The tactile sense as a mechanism for the reduction of visual load elicited by control interactions: An automotive case study approach to the development of generic design recommendations

by

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A Doctoral Thesis

Submitted in partial fulfilment of the requirements

for the award of

Doctor of Philosophy

of Loughborough University

June 2010

Abstract

This thesis examines the potential for using tactile feedback to reduce the visual load that can be associated with interacting with controls. Using the automotive context as a case study, the thesis describes the process followed in the design of a prototype tactile interface (PTI) for the control of in-car secondary functionality (navigation, entertainment and climate control). There have been many examples of the use of active and passive tactile feedback to provide information to visually impaired people. There is however a paucity of previous research into the field of tactile feedback in mainstream product design. A literature review was performed examining various issues that are associated with tactile design including cognitive processing of tactile inputs, the use of tactile feedback in products used by visually impaired people and standard control design recommendations. This was followed by the generation of initial concepts and the first study, which examined how visually impaired people interact with electronic products that are unfamiliar to them, and also examined how they used their own equipment. The results from this study, and the literature review findings were combined into a series of design recommendations for the production of tactile interfaces that aim to reduce the visual load on the driver. These design recommendations were the basis for an iterative design process that resulted in the first, non functioning PTI interface model. The first PTI was constructed using rapid prototype technologies.

The first iteration PTI was examined in the second study, a user trial in a driving simulator. The study produced encouraging results with a >90% success rate for correct control selection without vision, whilst performing a driving task. The results from this study were used to refine the design of the PTI and a working, hi-fidelity prototype was constructed for use in the final study. This study involved 'on the road' user trials comparing the glance durations made to the PTI and to a baseline system using a 'repeated measures' structure. The data from these user trials were examined to determine if the PTI exhibited a reduced visual load when compared to the baseline system. The results showed the PTI fostered significantly reduced summed glance durations for 7 of the 11 tasks performed when compared to the baseline system. Three of the 11 tasks that were performed in the study produced a reduction of summed glance duration of >50%. The PTI was also shown to foster non-visual interaction, with all participants performing at least one control interaction without looking at the control arrays. The tactile coding and symbolic layout of the PTI have been shown to be beneficial in terms of reducing 'eyes off road time' and therefore reducing the risk of distraction related accidents.

A review of the results from the three studies described in this thesis has enabled the development of generic design guidelines for the production of tactile interfaces where a reduction in visual load is required for the safety of the operator.

The thesis has made a contribution to the understanding of the use of the tactile sense during product interactions, and highlighting the benefits as well as the limitations of the tactile sense as a feedback mechanism.

Acknowledgements

I would like to thank the following people for their valuable assistance during the period that I have been occupied with the production of this thesis:

- Firstly, my long suffering partner who has been a constant source of support during the past few years. Laura, we can finally go to the zoo.

- In addition I would like to acknowledge the late Prof. J. Mark Porter. He was a true gentleman and an inspiration in my professional and personal life. Mark is greatly missed.

- And finally, my supervisor, Dr. Russell Marshall, who has proved more than ever that he has the patience of saint. Thanks Russ.

Contents

List of Figures

1 Chapter 1: Background, aims and objectives

1.1 Introduction

This thesis concerns the design of interfaces that reduce the need for vision for control interactions through the mechanism of the tactile sense. A case study example is used that involves the design and build of a Prototype tactile Interface (PTI) for use in the automotive environment.

Driving a road vehicle is a task that requires a high level of visual attention to the road ahead, enabling the driver to determine the proximity of other vehicles and other hazards. Secondary in-car functions such as In-Car Entertainment (ICE) and Heating Ventilation and Air Conditioning (HVAC) have traditionally been controlled using switches, sliders and rotary knobs. The operation of these controls diverts the attention of the driver away from the road ahead during control interactions. The advent of satellite navigation systems (SATNAV), in the automotive environment has provided an alternative control methodology to car designers.

In addition the inclusion of a computer and the associated screen that are used to display maps and direction of turn information for the SATNAV system, gives the option to control other secondary functions associated with ICE and HVAC within a graphical user interface (GUI) with interaction provided through touch screens or joysticks. This reduces the number of physical controls in the interface. This option has been taken by a number of automotive manufacturers, presumably to reduce the cost associated with adding buttons to a dash board and to improve aesthetics. Research has shown that these systems can further divert the attention of the driver away from the road when compared to the operation of traditional physical controls. An example of the reduction of the number of physical controls can be seen in Figures 1.1 and 1.2. These figures show the interior of the BWM 5 series vehicle in the 1996 and 2009 models. The 1996 model has 37 physical controls on the dash board, controlling approximately 37 functions. The 2009 model has 21 physical controls and the ability to control over 700 functions through the GUI and haptic (active force feedback) rotary controller combination. The use of GUI based interaction inherently requires the driver to look at the screen, distracting the driver from looking at the road ahead and raising potential safety concerns.

Figure 1.1 1996 BWM 5 series (37 controls on dashboard)

Figure 1.2 2009 BWM 5 series (21 controls on the dashboard)

These safety concerns relate to the number, and duration, of glances that are made into the car when interacting with the menu structures that are inherent in GUIs. The potential of having an accident has been shown to increase with larger glance durations away from the road, and controlling SATNAV systems whilst driving has been shown to produce relatively long glance durations when compared to the operation of other in-car secondary systems. The concern expressed by the ergonomics community has been reflected in an initiative by the International Standards Organisation (ISO 16673, 2006) to standardise the assessment of the glance durations that are elicited by SATNAV systems.

Ideally interfaces for secondary functions should minimise the number and duration of glances to reduce the risk associated with having the 'eyes off the road'. This thesis examines the potential of the tactile sense to provide state-of-the-system feedback to the user, reducing the need to use vision for control interactions. The tactile sense is currently under-used in the design of products (J.M. Porter, 2005), and has the potential to provide information to the user that does not require the use of vision. The concept of using the tactile sense to aid product interactions where vision is required for other tasks is not new. One of the first 'ergonomic' studies ever performed by Alphonse Chapanis in 1947 was the design of tactile knobs that allowed aircraft controls to be discriminated by touch alone; however, there have been no mainstream examples of the use of tactile coding to allow control discrimination since this work.

The thesis uses the design and evaluation of a Prototype Tactile Interface (PTI) for controlling secondary functions in the automotive environment as a case study. It has been suggested that there are similarities between the driver of a car, and visually impaired people, as they are both resource-limited with respect to vision (Prynne, K. 1995). This suggests that any exploration of tactile coding could be informed by observing visually impaired people as they interact with products, noting the strategies used and the tactile features that allow successful product use.

The following thesis describes a case study design process with the aim of reducing the number and duration of glances made into the car whilst performing secondary in-car tasks, through the mechanism of tactile coding. This case study also formed part of a research project called BIONIC.

The BIONIC (Blind Operation of iN of In-car Controls) project was performed at Loughborough University between 2001 and 2005. The project was set up to explore the possibility of reducing the visual load associated with interacting with secondary in-car functions such ICE, SATNAV and HVAC. The BIONIC research team consisted of four members. The author was hired as a research associate to work on the project as a designer and ergonomist whilst also registering for a part time PhD. The other team members were Prof. J. Mark Porter, a professor in design ergonomics at Loughborough University and the author's project and PhD supervisor, Dr. Gary Burnett, an expert in the assessment of in-car technology such as SATNAV systems and a lecturer in the Computing department of Nottingham University, and Katharine Prynne, an engineer working for Honda R&D in Swindon. The project was funded under the Foresight Link programme (EPSRC). The project collaborators were Honda R&D, the Honda technical development centre based in Swindon, Visteon, a third tier automotive parts manufacturer, ARRK, world leaders in the rapid prototyping and manufacturing, the RNIB (Royal National Institute for the Blind) and ESRI, the Ergonomics and Safety Research Institute based at Loughborough University. As part of the project brief Honda R&D set a bench mark of project success of a 10% reduction in the length of glance durations made when interacting with secondary functions.

1.2 The aim and objectives of the thesis

The aim of the thesis is as follows;

- To examine the potential of the tactile sense to reduce the visual load on the driver of road vehicles

The objectives of the thesis are as follows;

1. To explore the strategies used by visually impaired people when interacting with electronic products in order to examine the use of the tactile sense

2. To generate design recommendations based upon the results of this exploration and a review of the literature

3. To build a working, high fidelity prototype tactile interface that allows the user to control secondary automotive functions based upon these recommendations

4. To test this prototype tactile interface in a 'simulator study' and finally an 'on the road' study

5. To generate generic design recommendations for the production of controls and control arrays that employ tactile coding

1.3 The structure of the thesis

The thesis contains the following chapters and content.

Chapter 2. Literature review

This chapter reviews the literature examining the use of the tactile sense in control design, the opportunities and limitations of the tactile sense, and the methods used to evaluate in-car interfaces among other issues.

Chapter 3. A study examining the strategies used by visually impaired people when interacting with electronic packages.

This chapter describes a study that examines the strategies used by visually impaired people when they interact with familiar and unfamiliar electronic products.

Chapter 4. Building a design specification for the Prototype Tactile Interface based on the literature and the experience of visually impaired people

This chapter describes the combination of the recommendations from the literature and the study described in Chapter 3. This, combined with various studies and design exercises, informed the design process described in the next chapter.

Chapter 5. The design and initial testing of the prototype tactile interface

This chapter describes the design exercises that generated version 1 of the PTI, with a subsequent testing of the interface using a driving simulator. The lessons learnt from this process are described and applied to the design of the second and final PTI. This version was used in the 'on the road' user trials.

Chapter 6. Final PTI experimental trials methodology

Chapter 6 describes the methodology used to undertake 'on the road ' user trials that compared the performance of the PTI to a baseline system.

Chapter 7, Results from the analysis of the road trials data

This chapter reports the results that were produced by the 'on the road' user trials.

Chapter 8. Discussion

Chapter 8 discusses the results from the previous chapter and derives design recommendations for the generic production of tactile interfaces.

Chapter 9. Conclusions

Chapter 9 concludes the thesis, describing the contribution to knowledge.

2 Chapter 2: Literature review

2.1 Introduction

The previous chapter has introduced the concept of using the tactile sense to reduce visual demand on drivers when operating secondary in-car controls. The following review of the literature has been designed to provide baseline information for the design of interfaces that use tactile feedback to provide system state information to users. The review of the literature has been split into sections that deal with the following issues:

- The assessment of in-car interfaces
- Designing to exploit the tactile sense
- Control design recommendations
- Why use the tactile sense? Alternative options for reducing 'eyes off the road' time

2.2 The assessment of in-car interfaces

2.2.1 Background

It has been shown in a study by V.L.Neale *et al* (2005) that 93% of road vehicle crashes that occur are due to inattention to the road ahead. Distraction related accidents have been linked to the increasingly complex driving environment that prevails at the start of the 21st century. The environment external to the car has become more complex in relation to traffic density and traffic management systems, including speed cameras, which increase the workload on the driver. This workload takes the form of increased visual interaction with the speedometer and the signage indicating the current speed limit.

The internal driving environment has become more complex due to the introduction of devices such as navigation systems, mobile communications and entertainment systems. Each of these devices has the potential to increase the cognitive workload on the driver when placed in the automotive environment. This workload takes the form of a dialogue between the user and the various system input and output devices. For example a navigation system may require the user to regularly look at an image on an LCD screen that will instruct them as to which direction they should take. This kind of interaction increases the time that the user spends with the 'eyes off the road', and therefore distracts the attention of the driver away from the primary task, safe driving. The 'technology push' ideology (S. R. Chidamber, 1994) that can be found in the design of mobile phones (e.g. adding functionality such as cameras and MP3 players, increasing the perceived 'usefulness' of the device) is also evident in the design of vehicles. In-vehicle 'technology push' has taken the form of adding functionality such as Satellite Navigation systems to the automotive environment. The advent of screen based technology within the automotive environment, initially to present navigation instructions to the user, has allowed automotive manufacturers to embed other functions within a graphical user interface which replaces conventional dash mounted controls. These new in-car technologies are generally called ITS (Intelligent Transport Systems). According to Galer Flyte (1995) these systems can be sub divided into 3 main categories:

Category 1

Systems that "directly impinge on the driving task", i.e. active systems that affect the speed and direction of travel of the vehicle using sensing technologies. Examples of these systems include intelligent cruise control, which will maintain a safe distance from the vehicle in front using RADAR technology. These systems have been included in Mercedes, Audi and VW automobiles, and have been included in Ford vehicles in 2008/9 (inautonews 2008)

Category 2

Systems that "provide information relevant to components of the driving environment, the vehicle or the driver", i.e. traffic and travel information, vision enhancement e.g. night vision systems (Bellotti 2004), and route guidance/navigation systems.

Category 3

Systems that "are unrelated to driving", i.e. entertainment devices, email, and internet browsing.

These devices generally require some form of manual control from the driver, ranging from simple on/off selections, to alpha numeric data entry.

