on the device. However, when reviewed against the photo recall test there was no correlation between eyes-down time and the ability to engage and recall their environment.

8.5.3. Field Notes

Participant’s attitudes towards the tasks varied across condition.

8.5.3.1. Visual Device

When using the visual device, participants tended to give very little vocalised feedback about the device or how they felt using it.
Participants varied in usage style with some participants staying very engaged with the device and others simply glancing at the device from time to time. Those that glanced at the device from time to time appeared more confident in their ability.

Whilst the test area was chosen for its safety and lack of vehicular traffic one participant using the visual device was ‘honked’ at as she stood in the path of a small vehicle towing carts full of visitors for a guided tour.

8.5.3.2. Tactile Device

Participants seemed nervous and excited when using the tactile device and many would look to the researcher for confirmation that the actions taken were correct. Unlike with the visual device, participants verbalised their thoughts and actions. As the task continued, participants visibly relaxed into the navigation method as their pace became more confident and fewer confirmation questions were asked. One participant chose to run with the tactile device, when interrogated on the decision he fed back that this is the usage context in which he most envisioned using the device.

Interesting usage of the tactile feedback was noted in a few participants where participants utilised compass direction and the regularity of the devices’ feedback to aid in decision making. If unsure of which direction to take, the participants would stand still, pivot on spot and wait to receive feedback; as the ‘turn around’ command was so distinct it was this command they were waiting to feel and so would pivot until that command was given, then walk the opposite way. The ‘turn around’ and ‘walk forwards’ commands were seemingly very valuable navigation tools and many participants, after making a navigation decision, would vocalise that they were waiting for one of these commands to confirm that decision.
8.5.3.3. Audio Device

Similar to the tactile device, many users chose to verbalise their thinking and actions when using the audio device. Many participants commented on their lack of understanding of the communicated distance.

The audio device regularly caused users to make an error at one particular point on the route. This was seemingly caused by a lack of an expected command but users perceived the device to have given incorrect commands. Figure 64 shows the area of the route (point B) where users chose the incorrect route (red line).

![Figure 64: Audio induced error in navigation](image)

At point A the device gave the command “in 150 hundred feet take a slight right” after 150 feet (Point B) it then gave the command “in 150 feet take a right”, users perceived this to be a command fault and that they had another equal distance to walk before turning right and therefore continued forward at Point B. However, the second command was actually in reference to Point C, thus causing an error in navigation. Most participants (including those who took the correct route) showed signs of confusion and nervousness when
undertaking this decision. Some of those who took the wrong path admitted to believing they were making an incorrect decision but felt that they should ‘trust’ what they believed the device to be telling them. It seemed that users expected a follow up command “take a slight right” at a closer proximity to the decision point.

8.5.4. User Opinion on System after Navigation Task

Participants were asked to fill in a questionnaire and participate in an interview after using one of the three devices. The questionnaire was laid out to enable Likert-style responses to questions covering a variety of standard usability and enjoyment questions alongside more specified questions intended to make participants think of a variety of contexts of use.

8.5.4.1. Questionnaire Results

A Kruskal-Wallis H test (significance = 0.05) was conducted on all Likert scale-type usability questions, the test asked users to give a score of 1 if they strongly agreed and 5 if they strongly disagreed.

Table 11 (next page) shows the central tendency in mean for each condition, the test statistic, asymptotic significance (p-value) and decision on null hypothesis retention (null hypothesis = the distribution is the same across categories)

It identified three questions that showed statistically different opinions between conditions.
<table>
<thead>
<tr>
<th></th>
<th>Central Tendency (Mean) (1 strongly agree – 5 strongly disagree)</th>
<th>x2 (2) test statistic</th>
<th>Sig</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Visual</td>
<td>Audio</td>
<td>Tactile</td>
<td></td>
</tr>
<tr>
<td>A.</td>
<td>The system was easy to use</td>
<td>1.6</td>
<td>1.9</td>
<td>2.1</td>
</tr>
<tr>
<td>B.</td>
<td>The system was fun to use</td>
<td>2.7</td>
<td>1.8</td>
<td>1.5</td>
</tr>
<tr>
<td>C.</td>
<td>The directions were easy to understand</td>
<td>2.2</td>
<td>2.6</td>
<td>2.3</td>
</tr>
<tr>
<td>D.</td>
<td>I could take in my surroundings whilst I walked</td>
<td>2.5</td>
<td>2.3</td>
<td>2.2</td>
</tr>
<tr>
<td>E.</td>
<td>I got confused by which direction I was supposed to head</td>
<td>3.4</td>
<td>2.5</td>
<td>3.3</td>
</tr>
<tr>
<td>F.</td>
<td>I was regularly worried I was walking in the wrong direction</td>
<td>4.0</td>
<td>3.1</td>
<td>3.6</td>
</tr>
<tr>
<td>G.</td>
<td>I remember the route I walked</td>
<td>2.6</td>
<td>2.7</td>
<td>2.5</td>
</tr>
<tr>
<td>H.</td>
<td>I had trouble talking whilst navigating</td>
<td>4.1</td>
<td>2.6</td>
<td>3.3</td>
</tr>
<tr>
<td>I.</td>
<td>I would be happy to use this style of device whilst walking alone</td>
<td>2.3</td>
<td>2.1</td>
<td>1.7</td>
</tr>
<tr>
<td>J.</td>
<td>I would be happy to use this style of device whilst walking with friends</td>
<td>2.6</td>
<td>3.5</td>
<td>1.9</td>
</tr>
<tr>
<td>K.</td>
<td>I would use this device in a crowded area</td>
<td>2.7</td>
<td>3.2</td>
<td>2.4</td>
</tr>
<tr>
<td>L.</td>
<td>I would use this device to get me from A to B quickly</td>
<td>2.4</td>
<td>2.6</td>
<td>2.1</td>
</tr>
<tr>
<td>M.</td>
<td>I would use this device to get me from A to B when walking for pleasure</td>
<td>3.0</td>
<td>2.5</td>
<td>1.9</td>
</tr>
<tr>
<td>N.</td>
<td>The device performed as well as I expected it to</td>
<td>2.0</td>
<td>2.2</td>
<td>1.5</td>
</tr>
</tbody>
</table>
1. Question B (Q-B) - The system was fun to use

A Kruskal-Wallis H test was run, the distribution for Q-B were not similar for all groups (as assessed by visual inspection of a boxplot). The mean ranks of Q-B score were statistically significantly different between groups $\chi^2(2) = 12.589, p = .002$

Pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons revealed that there was a statistically significant difference in Q-B scores between tactile (12.36) and visual (26.86) ($p = .002$) but not between any other combination. This shows that participants felt that the tactile device was perceived as more fun than the visual device. Number 12 (relating to participant 29 as participants were ordered into condition) is shown as an outlier where the participant strongly disagreed that the device was fun to use. On review of the qualitative feedback

Figure 65: Response to “The system was fun to use” across condition
this is reflected as the participant did not like that the device did not allow her to engage with her surroundings.

2. Question H (Q-H) – I had trouble talking whilst navigating

A Kruskal-Wallis H test was run, the distribution for Q-H were not similar for all groups (as assessed by visual inspection of a boxplot). The mean ranks of Q-H score were statistically significantly different between groups $\chi^2(2) = 7.890, p = .017$

Pairwise comparisons were performed using Dunn’s (1964) procedure with a Bonferroni correction for multiple comparisons revealed that there was a statistically significant difference in Q-h scores between audio (13.69) and visual (25.25)($p = .015$) but not between any other combination.
This shows that participants felt that they had more trouble talking when using the audio device compared to the visual device, but the tactile varied too much to draw significant results against either other condition. Two participants are noted as outliers in the boxplot in Figure 66, these were participants 29 (also seen in prior section discussing system ‘fun’) and 13. On review of the qualitative data participant 29 felt that the visual system lagged which increased her cognitive load and thus made it difficult to maintain conversation. Reflecting on the qualitative data from participant 13 she discusses that splitting her attention between the device and talking is difficult particularly at decision points where she had to mentally engage with the device.

3. Question J (Q-J) – I would be happy using this device whilst walking with friends

Figure 67: Response to “I would be happy using this device whilst walking with friends” where 1 is strongly agree and 5 is strongly disagree.
A Kruskal-Wallis H test was run, the distribution for Q-J were not similar for all groups (as assessed by visual inspection of a boxplot). The mean ranks of Q-J score were statistically significantly different between groups $\chi^2 (2) = 7.518$, $p = .023$

Pairwise comparisons were performed using Dunn’s (1964) procedure with a Bonferroni correction for multiple comparisons revealed that statistically significant difference in Q-J scores between tactile (13.27) and audio (25.38) ($p = .019$) but not between any other combination. This shows that participants felt that they were happier to use the tactile device when walking with friends when compared to the audio device.

Number 26 (participant 38) is shown as an outlier in the audio condition who agreed that they would be happy to use the device when walking with friends. When referenced against the qualitative feedback it is noted that the participant felt like the audio device was visually discreet and appropriate for a ‘tour guide’ style situation.

Number 34 (participant 28) is shown to strongly disagree that they would use the tactile device whilst walking with friends. However, on review of the qualitative information very little evidence was seen to clarify this opinion. Reviewing against other questionnaire answers this participant also strongly disagreed that they could visually engage surrounding areas and therefore it is theorised that the participant felt they had to concentrate heavily on the device.
8.5.5. Qualitative Feedback

8.5.5.1. Overview

As discussed in the methodology, data was coded to themes. Two frameworks were utilised, one showing positive comments and one showing negative comments.

The graphs shown in the following sections show the percentage of participants who discussed each theme in a positive and in a negative light. The quantity of data coded to each theme was not taken into account, simply whether or not it was cited.

*Note: Due to technical failure in interview output from one member of the visual condition it is not presented in the data, meaning that 13 visual conditions interviews were utilised in the qualitative analysis.*

8.5.5.2. Attention

![Graph showing percentage of participants per condition who made positive/negative statements related to 'Attention'](image)

*Figure 68: Qualitative data coded to "attention" split by positive and negative*
All participants discussed attention at some point during their interview. Those who used the tactile device were the most positive and those who used the audio device least positive about how the device allowed for them to engage with their surroundings.

Contradicting the quantitative data, many participants in the tactile condition cited the ability to visually engage with their surroundings as a benefit, especially when walking in a leisurely fashion. This was aided by the command style of the device which provided the user with the information as they needed it allowing them to disengage from the device when no changes in direction were required. This was further evidenced by many participants choosing ‘scenic’ or ‘leisurely’ style contexts when asked if and when they would use the product and also when interrogated about the device’s potential use in a busy city centre participants noted the ‘eyes-up’ style interface as a benefit.

*Also, you don’t need to have your eyes down either, so you can like, not get hit by a car!*  

**PARTICIPANT 38 – TACTILE CONDITION**

Whilst participants felt that they could visually engage, over 50% of the participants found talking whilst navigating difficult whilst using the tactile device. However, many participants speculated that the ability to talk and navigate may be easier with more familiarity with the product.

The visual device was seemingly the opposite of the tactile device. Nine out of the thirteen participants indicated that they found it easy to use the visual device whilst engaging in conversation, but some participants felt that they could not so easily engage in their visual surroundings.
I think the problem that I found with it was that my full concentration was on the visual aspect of it. So at St Fagans, the tourist attraction, I didn't really see anything, just the device.

PARTICIPANT 29 – VISUAL CONDITION

The high coding to ‘Negative – Attention’ when discussing the audio device was due to many participants feeling unable to hold a conversation whilst navigating. Similar to the tactile device, the command style of the device was also commented upon, both in a positive light, in which participants felt that they could disengage with the device when required and in a negative light where it was felt to either ‘interrupt’ a conversation or meant that the participants could never fully engage.

I felt like I could answer them and give you the right answer but I was like waiting on the next command from the audio so I couldn’t like give you my full attention because I was torn between listening and speaking to you.

PARTICIPANT 11 – AUDIO CONDITION

Overall, most people felt that it was more difficult to engage with conversation when using an audio device and this correlates with the quantitative findings as seen in the previous section.

Many participants did note that the audio device allowed them to engage visually with their surroundings however, unlike the tactile device this was less frequently discussed in
reference to leisurely walks and more frequently cited as a benefit when using in busy or
dangerous contexts.

8.5.5.3. Fun

The tactile device was the only condition in which users noted how they enjoyed using the
device with as many as 55% of the participants commenting on this.

I liked it, I was curious to use it, I just think it was a fun device...

PARTICIPANT 36 – TACTILE CONDITION

Both the audio and visual condition had negative comments made indicating that the
participant did not enjoy using the device, in both scenarios this was with the minority of
participants (2/13 visual and 1/13 audio) and most participants simply did not comment on
enjoyment levels at all. These results correlated with the usability questions where there
was a statistically significant difference between the perceived levels of ‘fun’ between
tactile and visual devices. All three negative comments received were comparing the
devices to using a paper map, and noting that the devices were ‘less fun’ than their traditional, less technology driven, counterparts.