An example of the integration of computer technology into the automobile is the 2001-present Model BMW 7 Series (see Figure 2.1). The combination of an LCD screen and Haptic (active tactile) force feedback controller, known as the I-Drive allows the operation of over 700 separate functions. The 700 separate functions are subdivided into different functional groups. All of the 700 functions embedded in the I-Drive system are accessible whilst the vehicle is in motion, including complex interactions such as 'typing' a name for a destination within a navigation system.

Figure 2.1. An example of a GUI in the automotive environment. The 2001 model BMW 7 Series with the I-Drive system

BMW is not the only manufacturer implementing graphical user interfaces within the automotive environment. A number of other brands including Lexus, Mercedes, Volkswagen, and Nissan use an LCD screen as an opportunity to embed non-navigation functions within a graphical user interface (GUI).

It is suggested that the selection of functions from a GUI, with its inherent menu structures, will generally take longer than selecting one physical button from the dashboard. It is the navigation through the interface to find the desired option that increases the interaction time with the system. The potential for these new technologies to demand too much of a driver's visual and mental attention has fostered a range of research studies that look to quantify and regulate the amount of time that users spend looking into the car when driving (Tijerina et al 1998, Tsimhoni, O. 1999, Green 1999, ISO 2006,).

These new GUI technologies have been implemented in high end cars and the percentage of vehicles on the road that use them is assumed to be small. However, the proliferation of the technologies to lower priced, more widely available vehicles is likely when one considers the common implementation of functions such as air conditioning to low end cars, once the preserve of more expensive vehicles. There is potential for these interface technologies to proliferate to lower end models, increasing the number of vehicles using the systems on the road, with an assumed increased risk of accidents.

A more recent cause for concern is the availability of low priced after-market navigation systems that can be attached to the windscreen of a car, and which utilise small touch screens. There has been an increase in the sales of the devices with no apparent discussion of their safety implications. For example, in the fourth quarter of 2008 sales of TOMTOM portable navigation systems hit 3.4 million units (Reuters 2009).

2.2.2 *Evidence for the link between driver inattention to the road ahead and the prevalence of accidents*

The implementation of category 2 and 3 ITS technologies in the automotive environment has raised concerns by researchers for many years with the first studies being performed in the early 1990's. The first study that examined navigation system use on a test track was performed by Tijerina, Parmer and Goodman (1998). The study examined the ability of drivers to enter alpha numeric data into four navigation systems on a test track. During this study it was found that 90% of participants left their lane (a measure of driver inattention to the road ahead called lane exceedance) during a destination entry task, when using a particular system. This illustrates the concern that these systems distract drivers from the primary task of safe driving. In the Tijerina study the mean task times for entering destination information ranged from 40 seconds to 120 seconds depending on the age group, with older drivers taking longer to perform navigation-based tasks. This study showed that navigation systems contain functions that can involve task times for completion that greatly exceed those for standard vehicle controls and displays (checking the speed with the speedometer, turning on the lights of the car or increasing the volume of the radio). This concurs with other research that has demonstrated the negative effects of ITS technologies on the driving performance of young and older drivers (Reed & Green, 1999, and Fox, 1998).

Direct evidence for the link between distracting in-car technology and an increase in accidents was lacking until 2005, when a novel study was performed which recorded the driving behaviour of 100 individuals over a period of a year. The "100-Car Naturalistic Study" performed by V.L.Neale *et al* (2005) explored the causes of accidents that occurred in a one year period for 100 drivers in a metropolitan area of the United States of America. This was done by adding equipment to the vehicles owned by the participants that recorded five video streams of the driver's face, road ahead, interior and rear view. This was combined with equipment that recorded vehicle kinematics (lateral and fore-aft acceleration), and proximity sensors that were capable of detecting 'near-crashes'. The data produced by the video recorder and sensors was subsequently analysed to determine the cause of crashes and near crashes. Vast amounts of data were collected from the study (43 terrabytes of data). Further analysis of the data is ongoing, but the first round of data analysis has been completed by the US Department of Transportation. The data analysis has been performed in two separate ways. Any accident or 'near miss' has been isolated from the data and the behaviour of the drivers involved prior to the accident has been coded in terms of categories of inattention. This was followed by the ranking of the participants in terms of the prevalence of the accidents, and a subsequent random selection of 5000 time periods. This data was then analysed to determine to how prevalent accidents were for each type of driver inattention.

The key findings of the study were that 93% of accidents were caused by inattention to the road ahead caused by interaction with in-car technology, day dreaming, eating, smoking etc. It is therefore considered important to reduce the 'eyes-off-road time' (the combination of the number of discrete glances required to perform a task such as entering a navigation destination, and the direction of those glances) that is elicited by the use of secondary functions.

2.2.3 Methods for the assessment of driver distraction from ITS systems

The assessment of the distraction potential of new technologies is a developing field. The methods that are reported in the literature for the assessment of secondary control interfaces all focus on objective and subjective measures that are gathered in user trials, hence taking a human centred design approach. The following sections discuss the different experimental methods that are used to assess the interfaces.

2.2.3.1 Experimental methods for the assessment of ITS interfaces.

A human centred design approach is generally applied to the assessment of eyes-off-road time elicited by ITS systems.

"As with many other consumer products, there will be a large variability in user characteristics (e.g. in perceptual and cognitive skills, computer experience, anthropometry) to consider when designing in-car computing systems. "Burnett (2008)

It is only by performing empirical user trials with a wide selection of the population based upon age, level of education and gender of participants, that a true picture of user variability in task performance can be gained. The following section describes the Human Centred Design methodologies that have been used in this field of research.

2.2.3.2 Measurement of 'Eyes-off-road' time

The measurement of 'eyes-off-road' time is an objective method that mostly uses cameras mounted in a vehicle to capture the eye movements of the user when driving. A typical assessment setup, such as Burnett (1997) uses a number of discreet 'lipstick' video cameras to record the movement of the driver's eyes, a view of the road ahead, and a view of the controls that are being interacted with. These video recordings are then coded by the experimenter using video play back technology that allows the recording to be examined frame by frame, allowing accurate (to 1/24th of a second) measurement of 'eyes-off-road' time. This can be a very time consuming and therefore costly process, with no options for the automation of the task.. Alternatively eye tracking equipment can be used to capture eye movements. Eye tracking systems have the potential to hasten video analysis to determine glance durations as they allow the experiment designer to see exactly where each participant is looking at any one moment (see Figure 2.2). Two forms of eye tracking hardware exist (Zhiwei and Qiang 2004). Those mounted into helmets or goggles that monitor the position of the eye ball, and those that use an external camera that monitors the combined head and eye location using infra red light to highlight the pupil, and derive the direction of gaze. Figure 2.2 shows an eye tracking system being used in an assessment of head-eye coordination when driving (MacDougall 2005). The system shown in

Figure 2.2 can produce video clips and telemetry data, showing the direction of view from the goggle mounted camera, with a superimposed red cross indicating the centre of gaze, allowing the experimenter to determine the current viewing target. It is anticipated that this capability would allow the analysis of the visual search method performed by each participant when looking for individual controls.

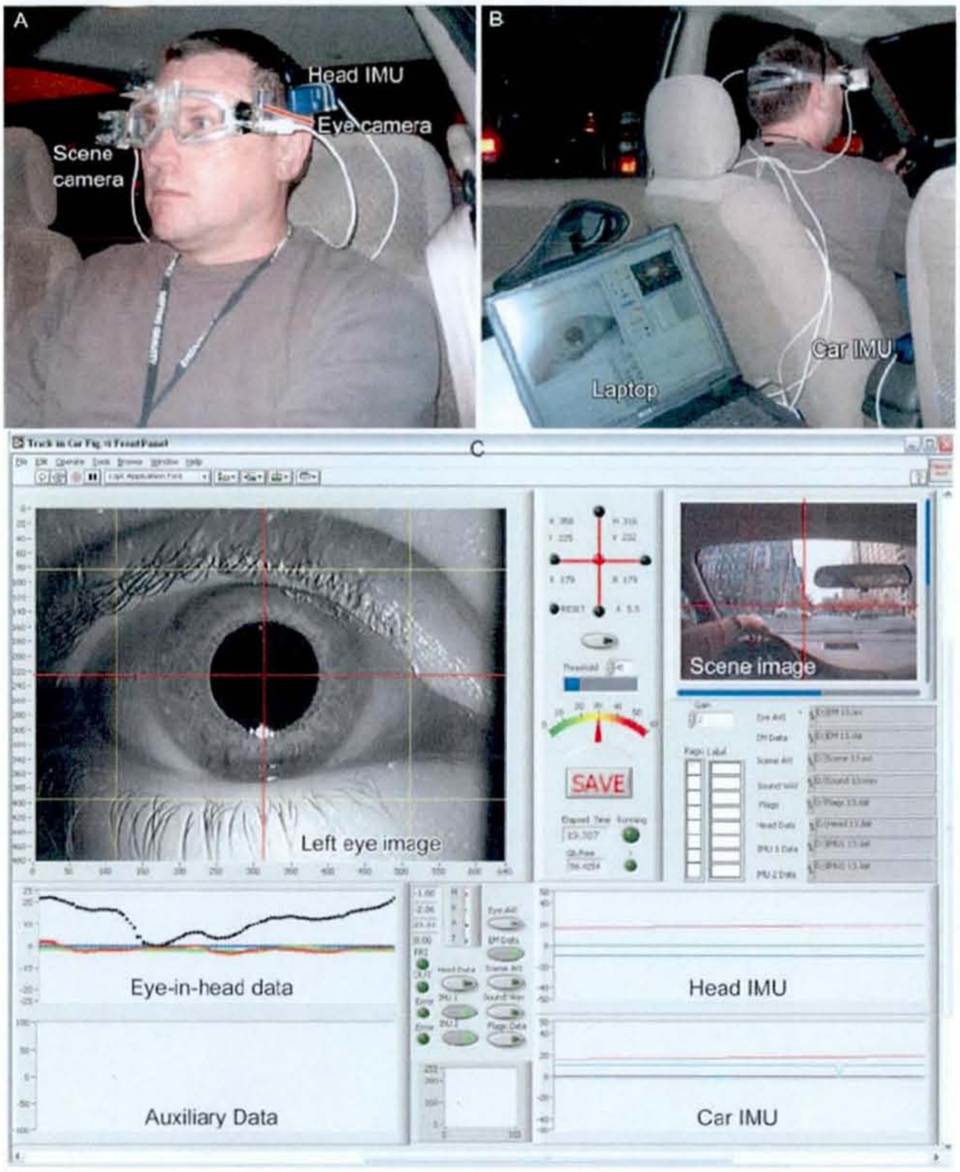


Figure 2.2. An eye tracking system in use in the assessment of head and eye movement during driving in New York City (Source: MacDougall, 2005)

The main benefit of these methods is that information can be gathered on the 'eyes-off-road' time for specific functions, and comparisons can be made between systems. The method can be used in a driving simulator and in on the road trials. An example of this kind of glance capture technique can be found in L, Tijerina (1998) and V.L.Neale *et al* (2005). The Tijerina paper describes a study in which cameras were used to capture glance durations exhibited by users interacting with a navigation destination entry task whilst driving on a test track. The experiment highlighted that glance durations in excess of 8 seconds were fostered by a navigation system that was tested. The method for collecting glance durations has been standardised by the ISO, in document ISO 16673 (2006). The standard procedure to measure a glance is defined as the time from when the user's eyes leave the road, until the eyes once again return to view the road ahead.

The negative aspects of this method include high cost to setup, and lengthy post processing of the captured video to determine eyes-off-road time for each function in the system being tested. The occlusion method, described below, was designed to reduce the cost of performing an assessment of eyes-off-road time, without the need to run user trials on the road or on a test track.

2.2.3.3 The occlusion method

The occlusion method was established in studies by Senders et al (1967). The premise of the occlusion method is that the task of interacting with in vehicle controls whilst in motion (sharing the visual attention between the use of interior controls, and monitoring the external driving conditions) can be simulated by periodically blocking the user's vision. The mechanism for blocking the vision of the user was a mechanical shutter system in the Senders study. This has evolved into the use of polarised glasses that can change state from vision, to blocked, in less than a second. The occlusion method therefore allows systems to be compared using the time required to complete the task, and number of glances that were made. This method can only be used whilst the vehicle is stationary, as the method requires the user to wear apparatus that blocks vision for set periods of time.

Figure 2.3: The use of Occlusion glasses in the automotive environment

The occlusion method was re-introduced as a method for the assessment of new technologies by Green (1999) which included the definition of the '15 second rule', that is, the task of entering a navigation system destination should not take longer than 15 seconds, in periods of 1.5 seconds. The method can be used to examine the interaction with other secondary functions such as ICE and HVAC functions. The measures used to examine ITS systems are TSOT (Total Shutter Open Time) and the value R, which is the ratio of TSOT divided by the TTT (total task time when the task is performed without Occulsion goggles). A ratio of R above 1 is thought to indicate a task that is too complex to perform whilst the vehicle is in motion. R is also considered to be a measure of resumability, i.e. the ease with which the user can continue the task after the small break that is forced by the occlusion goggles. However it is noted by Horberry *et al* (2008) that large task times can still achieve a value of R below 1.

This research led to the definition of a draft ISO standard, ISO TC22/SC13/WG8. This standard was designed to promote discussion in the research field regarding the occlusion method, and lead to the subsequent full ISO standard, ISO 16673 (2006). As is acknowledged in the foreword of the ISO standard, the method is seen as a cheaper way to analyse glance durations elicited by ITS systems.

> *"This International Standard is not intended to preclude direct measurement of eye glances as a method to assess visual demand. Direct measurement of eye glances is always desirable. However, direct measurements of eyes-off-the-road times, i.e. glance time measurements, are typically difficult and very costly to measure. The occlusion method estimates visual demand, including resumability, of a task using a means for intermittent viewing of the in-vehicle system. Evaluation by occlusion identifies driver interfaces that are likely to take the driver's eyes away from the road for excessively long durations."*
> ISO 16673

The occlusion method has caused some concern within the human factors research sector. The arbitrary switching between vision and no vision states has been suggested to be unrealistic in terms of the interruption of the user's cognitive processing (Lansdown *et al* 2004). The requirement of the system to be used in a stationary context, or on a test track/driving simulator study also limits the realism of any tasks that are to be evaluated. Finally, the ISO standard fails to define a maximum limit for the number of glances that can be made which was not the case for the research upon which the standard was based, (Green 1999). Therefore, the measurement of 'eyes-off-road' time during an on the road study is considered to be the 'gold standard'.

2.2.4 Established glance duration limits

One of the earliest and highly regarded studies on glance durations for in-car tasks was performed by Wierwille and Dingus (1988). This study involved on the road trials in an instrumented car with participants being given common in-car tasks to perform at intervals. The lengths of the glances were recorded and means calculated. The list of tasks performed and the mean glance durations can be seen in Table 2.1. It should be noted that mean glance durations of nearly 11 seconds were recorded for a navigation task where a street name had to be read from the screen (Roadway name).

Range (s)	Task	Mean total time (s)	Standard deviation (s)
< 1.0	Speed	0.78	0.65
	Following Traffic	0.98	0.60
1.0 - 2.5	Time	1.04	0.56
	Vent	1.13	0.99
	Destination Direction	*1.57*	*0.94*
	Remaining Fuel	1.58	0.95
	Tone Controls	1.59	1.03
	Info. Lights	1.75	0.93
	Destination Distance	*1.83*	*1.09*
	Fan	1.95	1.29
	Balance Volume	2.23	1.50
	Sentinel	2.38	1.71
	Defrost	2.86	1.59
	Fuel Economy	2.87	1.09
	Correct Direction	*2.96*	*1.86*
2.5 - 4.0	Fuel Range	3.00	1.43
	Temperature	3.50	1.73
	Cassette Tape*	3.23	1.55
	Heading	*3.58*	*2.23*
4.0 - 8.0	*Zoom Level*	*4.00*	*2.17*
	Cruise Control	4.82	3.80
	Power Mirror	5.71	2.78
	Tune Radio	7.60	3.41
> 8.0	*Cross Street*	*8.63*	*4.86*
	Roadway Distance	*8.84*	*5.20*
	Roadway Name	*10.63*	*5.80*

Table 2.1 The mean glance durations found in Wierwille, Dingus study (1988)

Paul Green (1999a) summarised the glance duration data literature and made the following statements.

> *'The shortest mean glance time that led to a lane departure was 1.58 s (determine remaining fuel) '*
>
> *'The largest mean glance time that led to no errors was 1.83 s (destination distance).'*
>
> *'This could suggest that tasks with total glance times of less than approximately 1.58 s will not lead to any appreciable lane drift when driving on mostly uncongested roads'*
>
> *'no departures did occur in some circumstances for total glance times of up to 1.83 s.'*
> *Green 1999*

The premise here is that there is a length of glance duration for which a lane exeedance is less likely. This was based upon 1.58 seconds being the shortest glance that fostered a lane departure by a participant when driving on real roads in Virginia USA (Weirwille and Dingus, 1988). This interpretation of the data suggests that if the glance durations fostered by new in-car technology are less than 1.58 seconds, they are less likely to cause a lane exceedance, and less likely to cause an accident. There has been no definition of a 'safe' glance duration limit in the literature. If a user is driving down an empty flat road with clear visibility of the road ahead and behind the vehicle, glance durations could be longer than those used in heavy traffic. It is presumably the difficulty in defining the context of a glance duration that has limited the ability of the research community to define a 'safe' glance duration length.

However, it could be presumed that if glance durations elicited from ITS systems do not exceed those for standard driving tasks, those ITS systems are not importing further risk into the driving environment. For example, the mean glance duration for determining the fuel level in table 2.1 is 1.58 seconds. Therefore glance durations that are less than 1.58 seconds could be considered to have no further potential to cause an accident than the commonly performed task of checking fuel level. Glance durations of up to 1.83 seconds can be said to import no higher risk of an accident when on a straight piece of road with light traffic according to Green (1989). The thresholds for glance duration can therefore be defined as less than 1.58 seconds or less than 1.83 seconds in light traffic.

There are many in-car secondary tasks that require longer than 1.58 seconds to complete as shown in table 2.1, and so multiple glances are often made to complete a task. The larger the number of glances that are required to perform a task, the more potential there is for the user to be distracted. This has been recognised by the definition of the '15 second rule'. The '15 second rule' established by Green (1999) was adopted by the Society of Automotive Engineers (SAE) in standard SAE J2365 (2002). The '15 second rule' places a limit on the total glance time that is required to complete a navigation based task. e.g. zoom map view, and can be used to assess any in vehicle interaction. The 15 second limit for eyes on task time was defined by a review of the data from a number of studies examining task durations such as Tijerina, Palmer, and Goodman's (1998), Campbell, Carney,and Kantowitz, (1997) The JAMA guidelines (Japan Automobile Manufacturers' Association,(1996). The recommendation from these studies was for task times up to 9 seconds. This was arbitrarily extended to 15 seconds by the SAE panel for use in standard SAE J2365b. It is recommended by Green (1999) that a 10 second threshold for total task time should be set.

2.2.4.1 Conclusions

The literature examining the prevalence of accidents due to driver inattention, combined with literature examining the specific use of ITS technology has allowed benchmarks to be set for glance durations that are considered to be relatively safe, combined with a limit on the number of glances based upon the total task time figures. The limits on glance duration that have been prescribed by Green (1999) are dependent upon the particular road conditions at the time that a glance is made. Glance durations that are longer than 1.8 seconds may be completely safe when on a single track road with clear visibility of the road ahead, conversely, glances shorter that 1.5 seconds could be considered dangerous when driving past a school at the end of the day in heavy traffic. This points to the need of consistency in any on the road trial that attempts to measure glance durations elicited from a secondary control interface. The user trials should be planned to ensure that where possible, all participants experience a similar level of traffic density. This is generally done by driving the same route for each experimental trial, at the same time of day, on the same day of the week. These effects can be removed by performing testing in a driving simulator, or on a test track, but these methods reduce the level of fidelity of the experimentation.

In order to examine if the tactile sense can be used to reduce the 'eyes-off-road time' exhibited by drivers when interacting with secondary tasks these bench marks are an essential analysis tool. The assessment of the glance durations that are fostered by ITS systems should be assessed against the 1.58 and 1.83 second benchmarks for single glances, with a total task time limit of 10 seconds.

2.3 Designing to exploit the tactile sense

One of the key aims of the project was to explore the experience of visually impaired people in terms of product interaction as suggest by Prynne (1998). The literature has been explored for any design process that produces a product that uses tactile output to provide information to the user.

The most obvious tactile communication method used by the visually impaired is Braille as discussed by Sadato (1994), and yet only 5-10% of the people that are registered as blind or visually impaired in the UK can actually read Braille (personal communication with John Gill, Chief Scientist of the RNIB). This was attributed to the difficulty of learning Braille. Other methods of tactile interaction have been shown to be used by visually impaired people. For example, tactile representations of building layouts have been designed to allow visually impaired people to conceptualise three dimensional spaces (Espinosa, M. A . 1998). ATM control panels use tactile symbols to allow the user to differentiate between cancel and accept buttons. There are also a range of vibro-tactile displays that use arrays of pins to present patterns to the visually impaired user. There has also been research into the use of pin matrix displays for the presentation of imagery to visually impaired people. These devices use pin matrix displays with variable pin height that allow the presentation of three dimensional structures.

The following section discusses the research that has been performed in these areas and the relevance of the research for the process of designing tactile in-car controls. The literature has been divided into research examining static and active tactile displays and research examining the capability of the body to sense tactile input.

2.3.1 The tactile sense

2.3.1.1 The body's ability to sense tactile input

The design of a device that uses tactile coding to present information to a driver requires knowledge of the tactile sensing ability of the human body, and the variation of the tactile sensing ability across the population.

The most sensitive area of the body for tactile input is the finger tip. The sensitivity of the skin at the tips of the fingers is attributed to five kinds of afferent nerve fibres (a nerve that carries signals towards the central nervous system) as described in Loomis,J.M. and Lederman, S.J (1986).

These five fibre types are;

- SA I : Slow adapting 1
  These afferents provide the finest level of spatial resolution, allowing fine detail to be explored with the finger tip. Sensitive to static stimuli such as pressure with a frequency range of 30Hz or less.
- SA II : Slow adapting 2
  These afferents respond to stretching of the skin and detect the direction of the stretch
- RA I : Rapid adapting 1
  RA afferents respond to dynamic deformation of the skin
- RA II : Rapid adapting 2
  These afferents respond to vibration in the range of 40Hz to 500Hz
- PC : Pacinian Corpuscles
  Deepest in the structure of the skin these structures respond to the highest range of vibration frequency (>500 HZ)

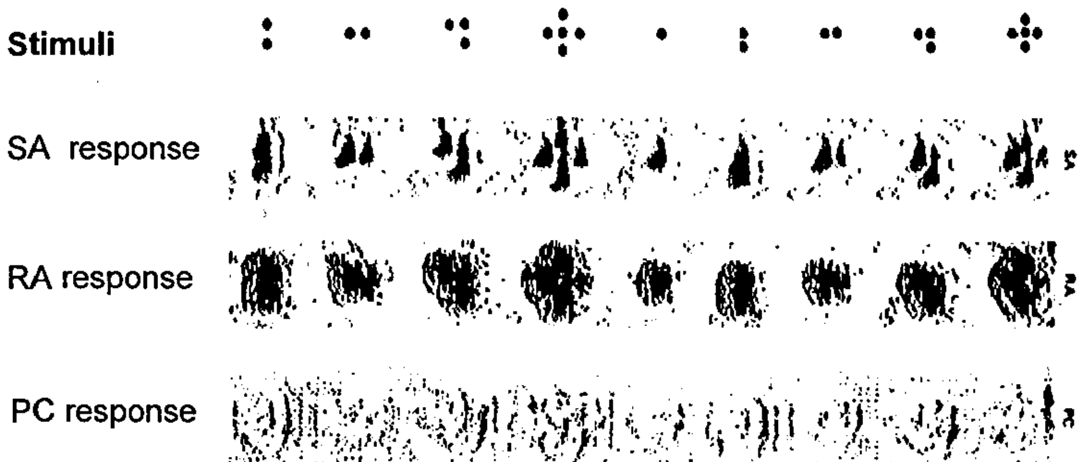


Figure 2.4: The different responses elicited by three kinds of afferents

The figure above shows the results of an experiment performed by Johnson et al (1981). This study showed the output produced by three kinds of afferent nerve ending. The study used direct output from the nerve endings, as shown in Figure 2.4. In terms of the spatial resolution of the dot patterns at the top of the image, the SA profile best matches the stimulus input.

The five kinds of afferents hint at the different capabilities that the tactile sense has in terms of tactile detection. The two main modes of tactile perception are spatial sensitivity and temporal sensitivity (Perera 2002). The spatial sensitivity describes the ability of a user to distinguish between two distinct inputs (e.g. two Braille dots). This type of sensation is detected by the SA afferents. Temporal sensitivity describes the ability of the user to detect vibration (e.g. that caused by running the finger over a textured surface, or detecting vibration used in mobile phones) and is detected by the RA afferents and the PC afferents.

The two types of tactile sensing (temporal and spatial) indicate the two different modes of tactile interaction. These are;

- Passive interaction: The finger in constant contact with a source of temporal stimulation (e.g. Holding a mobile phone and feeling the vibration alert to a new call or message)

- Active interaction: The user moves the tips of their fingers on and around shapes that convey information (e.g. using a TV remote control in the dark)

After reviewing the mechanisms that allow humans to sense tactile stimuli research has been sought that describes the resolution of the tactile sensing ability. The following recommendations were summarised in an internal document produced by the RNIB specifically for the BIONIC project (Perera 2002).