*if I’m not in a rush I’d rather use a piece of paper and have fun doing it, rather than fully concentrating on a device that is gonna walk me into people*

**PARTICIPANT 29 – VISUAL CONDITION**

8.5.5.4. Communication of Information

![Figure 70: Qualitative data coded to “communication” split by positive and negative](image)

All conditions received high levels of both positive and negative feedback on the way in which they communicated navigational information.

The majority of the negative feedback received on the visual device occurred around the subject of the ‘blue dot’ (the visual representation of the user’s position on the path). Many users felt that the blue dot would lag behind their actual position and this caused confusion when trying to navigate. Positive feedback received on the communication method was more varied, 8/13 participants identified the ability to look ‘ahead’ and ‘around’ the path
as a major benefit of visual devices, allowing users to more easily relate the navigation information to their surroundings.

*I could see my route ahead of me and it allowed me to take in my surroundings and be confident in where I was going next*

**PARTICIPANT 10 – VISUAL CONDITION**

The majority of the negative feedback on tactile communication (6 of the 9 participants with negative comments on the communication style) cited the necessity to decipher the meaning of the Tactons. Feeling was varied amongst participants, some felt that this was due to similarities between tactons (either in their location on the device or the pattern) and some felt that the cognitive demand of ‘learning’ the command meanings was challenging.

*... some of the signals were quite similar, the one that told you to bear left before going left, so yeah, to begin with I was very conscious about the buzzing, I wasn’t sure.*

**PARTICIPANT 36 – TACTILE CONDITION**

Some participants also felt that the tactons were not ‘loud’ enough and worried that if they were navigating through busy locations or with friends they may not notice the command. Tactile commands also received a large amount of positive feedback (10 out of 11 participants had positive feedback on the command style) with 3 participants directly
contrasting the previously mentioned feedback and claiming the Tactons were clear and easy to interpret. Many participants commented that with more learning time they would be easy to interpret. The majority of positive feedback was around the consistency and perceived speed of commands. Participants felt reassured that the route chosen was correct, or were quickly informed if incorrect, due to regular command signals being communicated.

*I really like the way it reiterated the fact I was moving forwards, like every 10 paces it was like 'yes you are right, just keep going' which I liked.*

**PARTICIPANT 16 – TACTILE CONDITION**

Users frequently cited the ‘turn around’ command as a particularly valuable command. Due to the distinct tactons it was perceived as a very clear navigation cue. Four out of the ten participants who made positive statements about tactile commands commented that this command style allowed the user to disengage with the device and required less cognitive load as users do not have to ‘read’ a map.

*...because it reminds you, you can still do what you’re there to do but then it kinda, gently nudges you in the direction you wanna end up in*

**PARTICIPANT 32 – TACTILE CONDITION**

This command style was also positively noted in the audio condition, where participants often felt that the instructional commands reduced the risk of human error and so improved navigational ability.
I find maps quite difficult sometimes, you can get lost on it, so if you did have audio
which would tell you, you could just pick it up any point and press go that would
be really useful.

PARTICIPANT 11 – AUDIO CONDITION

This benefit was regularly cited in reference to using the device in busy and time restricted
contexts. Overall, the audio commands were felt to be clear and easily understood with 9
of 10 participants who made positive comments referring to this as a benefit. However,
many participants commented that the additional ‘distance’ information was confusing as
participants struggled to visualise distance and or attach meaning to the “feet”.

Meters would have been better. I’m not completely sure the relation from a meter
to a foot, I got a bit confused at how far 150 feet was, I saw a right turn then I got
it wrong

PARTICIPANT 4 – AUDIO CONDITION

A lack of reassurance was also clear in the audio condition as 8 of 12 participants who made
negative comments around the command style stated that more guidance was needed
throughout the route.
8.5.5.5. Performance

Overall participants were more positive than negative about the performance of all conditions.

Reviewing the positive feedback for tactile command performance, four of the eleven tactile users stated that the regular reassurance from the “go forwards” command was a particular benefit of the device and enhanced their navigation performance.

*I was walking at quite a quick pace because it was telling me where to go.*

 PARTICIPANT 16 – TACTILE CONDITION

Two of the eleven made negative comments about the performance of the tactile aid: one participant questioned the device’s practicality whilst walking fast and one felt that the command style interface wasted time as you could not look ahead.

Similar feedback was seen for the audio condition where positive feedback was largely based around the route-based representation being very direct and usually providing
succinct and precise directions that removed the potential for human error. However, it was recognised that a lot of trust was required in the system and partnered with the lack of reassurance this was felt to negatively affect navigation performance.

…it didn't tell you when you've went wrong, so you just carry on walking and then it would say to do a u-turn.

PARTICIPANT 37 – AUDIO CONDITION

The survey representation of the visual interface was cited as increasing confidence in the device and also increasing navigational performance. By allowing you to see the complete route the participants could confirm that the device was performing correctly. However, this was undermined by slow updating of “the blue dot” (a dot which showed the position of the user on the path) which made users unsure that they were taking the correct turn.

On the device where the blue dot was that tells you which way you’re going - it was quite delayed so I had to wait a few second and then it would tell me that I’m going which direction, it was frustrating.

PARTICIPANT 13 – VISUAL CONDITION
8.5.5.6. Physical Form

The tactile condition stimulated the most comments about the physical form by far. This is unsurprising as, unlike the audio and visual conditions, the form was completely novel to all users.

A large amount of negative feedback is documented in Figure 74 with 9 out of 10 participants providing negative feedback. 7 of these 9 participants stated that they struggled to differentiate between the vibration zones, specifically between the forward and the right actuators.

*I was worried I couldn't distinguish properly between the vibrations, I know now that I managed to find my way here without turning around, but it left me with quite a feeling of uncertainty*

Participant 19 – Tactile Condition

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*Figure 72: Qualitative data coded to "Physical Form" split by positive and negative*
Further negative feedback was limited, with one participant wanting a smaller device (more pocket sized), two participants wanting to see it integrated into a product they would already be carrying, and one participant preferring a wearable device. The tactile device also received a large amount of positive feedback (8 of 10 participants) with 5 participants specifically stating that they would prefer a handheld device to a wearable.

 Um, I don’t really know why but I think I prefer it as a separate device. But I can’t really put my finger on why I feel that.

 PARTICIPANT 34 – TACTILE CONDITION

Overall the tactile device was perceived as comfortable and easy to hold, and 5 participants cited that the physical form made the product inconspicuous which was perceived as a benefit.

This matter of being ‘inconspicuous’ was mirrored in the audio condition feedback, where 3 of 4 negative comments received stated that the device was too conspicuous or intrusive and that it made users feel uncomfortable.

 I felt like a bit of an idiot but then I dunno, that’s probably just more to do with my idea of people walking round with headsets in.

 PARTICIPANT 37 – AUDIO CONDITION

One participant felt particularly strongly about wearing a headphone for the task and perceived it as rude to be wearing this style of device whilst walking with another person.
I often see people wearing headphones whilst walking around in groups and often find that a bit uncomfortable. It could be seen as rude, I wouldn't do it because I feel rude doing it.

PARTICIPANT 18 – AUDIO CONDITION

However, this was seemingly a contextual issue as other participants felt that it’s resemblance to an Mp3 player and the head-up nature of the device could have benefits in many scenarios.

The visual device had very little feedback in regards to physical form.

8.5.5.7. Safety

The visual device was the only condition in which negative comments were made in regards to safety. 7 out of 13 participants who used the visual device cited contexts in which they felt the device would be unsafe to use. These contexts included: using the device at night,
using the device around busy roads, using the device when lost (and becoming a target for crime).

...it just marks you out as a target. If you’re on your own in the dark with something that is 3 or 4 hundred pounds. You’re just asking to get robbed it’s silly.

PARTICIPANT 33 – VISUAL CONDITION

These fears were mirrored in the positive comments made about the tactile and audio devices where participants cited the discretion and eye-up nature of the devices as enhancing safety when compared to the visual device.

8.5.5.8. Technical

The majority of negative comments were associated with a lack of trust in the devices (and GPS) and their functional capabilities.
Personally, I’d probably just ask somebody because I’d worry that for example the
GPS would lose signal

4 of the 10 total (across all conditions) participants who made negative comments about
technology commented that the tested device had failed them during the trial. However,
the device had not malfunctioned (3 of these participants used the audio device and
encountered the error discussed in Chapter 8.5.3.3)

8.5.5.9. Other

A large variety of comments were coded to the “other” category. The most common of
statements in this category was 5 of the 10 participants using the tactile device stating that
they expected the device to become easier to use with more use and that there was a
learning curve involved in the device.

You probably would just need to practise a lot with that sort of device, it will just
become second nature
8.5.6. Usage Scenarios

All 11 participants in the tactile condition cited at least one example of when they would prefer to use a tactile aid over their standard method.

The most common usage scenario was that of walking at night with 9 out of 11 participants stating that they would prefer to use the tactile aid than any other aid in this scenario. The main cited reasons for this due to the inconspicuous design, which allowed you to navigate freely without being perceived by others to be lost and vulnerable.

*Because you cannot have your attention on the screen. If you were worried about safety you can have your wits about you, without having to look on a map about where you’re going. So for that, I think that would be a really good marketable thing about it.*

Participant 32 – Tactile Condition

Closely following night usage was that of leisurely situations, scenic walks, guided tours and so on. 8 out of the 11 participants stated they would prefer to use the tactile device over their traditional methods. Reasons for this included the ability to engage visually with their surroundings, deemed useful for scenic walks, and the fun nature of the device that was felt to be better in keeping with the context than traditional methods. Those who did not envisage using the device in this context stated that they would prefer to use paper maps or signage.

Only three participants felt that they would use it in time-restricted, city situation that indicates that the majority of participants do not feel it to be of functional equivalence to the visual device.
8.5.6.1. Compared Against Initial Preference

In Chapter 8.5.1 users were asked which device they would prefer to use if given the choice. 50% (19) of the participants chose the visual device and of them 6 were selected for the tactile condition. All six stated that there are scenarios they would chose to use the tactile device as opposed to their normal methods, some gave multiple scenarios.

Three participants stated that they would use the tactile device whilst travelling in the dark, these comments relate to the inconspicuous nature of the tactile device allowing the user to be less of a target for crime. Four users stated that they would use the tactile device for leisurely walks citing both the fun of using the device alongside the ability to visually engage with their surroundings. Only one of the six stated that they would use it for a city journey with time restriction and cited the ability to visually engage with landmarks and roads alongside the command style interface which they felt to be easier than using a visual device.

One participant who chose the audio device in their initial preferences was selected for the tactile condition. This participant gave the explanation “I would like to see how well it works” for their selection of audio which indicates that it is not their usual navigation method. When investigating this participant’s envisaged usage scenarios, he was one of the few participants who stated that they would chose use to the tactile device in a city. They also suggested that the device would be useful for scenarios like tradeshows or museums.
8.6. SUMMARY

This chapter displayed the results of a comparison between three pedestrian navigation systems each utilising a different interface modality: visual, audio and tactile. The results displayed show both functional metrics and qualitative feedback.

Touchstone performed well against the commercially available counterparts. Functional ability was shown to be similar and some distinct user benefits arose from the study.

Participants responded very positively towards Touchstone indicating that it was pleasurable to use, a quality which was not felt about the audio and visual aids. The command structure itself worked well, with constant reassurance meaning that users were able to trust the device more so than the audio device however the most trust was shown in the visual device which allowed for an overview of the journey.

Interestingly, the quantitative results indicated that the tactile device was not significantly better or worse than either other device at allowing greater visual engagement with the environment. However, data trends indicated that the device may be better than the audio counterpart and subjective feedback from participants indicated that they felt that they had a greater ability to visually engage with their surroundings than the visual counterpart.

Distinct usage contexts were identified in which Touchstone would perform well. These contexts were:

- Walking for leisure
  
  Participant’s perceptions that the device would allow them greater visual engagement with their surroundings, alongside the discreet nature of the command
feedback meant that participants felt Touchstone would be well suited to leisure scenarios.