Stevens (1992) reports that the spatial acuity of the skin on the finger tips deteriorates with age. After empirical studies looking at the detectable step heights in textures the following thresholds were determined.

- 1.95mm for young people (18-33)
- 2.68mm for middle aged (41-63)
- 5.03mm for older (66-91)

This shows a marked reduction in tactile sensitivity with age, but provides useful data for the design of controls that must be distinguished from the surrounding surface if they are to be inclusive for the whole population.

Other work has been performed looking at the ability of the tactile sense to differentiate between different patterns of texture. For example Kops and Gardener (1996) defined textures using three variables, when considering a texture that is created by using raised dots on a surface. These variables were;

- Intensity (Dot density)
- Spatial cues (Dot spacing)
- Angular orientation (Horizontal, vertical, oblique orientation of patterns such as tracks formed by the dots)

Textures are distinctive if their elements are tightly spaced along one axis and widely spaced along other axes e.g. forming paths for the finger to follow. High and low density patterns are easier to distinguish from each other from those with medium density textures. Gardener also recommended the use of combined coding techniques such as the orientation of a tactile pattern, combined with the density of the tactile pattern. There is an interaction between spacing and orientation. Patterns that differ in both variables are discriminated better than those that differ in only one variable. Also Lechelt (1985) found orientation deviation for patterns from horizontal and vertical positions rather than diagonal ones were more accurately discriminated.

2.3.2 The limitations of the tactile sense

There are a number of limitations of the tactile sense as described in the following sections.

2.3.2.1 Resource sharing of the visual cortex between the visual and tactile senses

One of the most important findings from the literature was the work of Sathian *et al* (2002) which showed that the visual cortex is used to process tactile inputs that use spatial and orientation coding. The implication of this resource sharing is that the driver could be interacting with a tactile interface, with their eyes on the road, but they would not notice an incident that would require them to take action due to overloading of the visual cortex (both tactile and visual inputs being processed in parallel by the occipital lobe (visual processing centre of the brain)).

Further work and a summary of occipital activation by Kosslyn and Ochsner (1994) has suggested that there is variability in the use of occipital lobe in tactile discrimination between subjects. This was emphasised by the work of Astur, Ortis and Sutherland (1998) which showed a gender difference in the brain centres used during navigation tasks, with males using the visual processing brain centres more than females when visualising routes. This suggests possible gender differences in tactile discrimination tasks that use the visual processing capacity of the brain.

It was also suggested that in a task where different locations must be identified physically (e.g. pointing to different locations) that over learning of the task can result in a shift of the neural processing of the task from the occipital lobe (whilst learning the interaction) to the motor centres of the brain, in effect using 'muscle memory' (the kinaesthetic sense) instead of the visual processing recourse. This indicates that different physical locations will prove a strong coding technique for object location, as the more the task is performed the less that the occipital lobe will be used to process control location, with the motor skills of the user taking over.

2.3.2.2 The serial nature of tactile interaction

Another limitation of the tactile sense is the serial nature in which information can be gathered as discussed in the design of the Shinohara display (Shinohara *et al*, 1998) and the Optacon device (Arezzo, 1980) see section 2.4.2.3. These devices present a single stimulus at any one time that must be interpreted using the tactile sense. No tactile displays have been found that attempt to present multiple tactile 'messages' at the same time. This is understandable when one considers the tactile link to the visual sense discussed above. It is not possible to view two discrete displays at any one time to gather information unless that information is of a peripheral nature, i.e. looking at a screen with alpha numeric data that is being read, with the background colour changing to display a warning or change of state.

An analogy of the tactile sense in the automotive context would be to restrict user vision to a viewable area that only allows a single control to be seen, thus removing the contextual cues of the panel layout in the peripheral vision. This is equivalent to using the sense of touch for control identification, which inherently requires the user to focus the touch sense on one object at a time. The work discussed in section 2.4.2.2 above suggests that distinct control location centres for specific functional groups can act as 'tactile peripheral vision'. This is highlighted in the literature in the discussion of tactile stimulus 'masking'. That is, two simultaneous tactile stimuli can interfere with each other, cancelling out one or both of the signals that is perceived (Loomis, J. (1986).

2.3.3 *Devices that attempt to use the tactile sense to convey information to users*

A number of devices have been designed that attempt to use the tactile sense as a communication channel. These devices have, in the main, been used to convey information to visually impaired people.

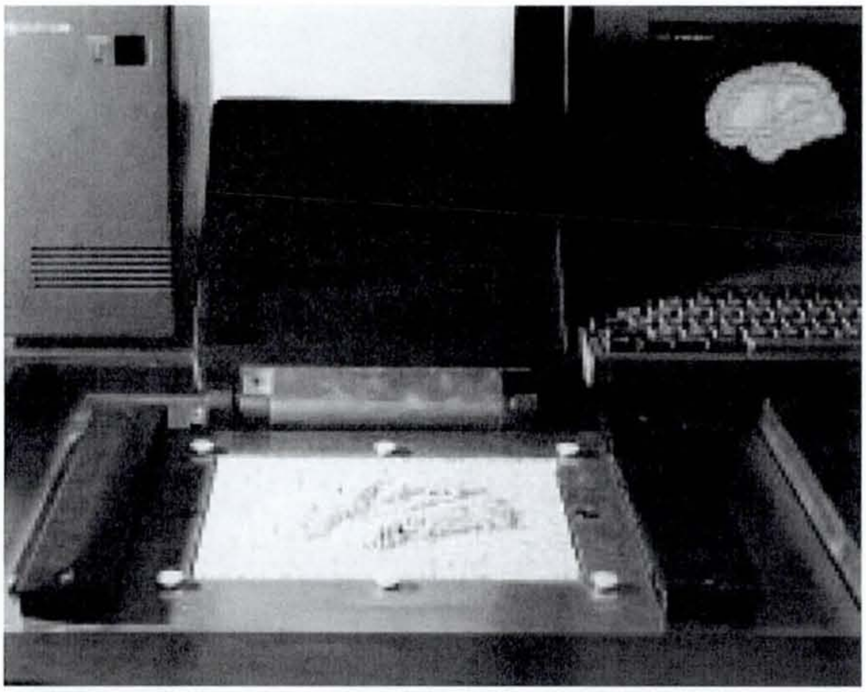


Figure 2.5. A 3D pin matrix display that is used to present tactile symbols and diagrams to blind people. Shinohara (1998)

2.3.3.1 Haptic devices used by visually impaired poeple

The term haptic originates in the Greek term *haptikos* 'able to touch or grasp'. Haptic interfaces generally provide some form of active tactile feedback to the user. Shinohara *et al* (1998) designed a three dimensional (3D) tactile display which allows people with visual impairments to explore information such as maps, scientific illustrations and circuit diagrams. The display took the form of a matrix of pins that combine to produce a display size of 200mm by 170mm. The pins are able to be programmed to display an image in three dimensions using different levels of protrusion of pins from a mounted surface (see figure 2.5). The experimenters used the 3D tactile display to present structures that represented scientific illustrations, Chinese Kanji characters and a tactile map, to visually impaired users in three empirical studies.

In the first study (n=6, blind participants with no level of vision) the visually impaired subjects were ask to recognise 10 Chinese Kanji symbols. An example of two such symbols is shown in Figure 2.6.

博多

Figure 2.6: Two Chinese Kanji symbols

The size of the Kanji symbols was varied using three conditions, 26mm x 27mm, 51mm x 52mm and 96mm x 99mm. Each display size increment used a portion of the display shown in Figure 2.5. The resolution of the symbols presented therefore increased as the character size increased, effectively using more of the pins as the character size increased. The table below shows the results in terms of size of display, response time, and correct identification of the symbol being presented.

Character size	Response time	Correct I.D. rate
26mm x 27mm	32 sec	0.63
51mm x 52 mm	17 sec	0.85
96mm x 99mm	13 sec	0.93

Table 2.2. The response time and success in identification of Kanji symbols of different sizes

The results showed that response time was less than half with the largest Kanji symbols presented when compared to the smallest.

The second study looked at the recognition of a three dimensional schematic of the brain. The six subjects were asked to explore the 3D diagram and then produced illustrations using a tactile drawing technique to demonstrate that they have received accurate information from the display. The visually impaired users were able to reproduce the structure of the 3D tactile image with great accuracy, showing that they had gained a suitable level of information from the device. The paper does not describe the user trials in great detail, but does show a reproduction of the tactile image produced a visually impaired person. The main aim of the paper was to demonstrate that the resolution of the 3D tactile display was high enough to allow detail to be discriminated by visually impaired users. This was achieved. The final study performed with the six participants examined the use of a tactile map to provide navigation and layout information that related to the campus in which the participants studied. The participants were accustomed to navigating around the campus.

The study showed that the participants were very good at differentiating between the elevation of ground level and the height of buildings, but poor at identifying orientation and distance between locations. There have been two dimensional (2D) tactile displays in production for some time, such as the OPTACON (Optical Tactile CONverter) device.

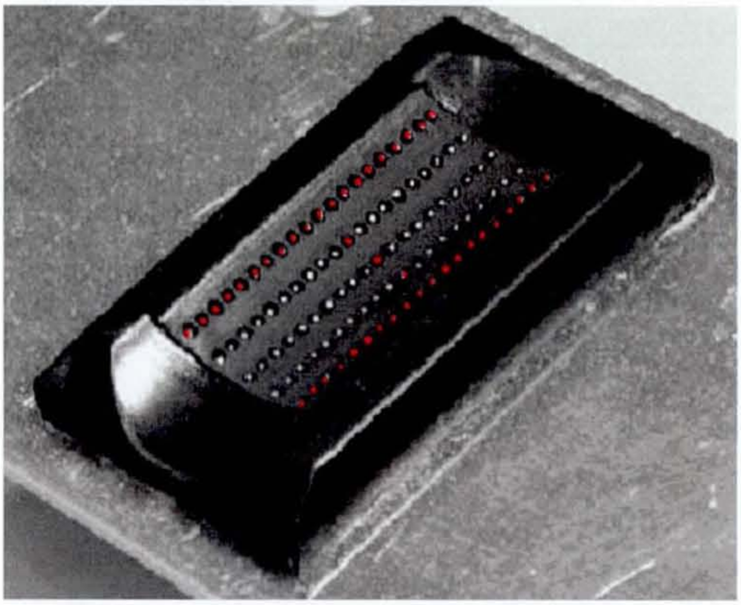


Figure 2.7: The Optacon vibrotactile display. The red dots on the image illustrate the pins that would vibrate to show a letter H

The OPTACON device uses pins that vibrate to allow users to feel letters are being scanned into the device using a scanner as shown in Figure 2.8. The user keeps the finger in one position, and, with training is able to read standard text.

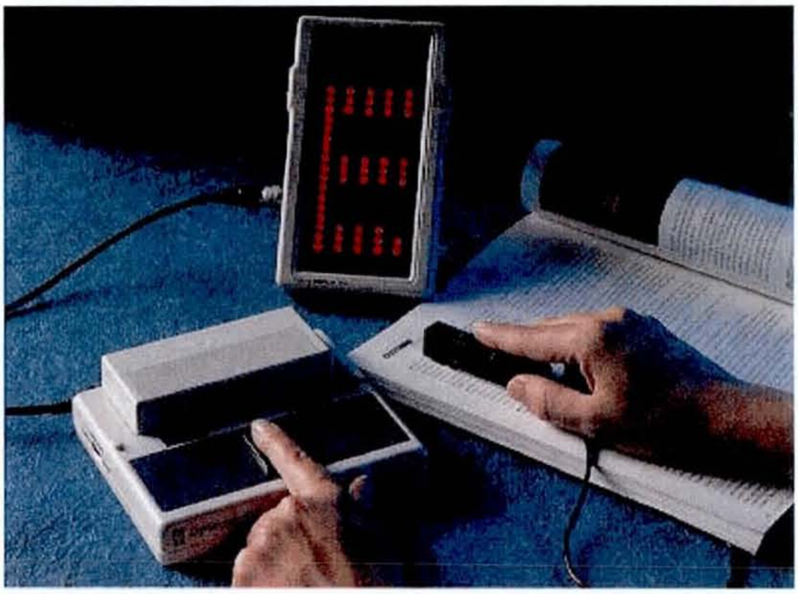


Figure 2.8: The Optacon vibrotactile display in use

The use of these devices relies upon extended training and practise periods. The Shinohara display and the OPTACON device have shown that active tactile feedback can provide information to the user using the tactile sense only.