- Inconspicuous navigation
  For moments when pedestrians do not want to advertise that they may be lost, disoriented or do not know their surroundings the devices inconspicuous form and silent feedback method provided a feeling of security.
The previous three chapters have shown the results of the various studies undertaken throughout the research project. This chapter will discuss the results, contextualising them against existing literature. The chapter is split into four sections; the first two sections correlate with the two-phased research approach, the third discusses study limitations and the forth summarises the discussion providing a concise response to the research question:

“How might the employment of theories of resonance and extra-ordinary users in the collaborative design process results in better design outputs?”
9.1. PHASE ONE: PRACTICE – LED RESEARCH USING A PARTICIPATORY DESIGN STRATEGY

9.1.1. Reflection on Generative Methods

A variety of authors suggest that evaluating a product from the point of view of a person with impairments may lead to unique and novel insights (Lin & Seepersad, 2007; Hannukainen & Holtta-Otto, 2006; Pullin & Newell, 2007; Pullin, 2009) and when particularly discussing tactile interfaces, people with visual impairments had already been cited as potential experts in the field (Gustafson-Pearce, et al., 2005; van Erp, 2001; Burnett & Porter, 2001; Porter, et al., 2005). However, when reviewing the literature around Personal Navigation Devices (PNDs) there were no examples found of this type of approach. In fact, whilst it was occasionally cited as a point of interest there was a distinct lack of evidence to suggest that a process which integrated people with visual impairments as design informants had taken place.

On investigation into methods to integrate users into the design process User Centred Design (UCD) and Participatory Design (PD) were discussed as methods to include and in-turn gain empathy with the users (Sanders, 2002; Sanders & Brandt, 2010). However, in the case of people with visual impairments this was identified as a challenge due to the design process being largely dominated by the visual modality. Very few examples and very little advice was found in the literature on methods for inclusion of people with visual impairments and as such the research goal became to not only undertake and reflect upon a participatory process with these ‘extra-ordinary’ users but also to document it in order to help guide future practice. In Chapter 6 “Phase 1.A: Generative Research” a variety of participatory methods were undertaken with participants with visual impairments and the
process and results were documented, this sub chapter discusses the findings. The generative co-design methods were intended to provide an initial specification alongside providing inspiration for the design of the device. The methods were conducted with a group of participants with a range of visual ability (all but one registered ‘legally blind’) and all of which had an interest in “access technology”. The methods were inspired by Sanders’ (2010) framework of co-design techniques to help facilitate participatory design. However, the majority of methods had to undergo some form of transformation in order to make them available and engaging for people with visual impairments.

The collage activity, in the form of a mood board (Chapter 6.3.1) and card sorting (Chapter 6.3.3) were both transformed to be word games. Whilst it was felt that these word games did not provide an effective replacement of the tasks from which they had been originally derived, they did provide insight into the desired functional and aesthetic qualities in a method that was more engaging than traditional focus groups. Both tasks suffered from the inability to present multiple stimuli at any one time. With the mood board, this meant that no overview of themes could be seen by the participants, and with the card sorting task, it meant that the task took longer and required greater levels of facilitation.

The tasks that asked for physical engagement with prototypes (Chapter 6.3.5) and existing products (Chapter 6.3.4) were well received by participants as they asked participants to engage in tasks in a way that they have not previously experienced when involved with research projects or product development. The non-visual product feedback provided insight into user’s tactile preferences and intuitive interaction without being biased by visual cues such as button labelling. Likewise, non-visual modelling allowed for the placement of features that followed form and ergonomics as opposed to visual features.
When directly interacting with products, people with visual impairments gave feedback differently to what you would expect from people without visual impairment. These findings support Burnett and Porter’s (2001) paper in which they propose that people with visual impairments would provide a greater level of insight through better verbalisation of the tactile interaction experience. However, they identify the different product exploration styles and participant’s lack of experience with the product as a potential problem with the technique. Arguably this could be seen as a positive as, in these studies, people with visual impairment gave insight into which of the products presented had intuitive grip angles and even highlighting alternative grip angles that would not have been demonstrated by a user with even only a passing knowledge of the product. This implies that form assessments by people with visual impairments could go a long way towards overcoming problems with functional fixedness if attempting to design a novel interface system.

Whilst Burnett and Porter note that tactile exploration techniques for people with and without visual impairment are mostly similar, they do not reflect on the order of exploration. Tactile engagement explores the product detailing initially then builds to an overall image whereas visual engagement first explores the overall shape and size then moves to the product detailing. This was a key differentiator between the participants with and without visual impairment and supports the findings of Miao et al. (2009) in their tactile paper prototyping activity which noted that tactile noise should be avoided due to this different exploration style. The participant without visual impairment commented largely on general product form whereas those with visual impairment commented mostly on specific interaction elements such as button size and layout. For those designers looking to attain feedback on control mechanisms such as TV remote controls this could have high value.
9.1.2. Generative Method’s Placement on Frameworks

Two frameworks were utilised to aid analysis and categorisation of the generative techniques.

When reviewing the group methods against Kaulio’s (1998) framework many of the methods fell into the category of design for users. Whilst not entirely unexpected, as these tasks were conducted at a stage of the project where needs identification (rather than solution generation) was a priority, these tasks are not truly participatory in that the user group is not actively participating in the design process, merely providing insight that will inform it. Two methods were identified which allowed for genuine participatory input, these were ‘ranking’ and ‘3D models’, the output of which was utilised to create the end article. Table 12 shows the methods placement on Kaulio’s framework.

Table 12: Generative methods placement of Kaullio’s framework

<table>
<thead>
<tr>
<th>LEVEL OF ENGAGEMENT WITH USERS</th>
<th>STAGE OF THE DESIGN PROCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SPECIFICATION</td>
</tr>
<tr>
<td>DESIGN FOR USERS</td>
<td></td>
</tr>
<tr>
<td>Freelisting</td>
<td></td>
</tr>
<tr>
<td>Storytelling</td>
<td></td>
</tr>
<tr>
<td>Design with users</td>
<td></td>
</tr>
<tr>
<td>Existing product feedback</td>
<td></td>
</tr>
<tr>
<td>Design by users</td>
<td></td>
</tr>
<tr>
<td>Ranking</td>
<td></td>
</tr>
<tr>
<td>3D Models</td>
<td></td>
</tr>
</tbody>
</table>
Sander’s (2010) framework displays the purposes for which each method could be utilised. When looking at the method’s results against this framework it becomes evident that all methods aided the understanding of the user’s current situation. This corroborates what Sanders lays out as the primary goal of PD itself; to help the designer gain empathy with their participants in order to improve the final design. As Brandt (2006) notes “the designing of the design process itself is just as important as designing the artefact” and so it is expected that, as empathy and understanding towards the user group grows, so too will the design of the design process itself through better, accessibility, engagement and involvement of visually impaired user groups.

Table 13: Generative techniques analysed against Sanders’s framework

<table>
<thead>
<tr>
<th></th>
<th>PROBE</th>
<th>PRIME</th>
<th>UNDERSTAND</th>
<th>GENERATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Collage) Free listing</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Storytelling</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Existing Product Feedback</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>(Card sorting) Ranking</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3D models</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
9.1.3. Generative Method Recommendations

On reflection of the tasks undertaken a list of recommendations was generated. This list (presented in table 14) reproduces the recommendations made throughout chapter 6 and augments it with a small number of additional recommendations created from the cross-case discussion earlier in this chapter.

Table 14: Recommendations for generative design with people with visual impairments

<table>
<thead>
<tr>
<th>Recommendations</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOODBOARDS</td>
<td></td>
</tr>
<tr>
<td>Participants to ‘shout out’ examples of products (or services, or materials, or sounds etc.) that respond to a particular statement e.g. “items that are stylish”. These suggestions are documented then post-hoc a collage is made by the researcher.</td>
<td></td>
</tr>
<tr>
<td>Be sure to recruit participants who have an active interest in the areas</td>
<td>A verbal based task it is difficult to provide stimulus material without leading. This results in answers that rely heavily on prior knowledge.</td>
</tr>
<tr>
<td>Start with an abstract aim e.g. “items that are beautiful / items that are comfortable” then gradually refine to specific focus</td>
<td>Avoid leading the subject through verbal prompts by starting with an abstract approach.</td>
</tr>
<tr>
<td>Conduct the moodboard task prior to priming the participants.</td>
<td>Participants struggled to consider items outside the particular focus of the project. Conducting the task prior to the participants knowing the specific project aims will produced more generalised results.</td>
</tr>
<tr>
<td>Prepare verbal stimulus material prior to session</td>
<td>Due to lack of stimulus material participants are quick to run out of ideas</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>If possible, have a note taker create a moodboard by image searching and collaging then and there</td>
<td>To assist the researcher in identifying themes whilst undertaking the researcher. This will help identify if the research is meeting the aim.</td>
</tr>
<tr>
<td>Consider bringing physical stimulus such as sample products and materials</td>
<td>Engaging the tactile senses made activities more engaging for participants</td>
</tr>
<tr>
<td>Encourage rapid flow of ideas by ‘shouting out’ answers</td>
<td>To avoid the activity becoming standard ‘focus group’ style discussion and encourage</td>
</tr>
<tr>
<td>Expect visual terminology and interpret appropriately</td>
<td>Visual terminology such as ‘it looks…’, ‘I can see it has…’ was used throughout</td>
</tr>
<tr>
<td>Be conscientious of every participant having a voice</td>
<td>Visual cues associated with a person waiting to speak are unavailable to the participants</td>
</tr>
<tr>
<td>Consider a ‘negative’ mood board also</td>
<td>Participants struggled to only consider positive elements. Allow them the freedom to discuss negative features in order to more easily move forward.</td>
</tr>
</tbody>
</table>

**STORYTELLING**

Participants are asked to tell a story about a particular event or occurrence in their lives.
<table>
<thead>
<tr>
<th><strong>Spend some time considering exactly what output you desire.</strong></th>
<th><strong>Due to the cumulative nature of verbal storytelling it is not easy to go back and add more.</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Be clear with the participants about what you would like to achieve</strong></td>
<td><strong>Once a participant starts story telling there is no way of correcting without interrupting the flow of the story.</strong></td>
</tr>
<tr>
<td><strong>Embrace the mundane</strong></td>
<td><strong>Whilst the story may seem dull, viewing ordinary experiences from extra-ordinary people gives an interesting perspective.</strong></td>
</tr>
<tr>
<td><strong>Present stories to different user groups and allow commentary</strong></td>
<td><strong>Insight was derived from the participant’s responses and questions about stories from a different user group with different engagements and navigation styles.</strong></td>
</tr>
<tr>
<td><strong>Consider recording the story and playing it back to add more details</strong></td>
<td><strong>Allows the facilitator to probe for more information without disrupting initial story flow.</strong></td>
</tr>
<tr>
<td><strong>Ask participants to retell the story as if they were using the proposed product</strong></td>
<td><strong>Shifting the activity from a ‘design for users’ activity to a ‘design by activity’ by asking them to describe how they imagine the product would work.</strong></td>
</tr>
</tbody>
</table>

**CARD-SORTING**

Product features and functions are identified and each constitutes a ‘card’. Participants are presented with these cards and are asked to prioritise or categorise e.g. “price or functionality?” or “tactile or audio?”
| Undertake the activity with physical cards (facilitating the participant’s answers) | Avoidance of audio noise from a laptop. Easier to order cards. |
| Present a maximum of three cards at once | The verbal version of this activity relies on memory of the cards presented |
| Maintain urgency in the response | Documents participants initial reaction as opposed to being drawn into conversations about benefits / negatives |
| Create a script or plan prior to the event detailing the ordering of the questions to attain the best information in the quickest fashion | As presenting cards must be conducted in ‘batches’ a script or plan avoids repetition |
| Consider utilising card-sorting to break up otherwise structured focus groups by creating cards ‘on-the-go’ | Focus group participants (with and without impairments) can get distracted by tangential issues or absorbed in debate. This task resolves conflicts quickly and effectively. |

**EXISTING PRODUCT FEEDBACK**

Participants are presented with a selection of products and asked to feedback on likes and dislikes.

- Do not ‘test’ the participants on their product knowledge. If a participant asks what a product is answer them.
- Some participants may not have engaged with a product before and without being able to visually perceive any usage cues.
<table>
<thead>
<tr>
<th>participants may struggle to identify products</th>
<th>Do not immediately explain product usage</th>
<th>Allow the participants to first explore the product, providing insight into how recognisable the form of the product is.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do not indicate grip orientation by handing the product to the participant. Instead place the product on the table in front of them.</td>
<td>Provides insight into how intuitive a products grip orientation is based on form alone.</td>
<td></td>
</tr>
<tr>
<td>Do not provide verbal cues as to a features intended use e.g “what do you think of the thumb button”</td>
<td>Avoiding instructions on how to use/hold a product tests the intuitiveness of form</td>
<td></td>
</tr>
<tr>
<td>If filming, ensure the camera is directed towards the participant’s hands not their faces</td>
<td>Aids proper data capture</td>
<td></td>
</tr>
<tr>
<td>Expect feedback on product detail, such as buttons layouts, depths and tactile noise Probe for feedback on overall shape and materials</td>
<td>Due to the product exploration techniques of people with visual impairments initial engagement is with product detail</td>
<td></td>
</tr>
</tbody>
</table>

**MODELLING**

Participants are presented with solid, rough forms for the proposed product and asked to add expected features and feedback on form preferences.
<table>
<thead>
<tr>
<th>Explain the fidelity of the models</th>
<th>Participants may not have access to the (visual) cues required to appreciate it’s stage of fidelity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use a malleable material and ask participants to add their own features and give the participants simple tools to add their own features</td>
<td>Engage participants in the placement of features, overall form and detailing of the product.</td>
</tr>
<tr>
<td>Ensure the models are sturdy</td>
<td>Participants may not have access to the visual cues of a delicate model. Simple tactile exploration of a product can be violent enough to break delicate prototypes.</td>
</tr>
<tr>
<td>Use Styrofoam</td>
<td>Styrofoam proved to be an apt material for modelling with people with visual impairments. Sturdy enough to hold overall form, but malleable enough to add tactiley perceivable features.</td>
</tr>
<tr>
<td>Consider creating a list of initial features to consider</td>
<td>Participants started the task slowly but once they had got used to the task embraced it. Proving a few examples allowed users to understand the task better.</td>
</tr>
</tbody>
</table>
Recognise the diversity within the demographic

Many activities relied on participant’s knowledge of similar devices, whilst the impairment may be important to the research if the participant is not interested in the subject area and has little knowledge of current solutions, output will be extremely limited.

Be clear and explicit in the task instructions and aims

Participants cannot simply ‘watch’ somebody else to understand how to complete the task.

Engage the tactile sense

Participants emotional response to tasks was better when the tactile sense was involved.

Be user centred in your approach

Amending already documented activities to be ‘accessible’ produced different results to the original activities, were less engaging and showed less interesting results.

<table>
<thead>
<tr>
<th>9.1.4. Interrogation of the Involvement of Extraordinary Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is difficult to know how the project would have progressed without using people with visual impairments as design informants. There is no way of undertaking a control project as a design process is always going to be biased by the experience of the designer. However,</td>
</tr>
</tbody>
</table>

when compared to other attempts at tactile navigation devices within the literature, the
outcome that was produced using a participatory process with extra-ordinary users was
arguably more resolved and effective than many other attempts. This is supported by the
positive feedback on device functionality and usability evidenced by the results of the
comparative study.

Pullin and Newell (2007) suggest that the benefits extra-ordinary users bring to the design
process are:

- More radical starting points
- Less constraining than fixing mainstream products
- Encourages simplicity

Arguably, all three of these benefits were obtained. The first and second benefits are linked.
The output of the process was radical in that it was distinctly different to any other
navigation aid produced. Some previous attempts sought to utilise an existing mobile
phone system. By engaging extra-ordinary users, a ground up approach was taken which
created a solution, which whilst working with a mobile phone, was not integrated into it,
thus not constraining itself to a single vibration motor. When reviewing the literature, the
more successful tactile navigation trials were those in which location is utilised to encode
navigation information. Therefore restricting it to current mainstream solutions is not
desired. Finally, the new product arguably showed more simplicity than the prior academic
attempts. Prior attempts regularly utilised wearables such as belts and torso harnesses.

Whilst adding simplicity to the tactons themselves by allowing an ego-centric directional
command system, these ego-centric designs also created complexity in other areas. The
prospect of having to attach, or put on a harness added burden into an already extended
preparation routine that every person with visual impairment must go through before they
leave the house and this was not considered simple or desirable. Alongside this, the storage
of such an item once they had reached their destination and modest interactions such as finding the device in a handbag were considered. Overall the final output, Touchstone, a small, but not too small, handheld device provided a radical new starting point and fitted more comfortably into the lives of its users.

Pullin and Newell (2007) suggest that in some cases the extra-ordinary user approach, in the first instance, may not directly produce a solution for a broader population but this solution could then be utilised as an item of critical design (Dunne & Raby, 2001). However, this case evidenced the polar opposite. Throughout the research with people with visual impairments, from the very early stage contextualising focus groups through to the design activities with Tony and Andrea, a strong desire to utilise mainstream products was evidenced and as such the participants were enthused that the final output should be an accessory to what was deemed the highlight of all accessible mainstream technology, their iPhones. The extra-ordinary users also highlighted many day-to-day considerations which had been seemingly overlooked in academia’s previous attempts to create a tactile navigation aid; dismissing belts and gloves as inappropriate, bothersome or not socially acceptable for day-to-day use, and the idea of attaching the device to the dogs harness as both exclusive and inappropriate for the dog’s wellbeing.

What is clear is that a recognition of design resonance significantly changed the process and thus the outcome. Particularly when considering the commercial case made for this type of product and the original brief which instigated the research project. The original “Peepo” (Peepo GPS Ltd, 2014) concept lacked this recognition of contexts of use where tactile navigation technology would have benefit to mainstream users and in-turn created an exclusionary product. Once recognised, the process changed which not only created a product which was now usable by a larger population. It also became more appealing to
the core target audience as from the very initial interactions with people with visual impairments it was clear that the idea of an “access product” is demotivating and exclusionary.

9.1.5. Insights Drawn from People with Visual Impairments

The process produced many insights into the design of tactile interfaces and particularly navigation aids, those generalizable are listed below:

**Design of tactile interfaces in general:**

1. Button layouts should be consistent with conventions
2. Fewer, multi-functional buttons are better than many single button functions
3. Mainstream products are more desirable than products designed specifically for access
4. Contrast in material has importance:
   a. Soft rubberised indicates buttons or grip zones
   b. Hard smooth surfaces indicate body
5. Raised keys and buttons help differentiation more than large surface areas
6. Dials and sliders should be used where possible
7. Power inputs which allow for insertion in any orientation are preferable to USB
8. 1-9 keypads are the preferred data entry method for people with visual impairments
9. Buttons should be reachable from the ‘normal’ holding position
10. A clear ‘select’ or central button helps users navigate devices and memorise layouts
11. Button covers have value
12. Novel interactions are desirable
13. Rubberised materials increase perception of durability
14. Tactile noise should be avoided around the primary interface mechanism
15. Providing a “hand control reference point” (Porter et al. 2005) improves product navigation and learning

16. Physical prompts should be provided in order to help identify grip orientation

17. Wearable devices should take into consideration:
   a. Their impact on outfit selection
   b. Their ‘fit’ requirements for users of different sizes
      i. Avoid systems the user could ‘grow out of’
      ii. Avoid systems that draw attention to undesired physical traits

Design of tactile navigation systems:

18. Distance measurements require context:
   a. E.g. a ‘count-down’ whilst approaching a turn
   b. Providing an estimated time may have more value

19. Vibration is best utilised to replace generic, and regularly used commands
   c. Not specific contextual data
   d. Not future, or overview data

20. Headphones/Earphones are dismissed by users

21. Use of audio should be restricted to irregular commands/personalised contextual information in order to limit perceived vulnerability

22. A compass based system is recommended as:
   c. Turns off route can be quickly rectified
   d. User can pivot on the spot if unsure of correct direction.

23. Smaller is not always better
   e. Devices should be comfortable to grip
   f. Devices should be large enough to be easy to find when stored in a handbag/backpack

24. Bigger is not always better
   g. Devices should be small enough to be used discretely to avoid risk
   h. Devices should be small enough to fit in a coat pocket

25. The device should be easily stored when not in use even when at a destination which is not the home
26. Tactile command systems should fit with currently used command systems for Guide Dog users

27. Regular unobtrusive reassurance should be provided

28. Primary commands should include:
   i. Go forwards
   j. Prepare to turn
   k. Bear
   l. Turn
   m. Turn around
   n. Arrived

29. The use of a warning command should be avoided as it may cause an over reliance on the technology and detract from existing, known to be reliable, micro navigation aids/techniques

30. Tactile zones should be spread across as large an area as possible to aid differentiation

31. Handheld devices should consider a wrist lanyard or similar mechanism to allow the use to quickly drop the item should they require use of their hands

32. Handheld devices should be rugged and be able to withstand being dropped

33. Tactons should consider the speed at which the user is walking

34. Route reassurance commands should be limited to a maximum of once every ten seconds

35. ‘Prepare to turn’ should activate roughly 6 meters prior to turn

36. If used alongside a ‘prepare to turn’ command ‘turn’ should activate directly on the turning point

37. ‘Turn Around’ should be distinct and urgent.

These insights alongside an iterative development process where extra-ordinary users were the major informants resulted in a product that trialled successfully against common place counterparts. Consequently, it is felt that the process overall was a successful one. On reflection whilst the extra-ordinary users (and the earlier participants) involvement was well integrated there still lacked the sense of genuine creativity that is desired of a
participatory process. This manifests itself largely in an inability to abstract ideas and think beyond technology and products that are readily known to be available, and this was evidenced throughout the process. This finding clarifies the role of the designer in such projects, as co-creation with any untrained participant (with or without visual impairment) will likely lack the lateral thinking that designers have the skills and training to undertake. What the extra-ordinary users (and the other early participants) brought to the process was knowledge in the specific area that allowed them to:

- Develop a specification
- Make informed decisions

In a way that would not have been achievable by someone who did not have that level of experience.

9.1.6. A Method Story

Since undertaking the research more literature has been published around the subject matter, Hendriks et al. (2015) discuss this exact issue. After initially attempting to derive a set of general principles for co-design with people with cognitive or sensory issues it was decided by Hendriks et al. that this is an impossible challenge. Instead they make a case for method stories that provide critical reflection and description of the process rather than focusing on simply the design outcomes. The results chapters of Phase One of this research project (Chapters 6 & 7) provide the method story detailing the process undertaken in the development of the Touchstone device. However, Hendriks suggests some further key points to address and those that are relevant to the project are discussed below.

The Positioning of the Impairment in the Project
From the start of the project the ‘impairment’ was central to the design project. People with visual impairments were seen as experts on the subject. However, a key element that added to the success was the recognition of diversity within the demographic itself, and whilst visual impairment was central to this project there were many other key personality traits that made for successful participants in the design process. Whilst this was emphasized prior to the study’s start in the literature around extra-ordinary users (Pullin and Newell, 2007) it is felt that this study highlighted that the issue is particularly relevant when designing with people with visual impairments. During the mood board task it became clear that it is very difficult to present non-visual stimulus material in a subtle manner and a heavy reliance on existing knowledge was present. This reliance on existing knowledge was then seen in many other tasks. Had a visual impairment been the only specification for the participants then this existing knowledge may not have been sufficient to complete the task. Therefore, when working with people with visual impairments, whilst having the impairment as central to the project may produce novel insights it is recommended that this should only be one of many factors in participant selection.

The Aim for Equivalence

Hendriks (2015) asks practitioners to reflect on how they supported collaboration and provided for equal contributions. Phase One, the development stages, of this project went through two stages, one of which intended to support collaboration and varied contribution (in the generative phase) and the following phase actively encouraged imbalance by employing extra-ordinary users. Greenbaum (2000) discusses that when working with people with visual impairments it can often be difficult to control conversation due to the inability to perceive the (visual) cues of somebody waiting their turn to speak and thus the conversation become unequal, dominated by the most vocal
participants. However, the co-design techniques did well at overcoming this issue by providing a clear expectation for the participants’ involvement and feedback meant that very little participant dominance was seen.

Dealing with Ethical Challenges

A simple but important challenge encountered was that of documenting participants consent to partake in the studies. It was found that many participants owned a stamp which acted as their signature, and whilst the participants were happy to trust the author and stamp the consent forms provided, to ensure complete clarity and honesty consent was always taken in the presence of trusted neutral party.

The Adjustment of Techniques

Whilst the impairment was central to the design project, on reflection it was not felt central to the design of the research methods, particularly in the generative section of the project. As many methods were adapted from those suggested by Liz Sanders (2010) not all methods were well suited to the non-visual modality. The results chapter details that the generative tasks had varying levels of success. Key themes that arose from the transition of visual tasks into non-visual tasks were:

- A heavier reliance on prior knowledge as subtle and abstract stimulus are more difficult to present verbally
- As data was generated through verbal methods, the results were presented cumulatively and along a particular timeline as opposed to a visual presentation of results which allows for a summary view and for the observer to explore at their own pace and direction
- The participants showed higher levels of enjoyment and engagement with tasks which required fewer adjustments
These are significant issues within the research conducted. The aim of the investigation was to assess how involvement of users throughout the design process would add value to the outcome. Yet this ethos was not involved in the design of the process. That fact that participants engaged better with methods which required fewer edits implies that methods that themselves have been designed in a user centred fashion would have more success.

The Data Collection, Analysis and Interpretation

The areas that Hendriks (2015) identifies as problematic in data collection, analysis and interpretation are not identified in this study. Examples are unreliable verbal data from participants with cognitive impairments which is not relevant here, and difficulties in analysis of visual data. All data was clear and concise, however, data presentation via transcript of stylistic and aesthetic preferences is not ideal and data required translation to a visual modality to provide stimulus for design ideation. The majority of the data was driven by specifications rather than creatively generating concept ideas emphasising the role of the designer to add the creative element to the project.
9.2. PHASE TWO: DESIGN EVALUATION

The goal of the comparative study was to compare the Touchstone device when used with people without visual impairments against two commercially available modality specific systems. The findings of this study can then be utilised to understand the implications of design resonance, whether designing with extra-ordinary users would result in benefits for ordinary users.