2.3.3.2 Other Haptic interfaces

Very little research has been found which directly relates to the use of haptic interfaces in the automotive environment. The research showed a focus on haptic interface research in the field of virtual reality applications, such as providing force feedback gloves which allow the user to 'feel' virtual objects, and providing virtual CAD modelling tools. The BMW I-Drive is the single production example that uses haptic feedback in the automotive environment. The BMW I-Drive was developed in collaboration with Immersion, a company that had previously produced force feedback joysticks and steering wheels for computer gaming applications. The I-Drive system predominantly requires the user to look at the screen during interactions, but does include some tactile coding produced through the interaction with the haptic knob. The knob provides resistance to the twisting of the knob that attempts to communicate a number of variables. Appendix 1 shows the full range of haptic cues that are built into the I-Drive system. Figure 2.9 shows the top level functional groups that can be accessed by I-Drive users, by pushing the controller in the direction of the indicating arrows.

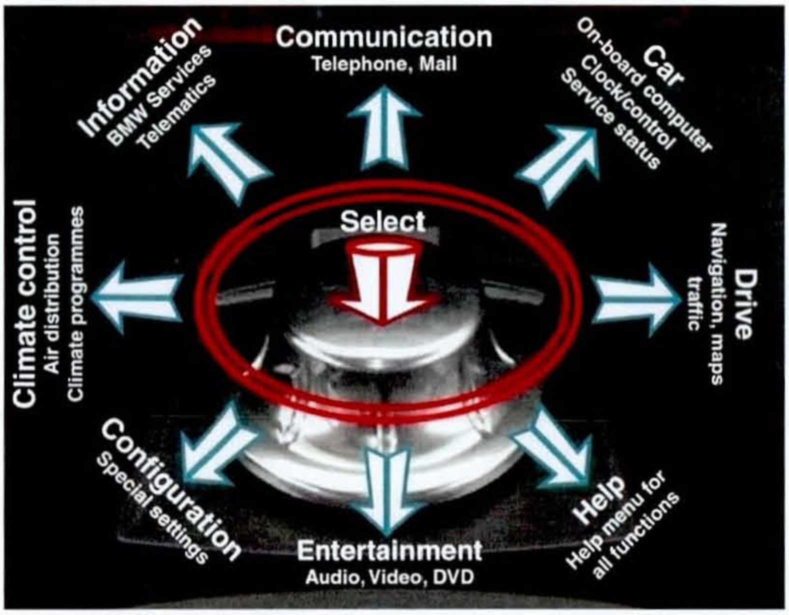


Figure 2.9: The eight sets of functions that can be accessed when using the I-Drive system

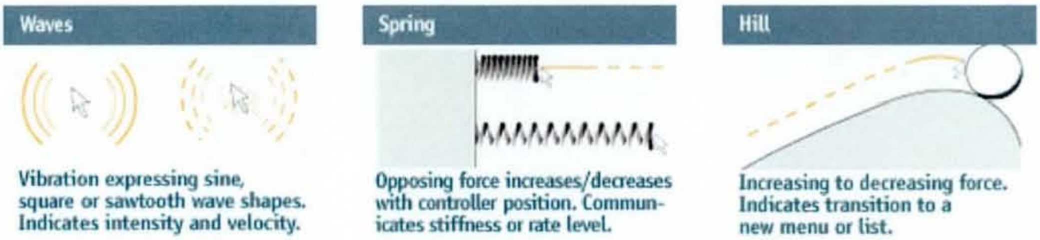


Figure 2.10: Three of the haptic cues built into the I-Drive system

Figure 2.10 shows three of haptic cues that can be experienced whilst scrolling through options or changing variables, by rotating the device. No studies have been found that examine the I-Drive interface, or publications that describe how the tactile feedback was designed and tested.

Many papers have been found that examine the use of haptic devices applied to improving software interfaces, or simulating real world activities. For example, a Virtual Reality system was combined with haptic forceps in a paper by Burdet, E. (2004). The haptic forceps provided force feedback that simulated the forces experienced by the surgeon when performing micro surgery. Chi-Cheng, C. (2006) described the design of a haptic device that allows designers to perform freeform CAD operations, effectively carving out of a virtual piece of clay. The aim of this work was to allow freedom to designers in the initial stages of CAD development of a product, when compared to parametric CAD software such as Pro Engineer or Solid Works, which were seen as too constraining.

A more theoretical application of haptic technology was examined in a study by McKnight, S. (2004). The study examined the potential of a multiple fingered haptic interface as shown in Figure 2.12. This device allows the user to grasp virtual objects using three fingers, with each finger receiving haptic feedback from a Phantom device (a haptic force feedback controller, see figure 2.11). The study demonstrated that a device that allows three fingers to be used for virtual object interaction improves the success of virtual product manipulations when compared to single or two finger systems.

Figure 2.11. The Phantom haptic interface

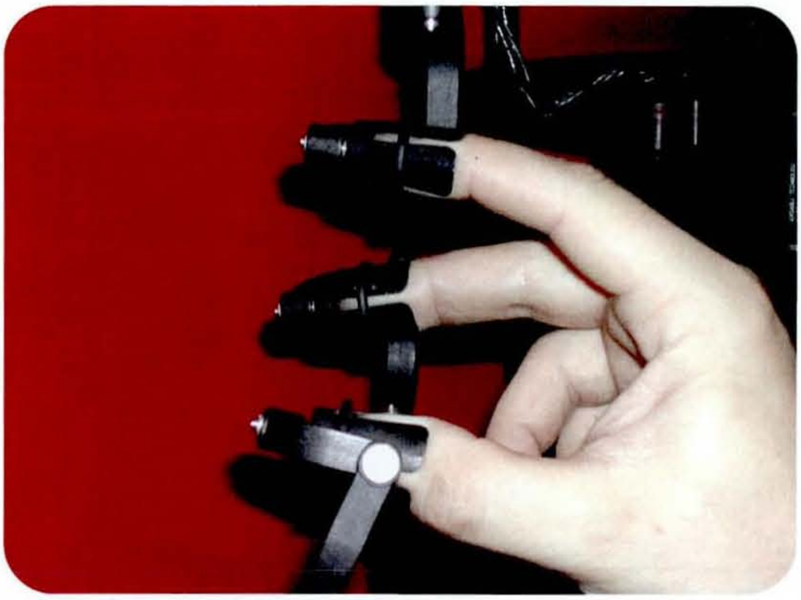


Figure 2.12. The device used in the McKnight study examining the use of three combined Phantom interfaces to provide three finger haptic feedback for virtual object exploration

A military application for haptic feedback takes the form of a body worn belt of vibration sources that the user wears around the chest. The vibration sources provide the user with navigation direction information by vibrating on the left side of the body if a left turn is required. The user knows that they are currently on the right heading when the vibration source in the centre of the chest is active. This work by Savick,S. (2008) aims to reduce the visual load on armoured vehicle operators by removing the need to look at a map display. This was achieved, with a significant reduction in response time and workload measures through the mechanism of tactile input. A similar piece of work was performed in the automotive context. The study aimed to investigate the feasibility of an in-car tactile navigation display with the emphasis on driver workload reduction, (Van Erp, J. B. F, 2004). The system used vibration sources or 'tactors' under the left and right legs in the driving seat. The coding of the pulses from these tactors presented direction of turn, and distance to turn information. A left turn would be represented by pulses under the left leg, with the increasing frequency of vibration indicating the reducing distance to turn. The experimentation performed compared the vibro-tactile system to a visual system that presented the same direction and distance to turn information. An LCD display showing a direction of turn arrow, and a distance to turn in metres was used. The experimentation performed showed that the mental effort required to interpret the navigation cues was significantly less for the tactile modality when compared to the visual. Also, drivers reacted more quickly to the distance to turn information from the tactile modality. The visual sense was being shared between the primary and secondary task when the LCD screen was used, resulting in higher mental workload, and poor recognition of visual information from the system. The tactile sense allowed the same resolution of data to be gathered by the user with reduced visual workload, and faster reaction to the signals from the system. It is acknowledged that the system is in the early stages of development; however, there is no current strategy for presenting information such as which turning of a round-about should be taken. If this problem can be solved the use of the tactile sense could be a valuable addition to the automotive environment.

The studies above show a number of instances where tactile coding has been used to convey state of the system information to the user. In most instances the tactile feedback received related to adding sensation to virtual interactions. The work by Van Erp, J. B. F, (2004) showed that the tactile sense can be successfully used to provide state of the system information to drivers.

2.4 Control design recommendations

The following section discusses the general control design recommendations found in the literature.

2.4.1 Introduction

As discussed by Overgard, K. (2007) in a paper discussing 'Knobology', ergonomics research can be separated into two related domains, the classical ergonomics research tradition and performance based ergonomics. Overgard suggests that the two research traditions correspond to the research basis for the recommendations for knobs and dials. That is, classical ergonomics has attempted to fit the workplace to the human using anthropometric data, and performance based ergonomics has focused on the aspects of control design that relate to shape, colour and mode of operation, using 'time' and 'error' frameworks. The 'time' framework refers to the time taken to locate and operate controls. The 'error' framework relates to inadvertent operation and incorrect selection of controls. It has been noted by Dainoff (1999) that the applied performance based assessment of controls is rare and this has been reflected in this literature review. The recommendations that are discussed below have been drawn from both the performance based and anthropometry based approaches.

Many ergonomics recommendations for control design were defined in the 1940's, 50's and 60's as a result of military research into the design of devices such as aircraft joysticks. The impetus for improving the design of controls came from the number of accidents that were associated with incorrect identification of controls. For example, in a 22 month period during World War II the confusion between landing gear and flap controls caused over 400 US air force accidents. This problem was resolved by Alphonse Chapanis, often considered the father of Ergonomics, who designed tactile caps for the levers of the landing gear and flaps controls of aircraft. Also in the 1940's, attempts were made to produce different shaped hand grips on levers to aid discrimination. Figure 2.13 shows two sets of these hand grips that were found to be easily differentiated from each other in user trials (Sanders and McCormick, 1992).

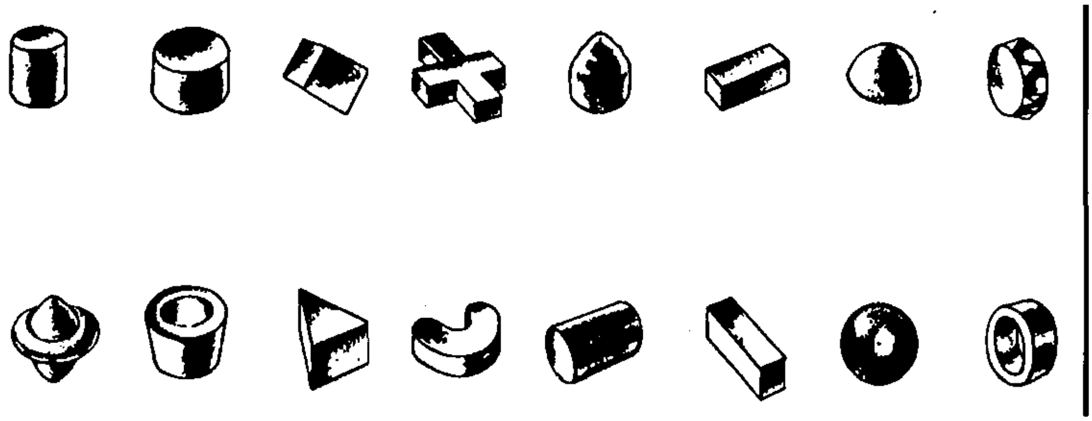


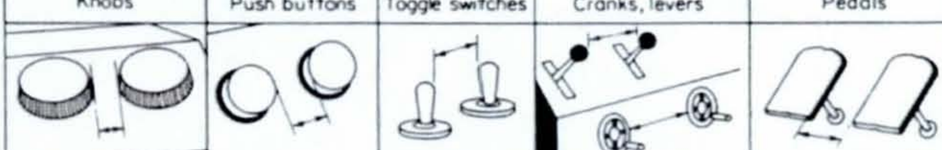
Figure 2.13 Two rows of control hand grips that were rarely confused (Source: Jenkins 1947)

The design exercise that produced the control hand grips shown in Figure 2.13 is rare and no design recommendations for the form of tactile controls have been found. There are no examples of the tactile sense being exploited in the design of controls that have been published in the literature, but there are numerous examples in general use that use simple tactile coding to aid discrimination. The tactile symbols used in the design of ATM key pads, and the seat adjustment controls used in some cars in cars are just a few examples illustrated in Figure 2.14.

Figure 2.14 The tactile symbols used in the control design of cash machine keypads, and the shape coding used in the design of a Mercedes seat adjustment control

2.4.2 General control design recommendations

The standard ergonomics texts such as *Human Factors in Engineering and Design* (Sanders, M. and McCormick, E., 1992), and *Fitting the Task to the Human* (Kroemer K. and Grandjean E., 1997) provide general recommendations relating to issues such as the size, shape, mode of operation and operational force limits of different types of controls such as push buttons, rotary knobs, toggle switches, cranks and pedals.



Number of body members and type of use		Knobs	Push buttons	Toggle switches	Cranks, levers	Pedals
1, randomly	in	2(1)	2(1/2)	2(3/4)	4(2)	6(4)
	cm	5(2.5)	5(1.3)	5(1.8)	10(5)	15(10)
1, sequentially	in		1(1/4)	1(1/2)		4(2)
	cm		2.5(.6)	2.5(1.3)		10(5)
2, simultaneously	in	5(3)			5(3)	
	cm	12.7(7.6)			12.7(7.6)	
2, randomly, sequentially	in		1/2(1/2)	3/4(5/8)		
	cm		1.3(1.3)	1.8(1.6)		

Figure 2.15. Standard control recommendations for the separation between adjacent controls (Source: Sanders and McCormick, 1992)

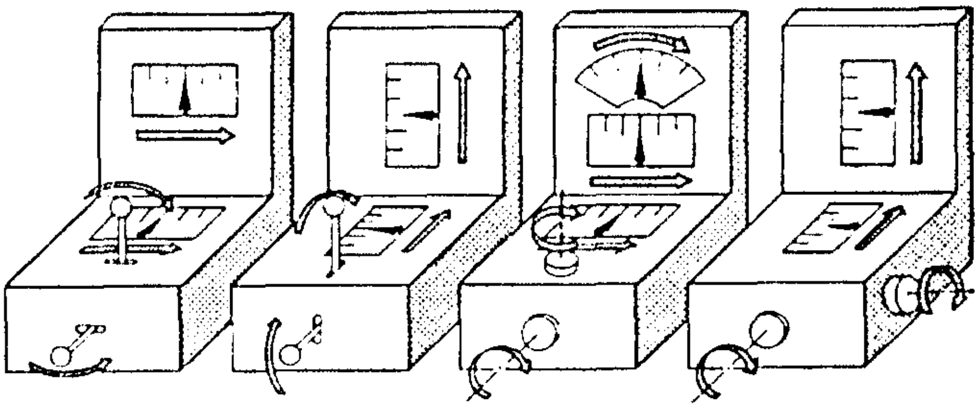


Figure 2.16 Standard control motion recommendations when associated with a display (Source: Sanders and McCormick, 1992)

It is noted that these design recommendations don't seem to be followed by many products that exist today. The recommendation to have at least 13 millimetres of separation between adjacent push buttons is incongruous with the design of current mobile phones and many other devices, including the controls that are placed in current automobile interiors. The design recommendations that refer to the size and positioning of controls were based upon the design criteria for manufacturing environments, and the operation of large scale machinery, where the safety element is critical. This is not the case for mobile phone use. It is certain that modern mobile phones were not considered in the definition of these recommendations. However, there are examples of control design recommendations that are relevant to the design of electronic products today. Figure 2.16 shows the direction of motion stereotypes that are associated with the motion of displays. These recommendations are still applicable to the design of products. For example, in order to increase the volume of sound from a HIFI system, the user would expect a rotary knob to be turned clockwise. It is considered to be important to design any physical controls that are included in the PTI using these 'stereotypical' control motion stereotypes as they have the potential to provide non-visual coding that exploits the previous experiences of control usage held by users.

Recommendations were found for the anatomical and anthropometric aspects of control design as follows Klarwowski, W. (1999);

1. The maximum strength, speed, precision, or body movement required to operate a control must not be exceed the ability of any possible operator
2. The number of controls must be kept to a minimum
3. Control movements that are natural for the operator are the best and least tiring
4. Control movements must be as short as possible, while still maintaining the requirement for 'feel'
5. The controls must have high enough resistance to prevent their activation by mistake. For controls that are only used occasionally and for short periods, the resistance should be about half the maximum strength of the operator. Controls that are used for longer periods must have a much lower resistance
6. The control must be designed to cope with misuse. In panic or emergency situations, very great forces are often applied and the control must be able to withstand these.
7. The control must give feedback so that the operator knows when it has been activated, even

Standards such as BS EN ISO 9241-400:2007 (*Ergonomics of human-system interaction - Part 400: Principles and requirements for physical input devices (BSI 2007))* that one would expect to contain control design recommendations actually only provide information on very specific aspects of human computer interaction input devices. A review of the literature has shown a lack of specific design recommendations for the design of controls. A number of studies have examined the design of specific controls. Some examples of these are discussed in the next section.

2.4.3 Specific control design studies

A study by Green *et al* (1987) examined the preferences of control location and type for a specific list of in-car functions. This was done by covering the surfaces of a car interior with Velcro, and allowing the participants to select a control type that they best associate with a particular function. The participants then placing the dummy controls onto the Velcro dash in the desired location. This effectively required the participants to design the control panel. Green found that certain functions were shown to be associated with certain control types and modes of operation. This is in line with ergonomic design principles discussed in section 2.2.2. Green (1999) also noted some differences between his results and the similar work performed by Black, Woodson, and Selby (1977). This focused on the preferred mode operation for a light switch found in 1977, which was shown to be opposite to the preferred mode of operation found in 1987. This was attributed to the common use of the counter intuitive method in Ford vehicles in the 1970's. This highlights an interesting point. That is, the stereotypical control motion associations that participants exhibit can be influenced by the poor design of a control that is found in wide spread use. It also shows that drivers base their expectations for control operation on previous experience. This is a point that should be noted in the design of the PTI. The PTI should exploit the preconceptions of users wherever possible to enable the previous experience of the user to support the conceptualisation of the PTI. The caveat to this is that if the expectations are based upon a control motion that is counter intuitive. This is a recommendation that can be inferred from the literature.

Faerber, B. *et al* (1993) described the assessment of four novel interface designs that aim to reduce the visual load on the driver when interacting with secondary automotive controls. Figure 2.17 shows the four control layouts that were designed to explore this issue, with the a large control handle at the bottom of each image. This handle allowed the analogue control of contiguous variables such as fan speed, music volume etc. Different technologies were used to allow interaction with a screen based system. These were, a prototype speech recognition system, the use of 'Hard keys' (each button has a single function) 'Soft keys' (each button has a different action depending upon the current mode, reliant upon on screen feedback) and 'cursor positioning' (the handle is used as a joystick to allow function selection from on screen options).

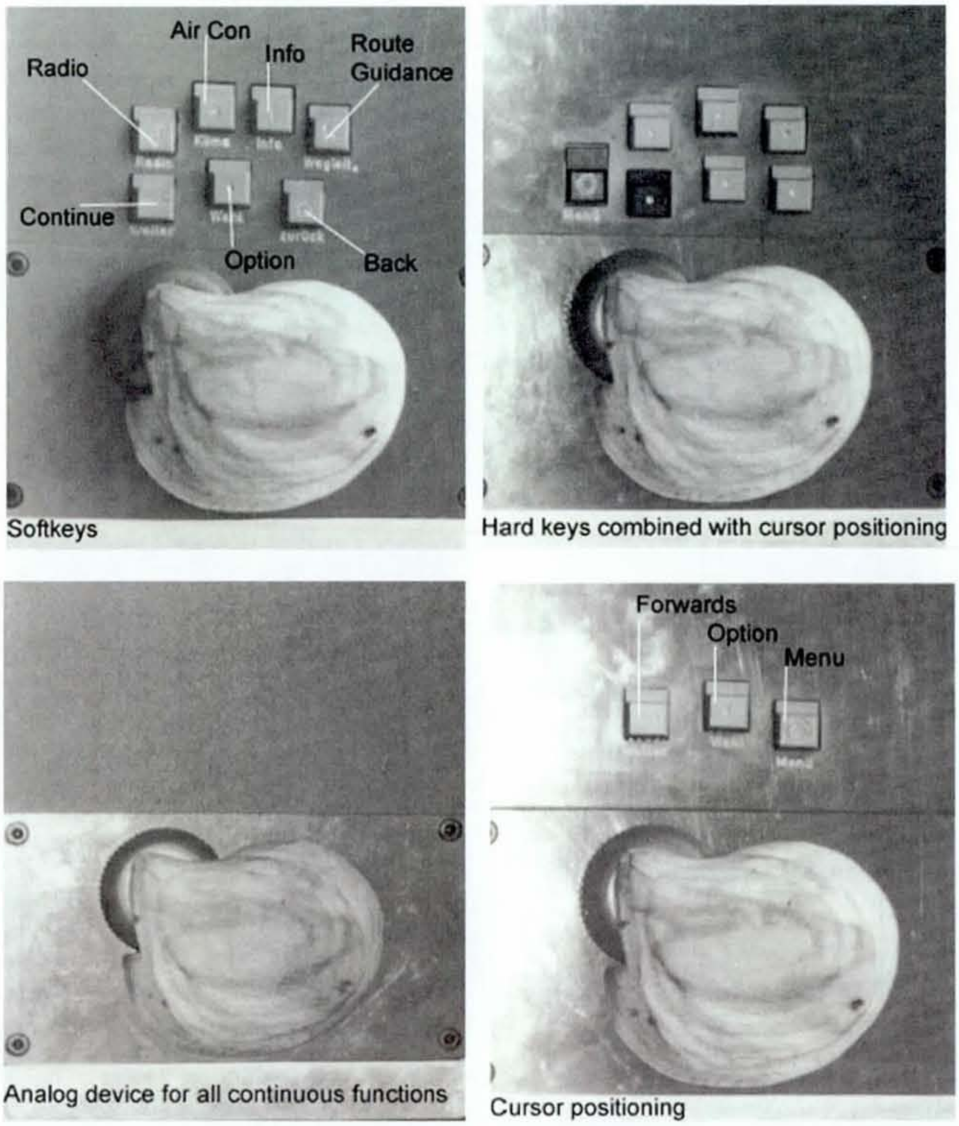


Figure 2.17. The four design evaluated in the study performed by Faerber, B. *et al* (1993)

The four systems were tested using a driving simulator and users were given tasks to perform such as 'change the radio station', and 'increase fan speed'. The results of the driving simulator study showed that the use of speech recognition produced the smallest number and duration of glances away from the road whilst performing control interactions. This was followed by the 'soft keys' arrangement, the 'hard keys' arrangement and the 'cursor positioning' arrangement. There were no specific design recommendations made in the study. The method of interaction with the system, and the design of the screen content were not included in the paper. It is therefore very difficult to derive any useful recommendations from the paper other than the use of speech recognition can reduce glance duration.

2.5 Why use the tactile sense? Alternative options for reducing 'eyes off the road' time

The following section discusses the current efforts by automotive manufacturers to reduce the eyes-off-road time using new technologies. Speech control has been implemented in vehicles produced by Daimler (Mercedes Benz Models), Jaguar, Landrover, and Honda among others. The aim of speech control is to allow users to control secondary functions associated with communications, HVAC, ICE and SATNAV without taking their eyes off the road.

2.5.1 Speech control

It is a natural assumption that speech control could solve the majority of the problems that are being addressed in this thesis. Speech is both hands free and eyes free in the context of the driving environment. Also, speech is an everyday activity, leading to the assumption that a control technology based on speech would allow for rapid learning of new control systems.

Graham *et al* (2000) performed a study comparing a speech control system used in the Jaguar S-Type car, with and without feedback, to the use of steering wheel mounted, and conventional controls. The speech recognition system used was capable of recognising 49 command words, plus a number set. For the experimentation the set of 49 command words was reduced to those that only control the entertainment functions. In order to prepare for the experiment fifty participants were selected on the basis of the following four sample frame groups:

- Female with age ranges from 21 to 35
- Male with age ranges from 21 to 35
- Female with age ranges from 50 to 70
- Male with age ranges from 50 to 70

The subjects were required to practice with the speech control system so that they gained a base line level of performance in order to keep experimental variables to a minimum. Subjects with strong regional accents were therefore excluded, as they were unable to reach the baseline level performance with the speech control system. Of those subjects that remained 10% were unable to reach the base line level of performance.

The experimentation was performed using a driving simulator incorporating a pursuit task, i.e. the participant must maintain a safe distance from the vehicle in front, also known as a tracking task. This was combined with a reaction test based on 'C' shapes appearing on the periphery of the driving simulator screen, with the orientation of the 'C' determining if an action (such as braking) should be performed. The results recorded during the experiment were the success or failure of the reaction tasks, the time to complete tasks, as well as a rating of mental workload for the tasks. It was shown that conventional controls produced the lowest task completion times. The number of participants who were unable to operate the speech control in the study has shown that, in its present form, speech control exhibits technological problems that demonstrate that it cannot be used solely to control the secondary functions of a car.