To achieve this, the following exploratory objects were assessed:

1. Initial choice and preferences for a pedestrian PND – in order to understand what users value and desire from their devices to then be compared against the outcomes of the study.

2. The ability of the systems to guide the user along a previously unknown route – in order to identify whether the innovative system adds functional value when compared to traditional systems.

3. The users’ feeling about the systems after use and their expected usage scenarios – in order to identify whether the users perceive any added value in the innovative system

9.2.1. Initial choice and preferences for a pedestrian PND

The majority of participants 55% (20 participants) initially chose the visual aid as their preferred navigation method due largely to a better expected functional capability. Likewise 68% (26 participants) stated that they expected the visual device to perform the best. However, this left 6 participants who, even though they believed the visual system
would perform the best chose a different system as their preference - these 6 users all selected tactile as their aid of choice.

Bosman et al. (2003) state that “novel systems [are] at a disadvantage” as users are more likely to trust a system with which they have previous experience. As such, it is not unexpected that the Touchstone device was not the initial choice for the majority of participants. However, 32% (12 participants) chose tactile as their preferred device stating expectations of a more pleasurable product experience as their reasoning. Again, this correlated with other results as the majority of participants expected the tactile device to be the most fun.

These outcomes show that whilst functional ability is the primary driver for using a PND, product experience is not insignificant, particularly in a usage scenario that is not critical. When placing this within the current literature it supports Robinson’s (2010) stance that current navigation methods are not perceived to be enjoyable experiences. He developed a tactile system that allows the user to scan for potential routes and make their own choices as opposed to a “didactic” command based system. However, their choice to use tactile modality is not clear. This research supports that when ones navigation requirements are pleasure based, as opposed to urgent A-to-B scenarios, the tactile modality has value.

9.2.2. The ability of the systems to guide the user along a previous unknown route

Two contrasting stances are taken in the literature could potentially predict the performance of the novel tactile device against the more commonplace counter-parts. Firstly, the literature around the impact of prior experience on product usability and functionality shows intuitive interaction relies on prior experience and that greater levels
of experience will produce better performance (Blackler, et al., 2009; Langdon, et al., 2010; Hurtienne, et al., 2013). Thus it would be predicted that the more established navigation information representation modalities, visual and audio, would outperform the novel tactile interface. On the other hand, literature discussing navigation devices regularly proposes that due to the visual sense already being heavily utilised when walking the tactile aid would decrease cognitive load and in-turn improve performance (Gustafson-Pearce et al., 2005; Pielot and Boll, 2010; Cardin and Thalmann, 2008; Tsukada and Yasumura, 2004). Thus many hypothesise that a tactile device would outperform visual and audio devices.

When reviewing the quantitative functional metrics: task completion, error rate, and time spent confused, no evidence is seen to support the hypothesis that a tactile device provides any benefit in improved navigation performance against audio and visual competitors. However, that a novel system, provided with a minimal amount of learning time can perform equivalently to a well-established method is very positive for the device and when viewed alongside the qualitative data, which indicated that users felt that with more learning time the device would become easier to use, implying that a longitudinal study may yield more positive results for tactile navigation.

Comparing against Pielot and Bolls’ (2010) study, which is the most similar as it compares a tactile aid to a visual aid in-context, their “Tactile Wayfinder” does not have equivalent functional ability to the visual device. This indicates that Touchstone may be easier to use than Pielot and Bolls’ Tactile Wayfinder. Theorizing as to why this may be, the Tactile Wayfinder attempted to encode future turns in the tactons that potentially confused the users; this theory is informed by the Touchstone user feedback that valued the immediacy and command style of the interface that was seen as lessening cognitive load. Simplicity in tacton commands by only providing the immediate information, was informed by the extra-ordinary users, indicating that their superior knowledge on the requirements of non-visual
navigation may have aided device usability, but as previously stated not outperformed existing visual or audio methods.

9.2.1. Route Drawing
The route drawing task was designed to investigate the spatial knowledge acquisition provided by the device by assessing the survey knowledge built up of the area. This task showed a significant difference between the visual and audio conditions, with more of the participants in the visual condition able to draw the path they had taken. However, no significant difference was seen with tactile condition and either other condition. That the visual device performed best in this task is not unexpected when considering the task asked the user to represent the path taken in a survey (allo-centric) style. However, whilst the visual device performed best much of the literature indicates that a standard map would have exceeded this performance (Münzer, et al., 2006; Field, et al., 2011; Ishikawa, et al., 2008). Munzer, et al. (2006) discuss an “active encoding principle”, this principle suggests that the requirement to cognitively process paper maps when navigating supports the incidental acquisition of spatial data. As GPS aids do not require this processing they perform worse than paper maps in spatial acquisition tasks. With this in mind a further study on the ability to recall route based navigational information between the audio and tactile devices might yield interesting results due to the level of processing natural language requires compared to the level of processing a new tactile language would require.

9.2.2. Photo Recall
The photo recall test examined the user’s ability to visually engage with their surroundings by asking users to recollect actions at decisions points utilising visual prompts. The results indicated that there were no differences across conditions. This result refutes many of the
research claims that the eyes-up navigation styles would encourage greater engagement with the surrounding area difficult (Brewster, et al., 2003; Lin, et al., 2008; Tsukada & Yasumura, 2004). The unexpected finding is particularly emphasised by the lack of correlation between eyes-down time and the ability to recall the photos. However, on review it might be suggested that the testing metric was insufficient as participants did not know that they would be asked to recall the information and thus processed the information passively. If this is the case then the tactile and audio device may still be safer to use as it still allows for visual engagement at a level that would be potentially life-saving, for example if when walking into a road the user was able to engage even at a passive level they would stop walking. This is supported by the qualitative data where participants of the tactile and audio conditions both noted that they felt like they could engage with their surroundings more, and by the fact that one participant in the visual condition unknowingly stood in the path of an oncoming vehicle.

9.2.3. The users’ feeling about the systems after use and their expected usage scenarios

The functional metrics collected indicated that all devices performed equally well for users without impairments, but in the analysis of the qualitative research distinct benefits and use case scenarios begin to emerge.

Compared Against Visual

Users were overtly more comfortable using the visual device than Touchstone, they asked fewer questions and sought confirmation from the researcher less frequently. The participants likely had more experience in using visual based systems meaning they felt
more confidence that they were using the device. Also, the visual device utilised a live
update of a survey based representation of navigation information. This type of
representation allows the user to more easily assess whether they are still on the correct
path and in turn increase confidence levels. That the two devices had an inherent
difference in their data representation techniques made them difficult to compare on a
like-for-like basis. Both devices provided live feedback on the user’s location however the
tactile device utilised a route-based, command style interface providing only imminent
data and in turn provided a very different user experience to the survey based
representation of the visual device.

The majority of participants in the visual condition indicated that they would use the device
in time sensitive, city contexts, whereas the majority in the tactile condition said they
would not. Conversely, in a leisure context, the majority in the visual condition said they
would not use the device, whereas in the tactile condition they would. In time-sensitive
contexts where functionality is critical the visual device is the most trusted. The survey
representation reassures the user that the technology is functioning correctly. However,
when time is not of importance, the head-up design of the tactile device makes the user
feel that they are engaging with their environment more effectively and having a more
pleasurable experience, though, it is interesting to note that the functional metrics did not
confirm this ability to engage with their environment more effectively. Some participants
across all conditions stated that in a leisure scenario they would prefer to use a paper map,
when analysed against the current cultural backlash of ‘eyes-down’ smartphone usage
(Khaleeli, 2014; Spencer, 2013; Kerley, 2015) this raises the point that the issues with eyes
down may actually be related to social perception of smart phone use as opposed to
environment engagement as the survey representation, in paper form, is preferred.
The usability metrics indicated that participants felt that Touchstone was significantly ‘more fun’ than the visual device. This same sense of pleasure in product usage was not seen in the audio device which for many was considered too intrusive for use on leisurely walks, therefore it can be said that specifically the tactile interface (and so an innovation driven by people with visual impairments) added value. This feeling of fun in product use is significant; for many years researchers have been arguing for the value of emotional engagement with products. Overbeeke et al. (2004) argued that product design has become too driven by cognitive requirements and that a greater level of attention should be paid to the physical and emotional sides of using a product. Jordan (2000) agrees stating that this cognitive approach to product design is “dehumanising” and that a holistic approach should be taken towards the user. He describes “four pleasures” to consider when designing a product which are:

1. Physio-Pleasure
Pleasure through the senses, touching, tasting and smell.

2. Socio-Pleasure
Pleasure derived from relationships with others or with society as a whole.

3. Psycho-Pleasure
Pleasure derived from the cognitive and emotional relationship with a product, associated with ‘ease-of-use’

4. Ideo-Pleasure
Pleasure derived from how a product relates to the users’ values.

Reflecting on the feedback on Touchstone it can be argued that it pertains to three of these pleasures. ‘Physio-pleasure’ as it engages the tactile sense creating new and interesting experiences and ‘Socio-pleasure’ as it allows for head-up use avoiding the stigma associated with smartphone usage, and it was the product that users would be most happy
to use when walking with friends. ‘Psycho-pleasure’ as performance tended to be better than expected, resulting in a positive response and the command tactons meant that users were able to disengage with the device at times where no action was required (which in this context was desirable) and that the tactons performed well at reassuring the user was walking in the correct direction.

Interestingly, the interview data reveals that many participants felt it harder to engage in conversation when using the tactile device compared to the visual device. This does not support other responses where users indicated that they would be happier to use the tactile device with friends than either other device, nor does it support the prior statements that tactile is more effective for a leisure scenario, as users are more likely to converse when not under time pressure. However, many users did state that they felt this was due to the high cognitive load associated with computing the tacton meanings and that with more practise this load would significantly reduce.

Another usage context in which Touchstone was perceived to have added value against the visual device is whilst walking at night/alone. The physical design was considered an inconspicuous method of navigation. The eyes-up design, along with the ability to discretely hold it in the palm, was thought to enhance the users’ safety by not drawing attention to the product usage. This, alongside the perceived greater ability to visually engage with the surroundings, which helps the user identify risks, meant that users were enthused about the potential use in that scenario. Again, this preference was not clearly evidenced in the comparison between audio and visual as participants felt the audio device’s physical presence to be intrusive and uncomfortable and felt that the aural interface would obstruct their ability to perceive other people around them.

These PUCs support Pullin and Newell’s design resonance as it evidences an extra-ordinary users’ everyday device needs correlating with ordinary users’ needs in extra-ordinary
contexts. However, whether these product usage contexts are prevalent enough to drive a commercial case for Touchstone in a mainstream audience is unknown.

**Compared Against Audio**

The comparison between the audio and tactile interface is more easily drawn than the comparison against the visual device, as both devices utilise a route-based representation of navigation information utilising procedural instructions. As such, the qualitative data received on the device covered many of the same themes.

Due to the similar navigational experience, many of the decisions made by extra-ordinary users could potentially have been applied to an audio interface. Decisions such as:

- Physical form
- The commands relayed
- The amount of reassurance required
- The compass direction based command system

The physical form of the tactile device, when viewing the coding table (Chapter 8.5.5.6) seemingly received a high level of negative feedback, but on interrogation of the data this was actually one element repeatedly mentioned, concerning the tactile zones, whilst of vital importance this is not a problem that could not be resolved with small iterations on the product design itself. Excluding this issue, the overall feedback of the physical form was very positive, with many participants stating they would prefer it to the wearable devices that are more commonly seen in the literature (Cardin & Thalmann, 2008; van Erp, 2001; Pielot & Boll, 2010). In the audio condition, many users cited that they actively disliked the physical presence, so in this area it could be argued that the tactile device outperformed the audio device.
Other areas in which Touchstone arguably outperformed the audio device was in the commands relayed and the amount of reassurance provided; a common error was observed within the navigational performance of the audio condition which highlighted these two themes as areas of importance. A balance is required in the amount of reassurance required, too much and the system would demand too much attention, too little and users lose confidence. Seemingly Touchstone, in this scenario, gave the correct amount of feedback backed by the many participants who positively commented on the ‘forward’ command.

The audio distance commands were regularly cited in interviews as more confusing than helpful, and this was also evidenced by the audio error scenario. Without a survey representation of the navigation information the user is required to calculate the meaning of distance communication, adding extra cognitive load and a higher chance of human error. Van Veen, et al. (2004) conducted a study into the display of distance commands through tactons and produced a similar outcome indicating that performance was slightly worse when distance was encoded into the tactons. Andrea drove the specification to not include distance coding, whilst it was frequently discussed, she felt strongly that the navigation signals should be as simple as possible and as long as there is an awareness of the overall journey length, along with regular reassurance, no further distance information should be required. This was then confirmed in the field trial with Tony. This provides evidence of the extra-ordinary users’ valuable addition to the specification due to their superior experience in the context.

Visual, Audio or Tactile

Overall, the tactile device performed well against the more commonplace competition. Reflecting on whether tactile devices could be a replacement to visual navigation aids
(being the most common navigation aid) it seems unlikely. The lack of survey representation of the navigational information meant that the user must place their complete faith in the device and the associated technology (particularly GPS which many users stated was “unreliable”). However, it is worth noting that this is not the intended use scenario for Touchstone. Whilst not yet designed, it is envisioned that the initial programming interface, undertaken on a smartphone would also provide visual maps and so it is anticipated that the final system would in fact be a combination of the two modalities, potentially then also integrating audio feedback for any desired contextual information such as landmark identification. This system could then present the varying types of navigational information for more complete knowledge acquisition, landmark knowledge presented through audio, route knowledge presented through tactile, and survey knowledge presented through visual.

Current state of the art sees audio as the ‘go-to’ replacement for when a user should not, cannot, or does not want to engage visually (for example the audio output in a car or on current products designed for people with visual impairments). However, the evidence presented shows that this could be reconsidered, and that the Touchstone device provides a better user experience by:

- Providing more reassurance
- Decreasing user frustration through a less intrusive command style
- Appearing less conspicuous
- Providing clearer commands
- Allowing the user to engage with their surroundings more
- Providing a more pleasurable experience

And therefore would provide a better ‘partner’ to a visual system than many audio devices.
9.3. **STUDY LIMITATIONS**

On reflection of the research project a variety of limitations were identified. This section will review those with the most impact and suggest solutions for future consideration.

9.3.1. **Lack of iteration in ‘Phase One’ research methods.**

In the methodology section it was recognised that due to time limitation a true ‘action research’ approach was not viable, as such a more general ‘practice-led research’ approach was taken to the research undertaken with people with visual impairments. The research conducted allowed for reflection on the relative successes and failures of the methods in a “method story” style similar to what is proposed by Hendricks, et al. (2015). However, the lack of iteration meant that, particularly for the less successful methods, a limited amount of information useful for future practitioners was able to be drawn from the studies. Allowing more time to develop and iterate the research methods utilising an action research methodology would have provided more positive and categorical recommendations to share with the research community.

9.3.2. **Inability to conduct true comparison**

The research question asked how the employment of theories of resonance and extra-ordinary users may result in better outputs, however this is difficult to quantify when no comparative device was being developed. When discussing the outputs of the research methods throughout the development process with extra-ordinary users it cannot be categorically stated whether those outputs would be similar or dissimilar had the same method been undertaken with the people without visual impairment. This research project overcame this hurdle by comparing outputs to those commonly seen in research literature
however running parallel project with participants without visual impairments would have provided a deeper level of insight. Unfortunately, this was not possible within the scoped resources and timescale of this doctoral project.

9.3.3. Insufficient metrics

The study proved limited in the area around engagement with the visual environment. Additional tasks similar to those seen in the study conducted by Pielot and Bolls (2010) in a busy pedestrian area would provide insight into the differences between the ability to retain visual data, important for spatial knowledge acquisition, and the ability to react to visual data, important for safety. However, this should be constructed in a method that allows for control in order to provide true results. Initially Hyman’s (2010) approach, where he introduced a unicycling clown as “new and distinctive stimuli” was considered but then discarded as the stimuli was not natural to the setting, but on review, the distinctive element of it is not dissimilar to the surprise of seeing a car much closer than expected, and thus on reflection integration into the study would likely have provided valuable insight into the cognitive demand of the devices.

9.3.4. Learning Time

Many of the participants in the tactile condition of the comparative study noted that they believed with a greater learning period their performance would improve. The tactile condition was put at an unfair disadvantage for the functional metrics as participants had no prior experience with the device (Shluzas, et al., 2013; Langdon, et al., 2010). It would be interesting to understand whether a longer learning period would enhance the functional side of the device and alternatively whether it would decrease the emotional response to the device. Currently participants felt that the device was more fun and
enjoyable to use however with a longer period of usage there is a possibility that when usage becomes mundane this response would decline.

9.4. RESPONSE TO THE RESEARCH QUESTION

Utilising the design of a tactile navigation aid as a case study the research question driving this thesis was:

*How might the employment of theories of resonance and extraordinary users in the collaborative design process result in better design outputs?*

In the literature review and discussion sections of this thesis a variety of themes were deliberated that impact on the usability and functionality of products and specifically navigation systems. This section summarises how the Touchstone product, developed with resonance in mind and with the input of extra-ordinary users, responds to the key themes throughout the literature.

9.4.1. Ordinary Users in Extraordinary Contexts

The theory of design resonance proposes that the needs of the extraordinary regularly resonate with the needs of the ordinary in extraordinary contexts (Pullin and Newell, 2010). This work provides evidence of this theory by resulting in a design output that betters existing navigation aids in two extraordinary contexts. The first extraordinary context is that of navigating at night time, where Touchstone was perceived to be more discrete which would make the user feel less vulnerable whilst alone at night. The second was that of leisurely walking where the device was perceived to be more fun than traditional aids and to allow the user to engage more with their surroundings.
9.4.2. Usability for Mainstream Audience

A primary concern of participatory design with people with disabilities is that the resulting design would be too functionally focussed and would not be desirable or would have reduced usability for mainstream audiences (Ulwick, 2002, Schluza, 2013, Pullin and Newell, 2007). Common solutions within the literature detailed cumbersome belts and torso harnesses, whereas the product devised by extraordinary users provided a device which utilised existing technology and fit easily into a user’s handbag. Mainstream audience considered the device desirable and many commented that they would prefer it over other proposed ‘wearable’ solutions.

9.4.3. Cognitive Load and Engagement

Many researchers argue that, particularly visual, engagement with mobile devices will result in cognitive overload. This cognitive overload results in negative pedestrian behaviours which can be both socially restrictive and dangerous (Neider, et al., 2010; Schwebel, et al., 2012; Hyman, et al., 2010; Nasar, et al., 2008). To assess cognitive load, the study asked participants to engage with their surroundings both visually and through conversation with the study facilitator whilst navigating. Contrary to the research argument the quantitative metrics indicated no enhanced ability to engage with surroundings when using the tactile device. However, when assessing the qualitative metrics participants indicated that they felt that they could visually engage with their surroundings more effectively. It is theorised that the quantitative results were affected by the demands of the context as the task set did not require significant engagement with surroundings and thus this metric will need to be reassessed for future study in the area.
9.4.4. **Prior Experience**

Prior Experience is a primary contributor to a product’s usability and functional performance (Blackler, et al., 2009; Langdon, et al., 2010; Hurtienne, et al., 2013). Touchstone was completely novel meaning that no participant had experience with this type of product and yet it showed functional equivalency to both the visual and audio navigation aid with a minimum amount of learning time. This indicates that the tactile command system designed by the extra-ordinary users was intuitive. And when compared to the most similar study (Pielot and Boll, 2010), in which the tactile device did not perform at a functionally equivalent level to the visual device, it implies that the engagement of people with visual impairments as design informants was beneficial as it was their expertise in tactile navigation which specified the simplicity of the tactons.

9.4.5. **Pleasure of Use**

Overbeeke, et al. (2004) proposed that products with a heavy reliance on cognitive ability result in a reduction in pleasure derived from use. When assessing the qualitative data captured in the comparative study the tangibility of Touchstone showed increased pleasure of use by appealing to three of Jordan’s (2000) “four pleasures”: physio-pleasure, socio-pleasure and psycho-pleasure. This was backed up by participants considering the tactile device significantly ‘more fun’ than the traditional visual aid.

9.4.6. **Summary**

The employment of theories of resonance and extra-ordinary users in the collaborative design process of a tactile navigation aid resulted in a variety of areas of enhanced performance against traditional navigation aids when assessed against key research
discussion points. Whilst overall Touchstone did not functionally outperform the visual and audio counterparts it showed functional equivalence with a bare minimum learning time and a large amount of positive feedback from qualitative data.

The research project informs future practice by providing both:

- examples and recommendations on how people with visual impairments may be employed with a traditionally very visual design process
- specifications drawn from people with visual impairments for the design of better tactile navigation aids

The project augments and raises further debate within the discipline of user-centred design, the research project demonstrates that people outside traditional product users could add value to the design process. At the beginning of the literature review it is discussed that Clarkson, et al. (2007) recommends that an iterative development/feedback process with both users and experts will produce more usable products. This work augments that by demonstrating that the, currently undefined, “experts” may be extraordinary users, evidencing the theory that has previously been discussed by Pullin and Newell (2007).
10. CONCLUSION

10.1. THESIS SUMMARY

Resonance is the correlation of needs between extra-ordinary users and ordinary users in extra-ordinary situations. During the literature review a resonance was identified between people with visual impairments, and people without impairment whilst walking. In that, people with visual impairments cannot visually engage with mobile devices, and, pedestrians without impairment should not visually engage with devices as it causes dangerous and anti-social pedestrian behaviours. It was suggested that designing specifically for extra-ordinary users may uncover innovations for ordinary users in extraordinary situations, thus the following objectives were laid out:

1. Research and design a tactile PND with people with visual impairments acting as design informants
2. Explore and document ways to work with people with visual impairment, within a participatory design process for a PND.
3. Assess the output of this process, a tactile PND, in order to identify any benefits against traditional navigation aids.

In order to provide a response to the research question:

*How might the employment of theories of resonance and extraordinary users in the collaborative design process result in better design outputs?*

The research approach used a double-phase approach with the first phase centred on the design process and took a practice-led approach using a participatory design strategy.
During this process, alongside the documentation of input from visual impaired users, reflective practice was used to analyse the methods and their success. The second phase focussed on investigating the output of this process and took the form of a comparative study to empirically assess the value added by the novel device to the ordinary user.

10.2. MAIN FINDINGS

10.2.1. The Value of Working with Extra-Ordinary People

The main findings of the work show that working with extra-ordinary users in scenarios where resonance has been identified does bring additional benefit to the design in the form of deeper insights into: current solutions and approaches, physical product form for non-visual interfaces, valued navigation commands and communication methods, and, practicalities of non-visual product usage and navigation. Cumulatively this was evidenced by the resulting product which was distinctly different to other tactile navigation aids seen in academia, not constrained within existing technology nor too conceptual for practical usage; and when tested this product performed well against commercially available competitors.

10.2.2. User Centred ‘UCD’ Methods

The methods used to engage the participants in a traditionally visual process were not straight forward. A selection of recommendations are made and documented in chapter 9.1.3 intended to be utilised by researchers new to the area when planning their research studies. The most significant of which is that when deciding which design methods to utilise a user centred approach should be taken. Rather than amending visual tasks to be accessible, focus on creating tasks centred around the participants’ abilities and strengths.
10.2.3. Tactile for Mundane Commands
On testing the output of the process the device performed well against two commercially available, modality specific (one audio, one visual) counterparts. By providing an in-situ, three-way comparative study the work extended the knowledge around tactile navigation aids. The results did not support many of the common claims of the benefits of tactile navigation. However, it provided an argument for the use of tactons, rather than audio, for mundane navigation tasks when visual engagement is not appropriate.

10.2.4. Support for Resonance
The empirical findings also validate the theory of resonance in that, whilst not a replacement for standard methods of navigation for people without impairments, the tactile navigation aid did demonstrate qualities which would add value for ordinary users in extra-ordinary scenarios, namely, in situations where the user may feel vulnerable such as walking at night, and, in leisure scenarios where the need to get from A to B is not urgent and the user wishes to engage with a more pleasurable method of navigation.

10.2.5. Emotional Response
The tactile aid provoked an emotional response which was not replicated in the visual or audio conditions. The device engaged the user in a way that was complex enough to be entertaining and at the same time they perceived the device to be unobtrusive to their context. Whilst the functional results of the device saw no difference between the ability to allow the user a greater engagement in their surroundings, this perceived ability enhanced the users’ positive response to the product. By engaging a different sense, the device appealed to the users’ sense of intrigue, and through the utilisation of tactons
provided a sense of challenge, thus making (the previously mentioned) mundane commands seem exciting and game-like. This could be utilised as a method to overcome the growing stigma around technology use by providing an interface that not only recognises and respects the context of use but stimulates the user as opposed to simply drip-feeding information.

10.3. RESEARCH SIGNIFICANCE

The research shows practical significance for researchers working with people with visual impairments, providing a method story and thus knowledge base to help improve engagement and output when undertaking participatory design. Also, for HCI researchers working in the field of tactile navigation it furthers knowledge around how tactility may best be utilised to make product experiences more pleasurable.