This has been reinforced by a literature review paper examining studies that have explored the use of different in-car speech recognition systems (Baron *et al* 2006). This paper discussed and compared the results from 15 studies. The conclusions from this literature review show that there are still problems with the percentage of participants that can attain a suitable level of recognition from the speech control systems, after six years of development since the paper by Graham *et al* in the year 2000. This was highlighted by the general methodological approach taken in the assessment of speech recognition systems, i.e. simulating the accuracy of speech recognition systems using 'wizard of oz' (a system simulation in which feedback is provided manually by the experimenter) system simulations (10 of the 15 studies highlighted in the Baron Literature review used a simulation of a speech recognition system). Accuracy thresholds of 80-90% are routinely used in the design of speech control experiments, reflecting the word recognition accuracy levels found in current systems. The vast majority of the more recent papers that examine the use of in vehicle speech control are focused on the ability of speech recognition systems to deal with extraneous noise from the driving task. This indicates that the technology is not mature enough for main stream use at present.

2.5.2 Head Up Displays

Another potential method that is being explored is the use of Head Up Displays (HUDs). HUDs, project information onto a piece of glass that can viewed by the user as shown in Figure 2.18, removing the need to look into the vehicle in order to view displays (known as the head down condition). In the case shown in Figure 2.18 the current speed, gear and engine rev counter information is provided to the car driver. HUDs have been used to provide information to combat aircraft pilots since the 1940's with the use of a projected gun sight in fighter aircraft such as the Hawker Hurricane and Super Marine Spitfire (Tufano, D.R, 1997). These devices have developed over the years to include a greater level of information for the combat pilot, including altitude, rate of climb and descent, the G-Force being applied to the body, and weapons aiming and locking systems. The automotive industry has attempted to apply HUDs in a number of different vehicles over the past 10 years.

Figure 2.18. An automotive Head Up Display implemented in a 2007 BMW M5

Figure 2.19. An automotive Head Up Display showing direction of turn information produced by Seimens and implemented in BMW 5 and 6 series vehicles

The advantages of the use of head up displays in the automotive environment are generally assumed to be;

- The imagery displayed on the HUD is focused at infinity, therefore allowing the user to gain information from the display, at a focal distance that is the same as that required to scan the exterior environment

- The location and focal distance projection of a HUD produce reduced data acquisition times when compared to those for a standard dashboard mounted display

Ergonomics research performed for both the aviation and automotive contexts have raised problems with the use of HUDs which have not been addressed by automotive manufacturers who have implemented HUD strategies in their designs. The main problem that has been identified is the issue of mis-accommodation as report by Iavecchia *et al* (1988). There is a high variability of resting focal distance in the general population. An undetermined proportion of the population will have a resting focal distance that will interact with the imagery projected onto the HUD. This interaction, which has been empirically verified, will produce an effect where users can perceive objects in the outside world as being smaller, and farther away than they really are. There are obvious safety implications for the driving task, and the problem is far from being resolved, as the physiological effect is not currently well defined. The effect has been documented in the aviation field where pilots have had heavy landings because they thought that the runway was farther away than was actually the case (Tufano 1997). It is assumed that the application of HUD technology in the automotive environment will exacerbate this problem as the resting focal distance variability will be higher for the general driving population, than the pilot population.

A further issue that has been raised by Weintraub (1987) is that of *cognitive capture.* The effect involves the user reacting more slowly to unexpected incidents when using a HUD. The effect can be best described using the aviation context. In a study by Wickens and Long (1994) pilots were placed in a flight simulator and asked to pass through a layer of cloud and indicate when they could see a runway below them. The experiment was performed using standard instrumentation displays (head down, looking at cockpit mounted displays) as one condition, and with a HUD as a second condition. As would be expected the HUD condition produced faster recognition of the runway than the head down condition, due to the fact that the HUD allows the user to keep his or her eyes on the external view. The pilots were then asked to land the plane. The pilots were asked to perform this experiment on a number of occasions.

However, on the last occasion an obstacle was placed on the runway, and the time was recorded for the pilot to recognise the danger and abort the landing. The response to the danger was significantly more rapid for the head down condition than the HUD condition. Therefore the pilots were quicker at recognising an exterior danger situation, when using the technique that forced them to look away from the exterior view (head down use of displays and controls).

It is postulated by Weintraub (1987) that the action of moving the head, and changing focal distance when looking at the head down display, helps to switch cognitive 'modes' from scanning to information gathering. The HUD removes this step in the process, therefore forcing the user to perform both tasks at the same time, reducing the overall effectiveness for both tasks.

The combined effects of HUD focal distance, cognitive capture, and cognitive switching produce a situation where the use of HUDs in the automotive environment may produce unexpected detrimental results for drivers. The understanding of the field will be improved with further empirical research. However, HUDs cannot currently be recommended for automotive use.

2.6 Research questions

The literature review has raised a number of questions that will be discussed in the thesis. These questions are as follows;

1. Research question 1: Can the tactile sense reduce the visual load on the driver with a suitably designed interface?

2. Research question 2: What mode of tactile interaction is most applicable for the design of in-car interfaces, active or passive?

3. Research question 3: Can the experiences of visually impaired people help with design of the tactile device for use by people with normal vision?

2.7 Conclusions

The literature has provided very few examples of products that actively use the tactile sense to provide feedback to the user. However, the literature has identified the opportunities and limitations provided by the tactile sense. In addition, useful information has been gathered that refers to testing methodologies for in-car technology and has established glance duration, and task completion times as the metrics for the visual demand of in-car interfaces. The use of stereotypical control operations has been shown to be ubiquitous in the design of many products and is considered to be a strong coding technique for non-visual use. The use of haptic feedback in products that are used by visually impaired people has the potential to provide modal feedback to the non-disabled user. These issues have been explored in the design of three initial concepts in the next chapter.

3 Chapter 3: Preliminary investigations

3.1 Introduction

The following chapter describes two preliminary investigations that were performed to support the design process that was proposed in Chapter 1. These activities were the generation of initial design concepts, and a study examining the tactile cues used by visually impaired people when interacting with electronic products.

The development of the initial concepts was performed to provide models for possible methods of tactile interaction, and discussion amongst the project team members as the literature review was being performed. The criteria that were used in the definition of these design concepts were based upon the findings of the literature review that described the possible tactile interaction methodologies, i.e. the use of active or passive tactile feedback. The three concepts explore different methods of providing tactile feedback, whilst considering issues such as the level of modality of the interface, i.e. would controls perform different functions depending on the selected mode (modal, fewer controls) or would separate controls perform one function each (non-modal, more controls). Three concepts were generated, two of which were highly modal, with pin matrix displays providing active tactile feedback. The third concept considered the use of passive tactile feedback in combination with a lower level of modality.

In order to address research question 3 (section 2.8) a study was designed that examined the use of controls by visually impaired people. The hypothesis of the study is that design recommendations for the production of tactile controls can be derived from observing control interactions performed by visually impaired people. It was proposed that observing the controls that are used successfully without vision would allow the identification of controls that support non-visual interaction for people without visual impairment.

The following chapter describes the initial concepts and the study that was designed and performed with visually impaired people with the following sections:

- The initial design concepts
- The study with visually impaired participants
- Discussion of the results from the study with visually impaired people

This process provided design recommendations for control surfaces to be used with reduced visual load. A comparison is made between the initial design concepts and the subsequently produced design recommendations derived from the study with visually impaired people at the start of Chapter 4.

3.2 The initial design concepts

At the time of the design of the initial concepts the functions that were to be incorporated into the PTI were undefined. However, the definition of the three functional groups (ICE, HVAC, SATNAV) as discussed in the introduction provided a top level model of the PTI interface design process. This model was used to consider the level of modality of the interface, and the options for providing active or passive tactile feedback.

3.2.1 *Design concept 1. Multi modal, dual interaction point with active tactile feedback*

The first multi-modal design was based on the premise that two separate devices could be used at different locations in the car.

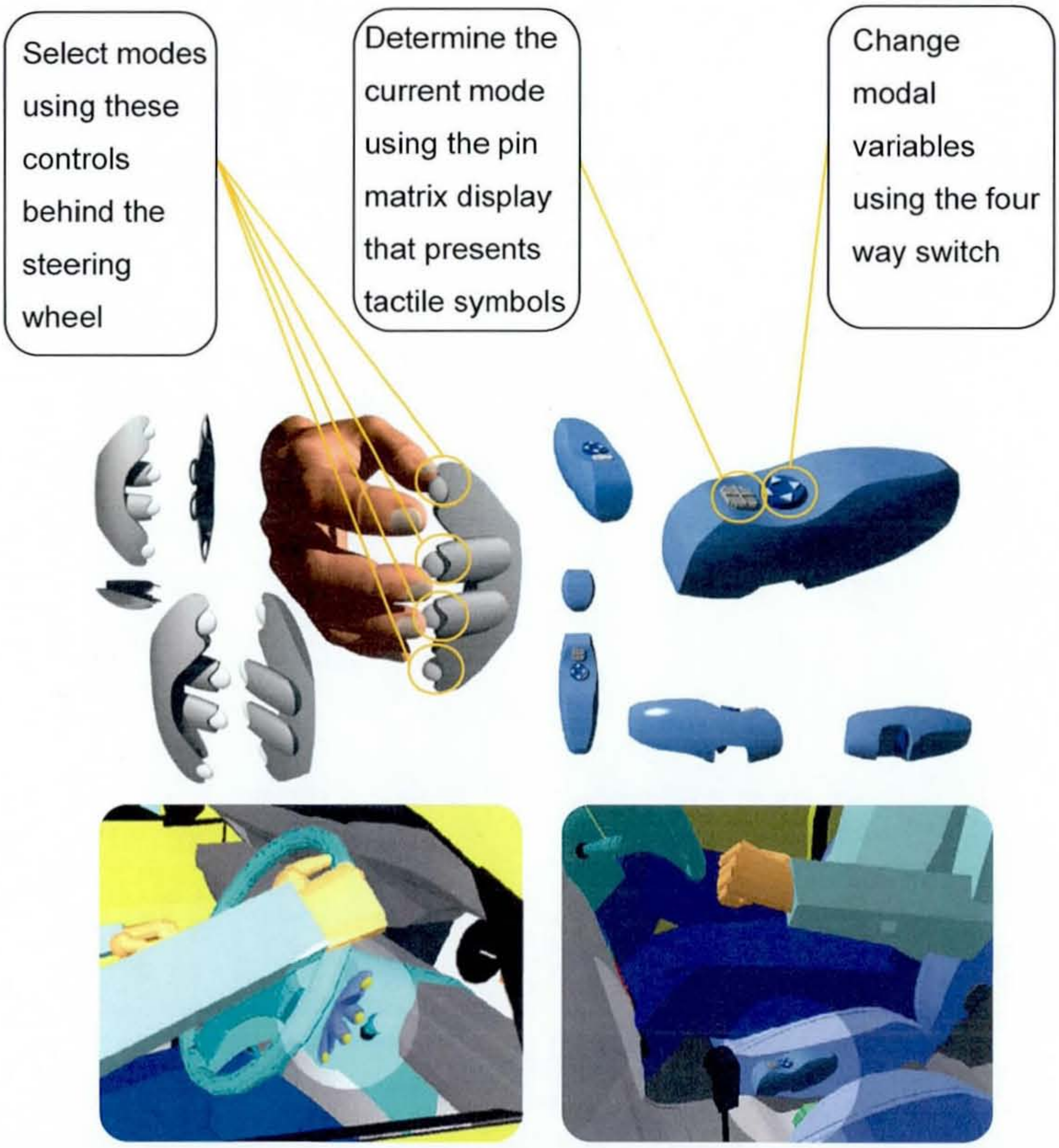


Figure 3.1: The multimodal concept 1. The two images on the left illustrate a device that could be placed behind the steering wheel that could be used to select different modes (e.g. ICE, HVAC and Navigation). The two images on the right show the design of a device that could be used to adjust the variables associated with the selected mode. This device was placed alongside the seat

It was proposed by the author that multiple interaction locations for arrays of controls that are grouped by function could act as a coding technique to aid the recognition of controls. The design of concept number one included a device placed behind the steering wheel with which different modes can be selected (e.g. ICE, HVAC and Navigation). A second device is located next to the seat and is used to select and adjust the variables within the selected mode. The device behind the steering wheel could be used to change mode with the right hand, without taking the hand off the wheel, and the left hand could be used to perform tasks such as increasing temperature, changing CD track, or scrolling through possible navigation destinations. The design of this concept considered the use of a pin matrix display to provide state of the system feedback to the user. This was based upon the work of Shinohara, M. (1998) that was described in the literature review (section 2.4.3). The pin matrix display that was designed and built in that work used 64 x 64 pins with an overall tactile display size of 200mm by 170mm. The pin matrix display that is being considered in concepts 1 and 2 was designed to be interacted with using the finger tip only, and so the envisaged size of the pin matrix display would be in the region of 20mm by 20mm. The pin matrix display (mounted on the top surface of the device next to the seat) would be used to provide modal information such as the current temperature setting, the CD track number, and the location within a list of options.