Finally, the work is significant as it highlights the artificial boundaries that many designers create around people with usage requirements that fall outside of the mainstream population by creating ‘access’ products which do not engage the larger population. For users who may be marginalised this work shows that their unique perspective and interaction styles can lead to innovative and desirable design, moving us away from add-on accessibility and into a realm of novel interfaces and practical solutions to everyday problems, for everybody.

From the margins to the mainstream

ROGER COLEMAN, 2003
10.4. CONTRIBUTION TO KNOWLEDGE

The research responded to the research question:

“How might the employment of theories of resonance and extraordinary users in the collaborative design process result in better design outputs?“.

It contributed to knowledge by:

1. Providing more evidence that working with people with visual impairments can produce benefits for all users by providing empirical evidence that supports the theory of resonance.

2. Making a series of recommendations for future researchers and design practitioners who plan to design collaboratively with people with visual impairments.

3. Demonstrating that tactile interaction enhances navigation devices for all users when used for mundane navigation commands when compared to both audio and visual. Improvements include:
   a. Pleasure of use
   b. Social perceptions of use
   c. Suitability for particular contexts:
      i. Leisure, or non-urgent usage
      ii. Scenarios in which the user wishes to remain inconspicuous
10.5. FUTURE WORK

Suggestions for future work include:

10.5.1. Further Method Stories

Some of the work in this thesis has already been disseminated to the greater design community through two conference papers published as book chapters (Andrews, 2014(a); Andrews, 2014(b)). It is hoped that these resources will be utilised by new researchers as currently there are very few resources available to advise them on how to engage and involve users who have a very different way of interacting with the world compared to themselves. There is still much more scope for research to be conducted in this area to document methods, their creation and the success particularly for people with sensory impairments. Many of the methods trialled were not particularly successful and the next logical step in this work is to go back and make adjustments to those methods in an attempt to improve the success rate, or even to undertake a study around the design of design methods with people with visual impairments. As mentioned in the discussion, Hendriks et al. (2015) call for “method stories” which discuss these issues in depth and it is with these shared experiences that design practice should move forwards.

A recommendation for further study would be with design informants with different classifications of ability, the current study focussed on people with visual impairments and how they could augment the design process, it would be of interest to understand how engagement with people with different types of impairments and thus, approaches to the world, would impact the outcome. This would be useful knowledge with the user-centred design discipline as it would allow designers to understand which the distinct functional and usability benefits that particular extra-ordinary users may add to their project.
10.5.2. The effect of learning style and representation of navigational information

In the preliminary questionnaires some participants cited ‘learning style’ as reason for their preferred condition. On a very brief literature search around the subject there appears to be little data concerning learning style and navigational preferences. In the case of tactility, this has particular interest, as whilst tactile navigation could be applied to Kinesthetic learning styles (Barbe, et al., 1979), on further consideration, it is more likely to fall into the domain of Auditory learners as the method is primarily based on rhythm and ‘listening’ to tactile commands as opposed to gestures and body movements.

A suggestion for future study is how learning styles impact on the preferred representation of navigation information, in other words which form of wayfinding commands, either: declarative, route based or configurational, survey based are most applicable for which type of learning style. This would be useful knowledge in the development of navigational aids which are better suited to the user and thus more functionally appropriate and safer to use.

10.5.3. Multimodal Navigation Devices

It is unlikely that many navigational contexts would require a single specific modality. Merging the benefits of all three modalities would likely produce an excellent final product. This relates back to Pullin and Newell’s (2007) original suggestion concerning the use of extra-ordinary users, in that after the specifications have been drawn, work can then be conducted in order to make the device more applicable to mainstream use requirements.

When creating the specifications for the tactile device with extra-ordinary users it was suggested that audio be utilised for landmark (declarative) knowledge similar to the notifications on existing navigation aids (Chapter 7.2). Throughout the comparative study
(Chapter 8: Phase 2 Design Evaluation) participants noted that they missed the survey representation (configurational) of navigation knowledge but that the route representation (procedural) allowed them to disengage with the device when no imminent action was required. This suggests that a combination of the three knowledge types required for wayfinding could be presented cross-modality.

A study of the efficacy and usability of this cross-modal device would further literature around the most effective means of communicating wayfinding information.
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## 12. APPENDICES

### I. Thesis Structure (Detailed)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Aim</th>
<th>Chapter</th>
<th>Design Output</th>
<th>Research Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Focus Groups</strong></td>
<td>To generate a greater understanding of the subject area and the users</td>
<td>Initial focus groups 3</td>
<td>Initial opinions on the original concept. Background knowledge on users view of subject area (navigation / electronic products / design)</td>
<td>Study Background</td>
</tr>
<tr>
<td><strong>Phase 1 A Generative research</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moodboarding / Freelisting</td>
<td>To generate a selection of products to act as design inspiration for the designer.</td>
<td>Generative Research 6.3.1</td>
<td>A selection of products that the design could use as inspiration</td>
<td></td>
</tr>
<tr>
<td>Storytelling</td>
<td>To aid the understanding of the types of navigational cues required for people with visual impairment</td>
<td>Generative Research 6.3.2</td>
<td>Stories detailing the types of navigation cues required for people with visual impairment.</td>
<td>Participatory Design techniques with people with visual impairment.</td>
</tr>
<tr>
<td>Card Sorting</td>
<td>To prioritize features and functions for the new device</td>
<td>Generative Research 6.3.3</td>
<td>Priority order lists for product features</td>
<td>Reflection on the success of method and suggestions for future use.</td>
</tr>
<tr>
<td>Existing Product Feedback</td>
<td>Gather feedback on existing products in order to identify features which aid access for people with visual impairment</td>
<td>Generative Research 6.3.4</td>
<td>A greater understanding of the liked and disliked features of small electronic products.</td>
<td></td>
</tr>
<tr>
<td>Modelling</td>
<td>To add detail to preconceived forms for design development and to identify preferred forms</td>
<td>Generative Research 6.3.5</td>
<td>Form preferences. A list of expected features. Placement of expected features on form</td>
<td></td>
</tr>
<tr>
<td><strong>Chapter 7: Phase 1 B: Design Development</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contextual Inquiry</td>
<td>To observe and uncover issues and strategies associated with current navigation devices for people with visual impairment.</td>
<td>Design Development 7.3</td>
<td>Identification of issues concerning non-visual navigation. Identification of key features of competitor product.</td>
<td>Reflection on application of findings for broader use</td>
</tr>
</tbody>
</table>
II. Plan sheets for initial focus groups

**ACTION FOR BLIND PEOPLE**

**FIRST SESSION - NAVIGATION**

- How often do you go somewhere new?
  - Process
    - What resources would you need?
• What would you avoid?
• How does it make you feel?
• Would you talk to anyone?
  • What would you ask?
  • How would you want them to answer?
• What sort of directions would you want?
  • Cognitive maps
  • Distance walked
  • Internal Compass
  • Landmarks
• How does this make you feel? Confidence?
• What would you do if you got lost?
• What is the biggest barrier?
  o Personal?
  o Physical?
• What enablers are there?
  o Cane
    • How does this increase your confidence levels?
    • What do you like about it?
    • What don’t you like about it?
    • What preparations do you do before you go out?
  o Dog
    • How does this increase you confidence levels?
    • What do you like about it?
    • What don’t you like about it?
    • What preparations do you do before you go out?
  o Other people
    • Would you ask a friend?
    • What can a person do to aid you?
    • What do you like about it?
    • What don’t you like about it?
  o Other GPS systems?
    • Which have you used?
    • What do you like about it?
    • What don’t you like about it?
    • What preparations do you do before you go out?
  o Other?
  o What is your favourite?
• Exploration?
  o Do you ever go out with no plans?
  o Would you?
  o Why/why not?
SECOND SESSION - PRODUCT

- What electrical products do you enjoy using? And why?
  - Tactile – materials, textures etc...
  - Button size – shape, braile etc...
  - Simplicity – button amounts, intuitive use etc...
  - Visibility – colours, text etc...
  - Shape – size, intuitive etc...
  - Overall look – in/conspicuous? Contemporary? Other products?
  - More?

From this create a list of ‘dos’ for a product. (List 1)

- What would make the very best GPS system

From this create a list of “do nots” for a product. (List 2)

  - What would make the worst GPS

- Have you tried any other GPS systems?
  - Good features?
  - Bad features?

In regards to Peepo models...

- List key features
  - Where would you expect to find...?
  - How does this compare to reality?
- How do they compare to list 1?
- How do they compare to list 2?
- What you change?
- What would you keep?
- Grip?

ROYAL NATIONAL COLLEGE FOR THE BLIND

FIRST SESSION

- What types of products do you use?
  - Reason for buying
  - Investigation of apple

- Touch screen or tactile buttons
  - Keypad type with touchscreen
• Impact of:
  o Brand
  o Looks

• Mobile on the move?
  o Use of headsets

• Any navigation aids?
• App or a dedicated product?
• Possibility of tactile.

SECOND SESSION (only one hour)

• Overview of previous session

• Discussion on audio feedback
  o Preference on tactile or voice recognition

• How do they feel about GPS in general?
  o Investigation of current GPS systems
  o Wearables?
  o Perfect GPS device – go round in a circle and say something they would want.
Title of Project: Developing a handheld navigational product for the blind and visually impaired

Peepo GPS are currently running research focus groups and observational studies to aid the development of a new product, a handheld GPS system for the blind or visually impaired. We are recruiting a variety of people with a range of visual impairments to gather well-rounded views and opinions.

- This is an invitation to you to join the study, and to let you know what this would involve. The study is being organised by Claire Andrews who is a Peepo GPS employee and research student at the University of Wales Institute Cardiff (UWIC).
- By the end of this preliminary stage of the project we intend to have a better understanding of the user needs associated with a product of this type. There is also the possibility using the results in future journal reports.
- The study is being funded by Peepo GPS.
- If you want to find out more about the project, or if you need more information to help you make a decision about joining in, please contact Claire on the telephone numbers given at the bottom of this sheet, or email us.

Your Participation in the Research Project

Why you have been asked

We are recruiting blind and visually impaired people around the country to aid us in our research. ‘XXX’ are aiding us in our recruitment and have indentified you as a potential candidate.

There is absolutely no obligation of any kind to join the study, no reasons have to be given and there will be absolutely no repercussions or discrimination from Peepo GPS if you do not wish to join the study.

What happens if you want to change your mind?

If you decide to join the study you can change your mind and stop at any time. We will completely respect your decision. If you want to stop it would help us if you could let us know (you could send us a note from the attached form, or telephone us) and it will save us bothering you with unnecessary telephone calls, however, if you do not wish to give a reason this is also fine. There are absolutely no penalties for stopping.

What would happen if you join the study?

Focus groups will entail questions and discussion around navigation and the design of hand held products. The groups may involve team discussion, word games and studying examples of current products.
Each group will have no more than 8 participants and will be no more than 1 ½ hours in length. Multiple focus groups will be needed throughout the project so it is highly likely that you will be invited to several gatherings, however, if you cannot or do not wish to attend any of the groups this is no problem, the groups are completely voluntary.

Are there any risks?

We do not think there are any significant risks due to the study. If you were to feel uncomfortable at any point you are completely free to raise the issue or pull out with no negative repercussions.

Your rights.

Joining the study does not mean you have to give up any legal rights. In the very unlikely event of something going wrong, the UWIC fully indemnifies its staff, and participants are covered by its insurance.

Any special precautions needed?

We are asking participants not to drink any alcohol on the morning when they are being interviewed, as this could interfere with the results and spoil their contribution.

What happens to the results?

Video and audio recordings of the research will be studied and transcribed. We will then look for reoccurring themes, values and views. This information will aid us in developing a specification for a handheld navigational aid which takes into account the final user!

Are there any benefits from taking part?

There are no direct benefits to you for taking part; however this study will help develop a product which will aid navigation with a more effective, ‘user based’ solution than any existing products on the market. When the study is complete we will keep you up-to-date with further developments of the product.

How we protect your privacy:

Your name, address and any other personal details will be kept separately from any other documented research and we will take steps to ensure that no one can identify you from the research findings.

Once we have finished the study we will destroy all of the audio and visual recordings of the studies that may indentify you. And any transcription will be coded and kept completely separately from your personal details.
We keep a copy of your name and address along with your consent form for 5 years as we are required to do so by UWIC and also it will aid us in contacting you for future focus groups if you agree to allow us to do so.

**PLEASE NOTE:** *YOU WILL BE GIVEN A COPY OF THIS SHEET TO KEEP, TOGETHER WITH A COPY OF YOUR CONSENT FORM*

Contact Details:

Claire Andrews

Tel: 07780612837
Email: c.andrews@uwic.ac.uk
IV Participant consent form - generic

Participant name or Study ID Number:
Title of Project: Developing a handheld navigational product for the blind and visually impaired
Name of Researcher: Claire Andrews

Participant to complete this section: Please initial each box.

1. I confirm that I have read and understand the information sheet for the above study, I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.

3. I agree to take part in the above study.

4. I agree to the interview / focus group / consultation being audio recorded

5. I agree to the interview / focus group / consultation being video recorded

6. I agree to the use of anonymised quotes in publications

_________________________    __________________________
Signature of Participant            Date

_________________________    __________________________
Name of person taking consent            Date

_________________________
Signature of person taking consent
V       Freelist Responses

PA4 - Old style nokia – good keypad
PA3 - Nokia 5510 – good layout and clear buttons
PA1 - “old square” ericsson phones – really clear and rubbery
PA4 - i-phone – beautiful and a touchscreen
PA5 - iphone – accessability
PA5 - Creative mp3 – small and rounded (and easy to use)
PA2 - HTC – nice shape and rubber back
PA3 - Nokia – rubber phones
PA1 - Trekker – rubber buttons, feel difference
PA4 - Trekker – layout is different but good
PA4 - Booksense – up down buttons
PA2 - Trekker – deep buttons
PA3 - Milestone – clear buttons, large and round
PA5 - Sky digital remote – everything surrounds the select button
PA3 - Anything without a USB – can’t work out which way
PA1 - Prompted pin chargers – can go in anyway
PA2 - Sliding keypad locks – you can tell whether it’s locked (don’t feel silly pressing buttons)
PA5 - Dials – can feel it’s different to other buttons
PA4 - Dial – quick to change

VI.    Vibration and pin array options
VII. Code for Arduino

(presented in two columns)

#include <MeetAndroid.h>

MeetAndroid meetAndroid;

const int vibpinL = 4;
const int vibpinC = 5;
const int vibpinR = 6;

void setup()
{
    Serial.begin(57600);
    meetAndroid.registerFunction(doProfile, 'A');

    pinMode(vibpinL, OUTPUT);
    pinMode(vibpinC, OUTPUT);
    pinMode(vibpinR, OUTPUT);
}

void loop()
{
    meetAndroid.receive();
}

void doProfile(byte flag, byte numOfValues)
{
    if (numOfValues > 0){
        int patternCode = meetAndroid.getInt();
        switch (patternCode){
            case 1:
                //walk forwards
                digitalWrite(vibpinC, HIGH);
                delay (1500);
                digitalWrite(vibpinC, LOW);
                break;
            case 2:
                //prepare to turn right
                digitalWrite(vibpinR, HIGH);
                delay (500);
                digitalWrite(vibpinR, LOW);
                digitalWrite(vibpinC, HIGH);
                delay (1500);
                digitalWrite(vibpinC, LOW);
                break;
            case 3:
                //prepare to turn left
                digitalWrite(vibpinL, HIGH);
                delay (500);
                digitalWrite(vibpinL, LOW);
                digitalWrite(vibpinC, HIGH);
                delay (1500);
                digitalWrite(vibpinC, LOW);
                break;
            case 4:
                //bear right
                digitalWrite(vibpinC, HIGH);
                digitalWrite(vibpinR, HIGH);
                delay (1500);
                digitalWrite(vibpinR, LOW);
                break;
            default:
                break;
        }
    }
}
digitalWrite(vibpinR, LOW);
delay (1500);
break;
case 5:
    //bear left
    digitalWrite(vibpinC, HIGH);
digitalWrite(vibpinL, HIGH);
delay (1500);
digitalWrite(vibpinC, LOW);
digitalWrite(vibpinL, LOW);
delay (1500);
break;
case 6:
    //turn right
    digitalWrite(vibpinR, HIGH);
delay (1500);
digitalWrite(vibpinR, LOW);
break;
case 7:
    //turn left
    digitalWrite(vibpinL, HIGH);
delay (1500);
digitalWrite(vibpinL, LOW);
break;
case 8:
    //turn around
    digitalWrite(vibpinL, HIGH);
delay (1500);
digitalWrite(vibpinR, HIGH);
delay (1500);
digitalWrite(vibpinL, LOW);
digitalWrite(vibpinR, LOW);
delay (500);
digitalWrite(vibpinL, HIGH);
delay (1500);
digitalWrite(vibpinR, HIGH);
delay (1500);
digitalWrite(vibpinL, LOW);
digitalWrite(vibpinR, LOW);
break;
case 9:
    //arrived
    digitalWrite(vibpinC, HIGH);
delay (250);
digitalWrite(vibpinC, LOW);
delay (250);
digitalWrite(vibpinC, HIGH);
delay (250);
digitalWrite(vibpinC, LOW);
delay (250);
digitalWrite(vibpinC, HIGH);
delay (250);
digitalWrite(vibpinC, LOW);
break;
case 10:
    //warning
    digitalWrite(vibpinC, HIGH);
delay (5000);
digitalWrite(vibpinC, LOW);
break;
}
}
delay(200);
Serial.flush(); //this is where i need a flush code
}
VIII. Pre-task questionnaire – comparative study

Personal Data

The following questions help us understand if the results vary across different demographics.

Please circle appropriate…

Sex:
Male  |  Female

Age:
18-25  |  26-35  |  36-45  |  46-55  |  56-64  |  65-74  | 75+

How is your eyesight, if you wear glasses please consider you eyesight in your current condition (wearing them now/not wearing them now)?
Good | OK | Poor

How is your hearing, if you wear an aid please consider your hearing in your current condition (wearing it now/not wearing it now)?
Good | OK | Poor

On a scale of 1-5 how well do you understand English? (1 being fluently – 5 not at all)
(Fluent) 1  |  2  |  3  |  4  |  5 (not at all)
How well do you know the St Fagans museum area?
Well | A bit | Not at all

**Walking Preferences**

*The following questions allow us to understand your preferences when walking to a new place.*

Which type of aid would you prefer for these journey lengths where the goal is just to get from A-B?

<table>
<thead>
<tr>
<th>Journey Length</th>
<th>A verbal description</th>
<th>A written description</th>
<th>A paper map</th>
<th>An electronic aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2 minutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Around 5 minutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Around 10 minutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 minutes +</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Which type of aid would you prefer for these journey lengths where the walk is leisurely?

<table>
<thead>
<tr>
<th>Journey Length</th>
<th>A verbal description</th>
<th>A written description</th>
<th>A paper map</th>
<th>An electronic aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2 minutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Around 5 minutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Around 10 minutes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 minutes +</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

We are testing three separate electronic travel aids to compare. The journey length is approximately 5 minutes. One gives you commands verbally, one visually and the other through vibration. The aid you will be trying will be chosen at random.

Which do you expect will be more effective?
Visual | Verbal | Vibration

Which do you expect will be more enjoyable?
If you were able to choose which would you choose?

Visual | Verbal | Vibration

Why?

IX. Post-task questionnaire – comparative study

Visual | Audio | Vibration

Post Test Questionnaire

Please rate the following statements:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Completely agree</th>
<th>mostly agree</th>
<th>neither agree nor disagree</th>
<th>mostly disagree</th>
<th>Completely disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>The system was easy to use</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The system was fun to use</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The directions were easy to understand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I could take in my surroundings whilst I walked</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I got confused by which direction I was supposed to head</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I was regularly worried I was walking in the wrong direction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I remember the route I walked</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I had trouble talking whilst navigating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would be happy to use this style of device whilst walking alone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Statement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------------------------</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>I would be happy to use this style of device whilst walking with friends</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would use this device in a crowded area</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would use this device to get me from A to B quickly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would use this device to get me from A to B when walking for pleasure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The device performed as well as I expected it to</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please look at the picture on the screen.

Did you see these junctions and if so which way did you turn?
I didn’t see this junction
I saw this junction but I don’t remember which way I turned
Left | Right

I didn’t see this junction
I saw this junction but I don’t remember which way I turned
I turned
I didn’t see this junction
I saw this junction but I don’t remember which way I turned
Straight on | Right
I didn’t see this junction

I saw this junction but I don’t remember which way I turned

Left | Right

What was the best element about the device?

What was the worst element about the device?

Can you think of a scenario in which you’d use this system?
X. Information sheet – comparative study

Title of Project: Developing a handheld navigational product for the blind and visually impaired

Claire Andrews is currently conducting research to aid the development of a new product, a handheld GPS system accessible by blind and visually impaired people. We are recruiting a variety of people to test and optimize the innovative tactile navigation system.

- This is an invitation to you to join the study, and to let you know what this would involve. The study is being organised by Claire Andrews who is a Peepo GPS employee and research student at the Cardiff Metropolitan University (Cardiff Met.).

- By the end of this stage of the project we intend to have a better understanding of the design specification for a navigation device for the blind or visually impaired

- If you want to find out more about the project, or if you need more information to help you make a decision about joining in, please contact Claire on the telephone number given at the bottom of this sheet, or email us.

Your Participation in the Research Project

Why you have been asked

We are recruiting a variety of people, sighted, blind and visually impaired people to participate in our research to aid the development of a tactile pedestrian navigation system.

There is absolutely no obligation of any kind to join the study, no reasons have to be given and there will be absolutely no repercussions or discrimination from Peepo GPS if you do not wish to join the study.

What would happen if you join the study?

If you decide to participate in the study you will be asked to complete various navigational tasks using a navigational device to guide you. You may try a variety of different feedback styles and different prototypes and report back on what was most easy to understand directional information and which you preferred.

Each walking exercise should take between 5 and 10 minutes then there will be a short discussion which asks you to rate the system afterwards. You may be asked to partake in more than one exercise dependant on time, weather and comfort.

Notes will be taken whilst you complete the task and you may be video recorded.

What happens if you want to change your mind?

If you decide to join the study you can change your mind and stop at any time. We will completely respect your decision. If you want to leave the study it would help us if you could let us know (through email, writing or direct verbal communication with Claire Andrews); however, if you do not wish to give a reason this is also fine. There are absolutely no penalties for stopping.
Are there any risks?

We do not think there are any significant risks due to the study. Care has been taken to make sure the routes chosen are safe. If you currently use any walking aid you are more than welcome to use this in the task.

Any special precautions needed?

We are asking participants not to drink any alcohol on the morning of the study.

What happens to the results?

Any video and audio recordings of the research will be studied and transcribed. We will then look for reoccurring themes, values and views. This information will aid us in optimizing the innovative tactile navigation system. Once all the information has been documented we will destroy the recordings.

Are there any benefits from taking part?

There are no direct benefits to you for taking part; however this study will help develop a product which will aid navigation with a more effective, ‘user based’ solution than any existing products on the market.

How we protect your privacy:

No personal details are required to be gathered for this study.

Your consent form will be kept for 5 years as we are required to do so by Cardiff Met. and also it will aid us in contacting you for future product development purposes if you agree to allow us to do so.

PLEASE NOTE: YOU WILL BE GIVEN A COPY OF THIS SHEET TO KEEP, TOGETHER WITH A COPY OF YOUR CONSENT FORM

Contact Details:

Claire Andrews

Tel: 07780612837
Email: clandrews@CardiffMet.ac.uk
XI. Consent form – comparative study

Participant name or Study ID Number:
Title of Project: Developing a handheld navigational product for the blind and visually impaired
Name of Researcher: Claire Andrews

Participant to complete this section: Please initial each box.

1. I confirm that I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.

3. I agree to take part in the above study.

4. I agree to the interview / focus group / consultation being audio recorded

5. I agree to the interview / focus group / consultation being video recorded

6. I agree to the use of anonymised quotes in publications

Signature of Participant Date

Name of person taking consent Date

Signature of person taking consent
### XII. Questionnaire for pilot study

<table>
<thead>
<tr>
<th>Visual System</th>
<th>Agree</th>
<th>Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>This system was simple to use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>This system was enjoyable to use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I regularly had to check I was making the right choices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The system was annoying</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sometimes I was worried I had made a navigation error</td>
<td></td>
<td></td>
</tr>
<tr>
<td>It was easy to confirm I was walking in the right direction</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vibration System</th>
<th>Agree</th>
<th>Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>This system was simple to use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>This system was enjoyable to use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I regularly had to check I was making the right choices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The system was annoying</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sometimes I was worried I had made a navigation error</td>
<td></td>
<td></td>
</tr>
<tr>
<td>It was easy to confirm I was walking in the right direction</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The best feature of the visual system was...

The best feature of the vibration system was...

The worst feature of the visual system was...
The worst feature of the vibration system was...

Can you think of a scenario in which you would rather use....

Visual?

Vibration?

Please mark how useful you found the vibration commands (if you did not receive a command please leave it blank)

<table>
<thead>
<tr>
<th>Command</th>
<th>Confusing</th>
<th>Not useful at all</th>
<th>Occasionally useful</th>
<th>Useful</th>
<th>Very useful</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bear</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prepare to turn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turn around</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arrived</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Any further comments please write here...
XIII. Published papers