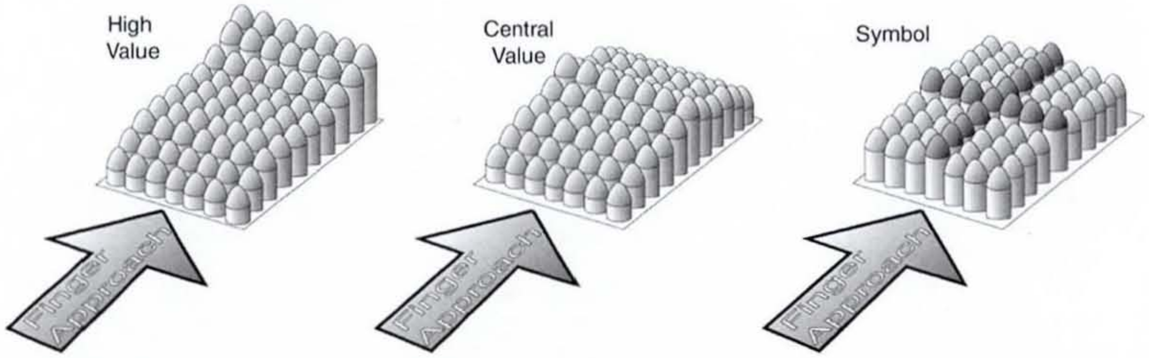


Figure 3.2: The figure illustrates how finger tip sized pin matrix displays were envisaged as a method for providing active tactile feedback to the user. The pins of the display have the ability to quickly change their protrusion levels with the combination of multiple pins making different symbols

At this point in the design process it was anticipated that the design of tactile symbols that could be presented to the user would be the most challenging design task. The airflow direction symbol used in automotive control panel design was presumed to be a well recognised symbol in that it is common in most vehicle interiors. The ISO symbol for airflow direction is shown in Figure 3.3.

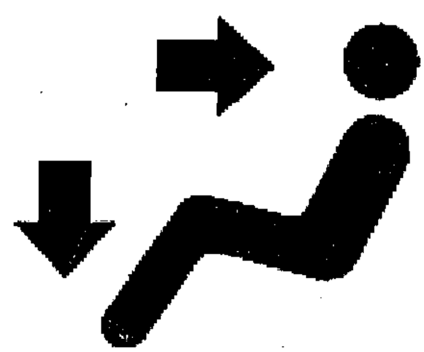


Figure 3.3. The standard airflow direction symbol that represents airflow to the face and feet BS ISO 2575:2004

It was proposed by the author that the airflow direction symbol could be replicated using a pin matrix display, with different protrusion levels of the symbol elements indicating the active functions. Figure 3.4 shows a possible design of a tactile symbol representing airflow direction. The top left image shows the airflow direction to the face, by the raised section that represents the head in the standard symbol. The top right image shows the symbol that would represent airflow to the screen and the bottom image shows the airflow to screen, face and feet.

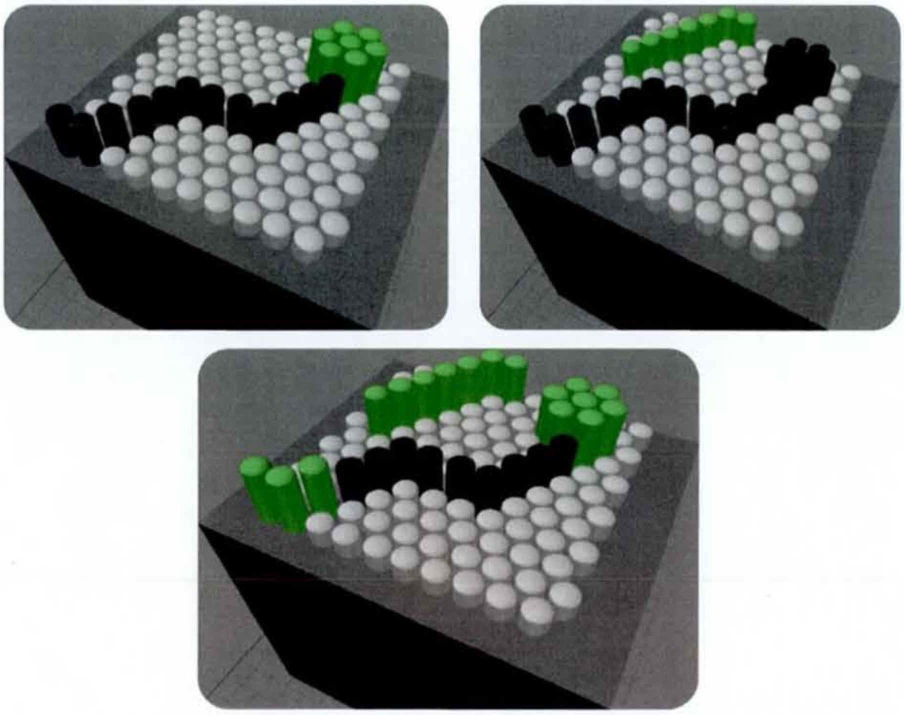


Figure 3.4. An example implementation of the airflow symbol using a pin matrix display (the green pins show the active mode through higher levels of protrusion

Symbols that were capable of providing navigation based information were also considered, as shown in Figure 3.5. These symbols could be used to present direction of turn information using arrow symbols as shown the in the left hand image in Figure 3.5, or more complex information such as the correct turning to take at a roundabout as demonstrated by the right hand image in figure 3.5.

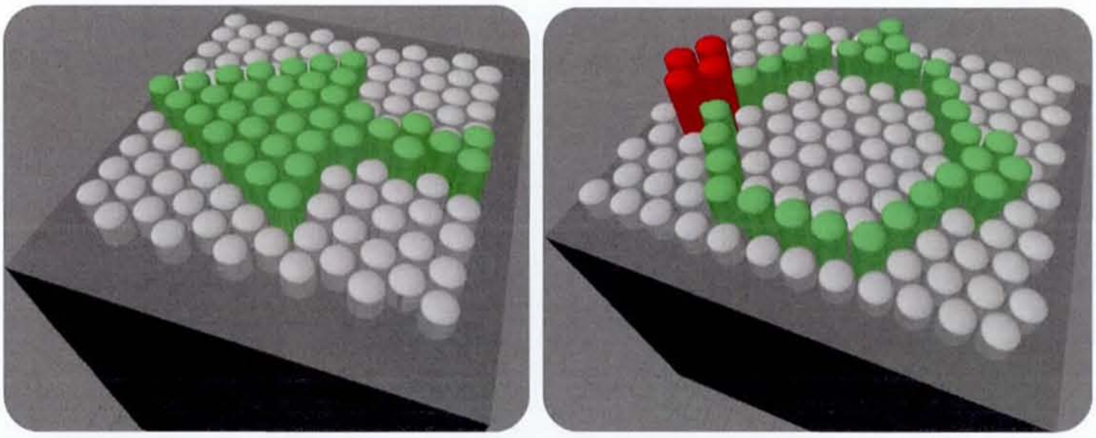


Figure 3.5. An example implementation of navigation information including direction of turn arrows (left hand image) and direction of turn at a roundabout with three possible options (right hand image)

3.2.2 *Design concept 2. Multi modal, single interaction point with active tactile feedback*

The second multi modal concept also used the pin matrix display concept, but in this iteration the display was located under the index finger as shown in figure 3.6. The mounting location for the device is shown in Figure 3.7.

Figure 3.6: The multi modal concept 2. The device was located on the left hand side of the steering wheel 1. Functions would be selected via the white buttons

Figure 3.7: The multi modal concept 2. The device was located on the left hand side of the steering wheel. Functions would be selected via the white buttons

It was envisaged that the top level modes (ICE, HVAC and Navigation) could be selected by the thumb using the white buttons on the triangular surface. The thumb wheel could be used to select modes within the top level functional groups, and variables could be altered by pitching the handle forwards or back (+/- 15 degrees). This could allow all of the functions to be selected and altered using the left hand only.

3.2.3 Design concept 3. Non modal, using tactile tracks to find functional groups and tactile indicators to find specific controls

The third concept that was generated considered a non modal approach, i.e. each control has a specific function that doesn't change. It was anticipated that tactile structures such as those illustrated in Figure 3.8 could be used to subdivide functional groups and indicate the location of specific controls. This design would be located on the dash board control panel as shown in Figure 3.8.

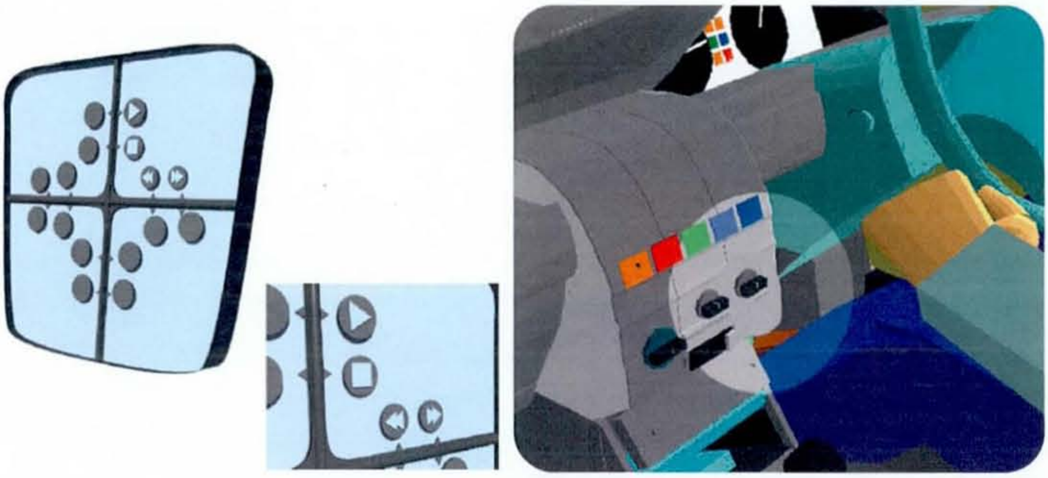


Figure 3.8: Located in the centre of the dash board, the non-modal design uses finger tracks to subdivide functional groups and tactile indicators to allow the identification of specific controls

At this point in the design process the most challenging aspect of the third concept was considered to be the form of the tactile markers that would aid control discrimination. It was thought that the sub division of the control panel would provide a strong coding technique to help with the identification of the different functional groups, and that the prominent location of the panel on the dash board would help the user to conceptualise the control layout using vision.

3.2.4 Summary

The three concepts that were generated in parallel with the literature review have helped to define the following questions;

- Should the PTI use multiple control locations to help divide the functionality and aid recognition of the available functions?

- Can pin matrix displays be successfully used to provide information to the user in an automotive context?

- Can static tactile symbols present a suitable level of information to the user?

The three concepts were a tool for the consideration of the issues associated with providing tactile feedback to the user as is discussed in Chapter 4. The following sections describe the study carried out with visually impaired people that was performed in order to expand upon the knowledge of tactile interaction.

3.3 The study with visually impaired participants

3.3.1 Lessons from the literature

It is the general consensus of opinion that visually impaired people do not have enhanced tactile perception when compared to people without visual impairment (Perera, S. 2002). Indeed, if diabetes is the cause of the visual impairment, tactile sensitivity can actually be reduced. It was considered valid to consider the tactile sensitivity of visually impaired people, and that of people with healthy vision as equivalent. In section 2.4 the literature has demonstrated that tactile symbols used in pin matrix displays, tactile maps and tactile control designs can convey information to the user through the mechanism of touch (Shinohara,1998, Espinosa,1998). It is therefore considered important to examine the control shapes that best convey function to visually impaired people, as these control shapes would also have potential for non-visual use by road vehicle drivers. The literature has also demonstrated that control motion stereotypes should be maintained in the design of controls that are to be used non-visually, utilising the preconceptions that are held by users based upon their previous experience of interacting with controls.

There are many causes for visual impairment, and there are different levels of visual impairment. The RNIB describe twenty seven main causes for visual impairment including Cataracts, Diabetic Retinopathy, Glaucoma, Macular Degeneration and Retinitis Pigmentosa. These conditions have different effects on the field of vision and the quality of the perceived image from the eye. This has made quantification of visual impairment problematic. A system for the quantification of visual impairment was devised for the OPCS (Office of Population, Censuses and Surveys) publication, The Prevalence of Disability Amongst Adults (HMSO 1988). The document produced described a survey performed with over 14000 participants. The data collection system used a pragmatic approach that rated the visual impairment of people by their ability to perform visual tasks. These tasks were placed in an ascending order of severity of visual impairment as can be seen in Table 3.1.

OPCS: severity scoring for visual impairment		Severity score
S1	Cannot tell by the light where the windows are	12.0
S2	Cannot see the shapes of furniture in the room	11.0
S3	Cannot see well enough to recognise a friend if close to his face	10.0
S4	Cannot see well enough to recognise a friend an arm's length away	8.0
S5	Cannot see well enough to read a newspaper headline	5.5
S6	Cannot see well enough to read a large print book	5.0
S7	Cannot see well enough to recognise a friend across a room	4.5
S8	Cannot see well enough to recognise a friend across a road	1.5
S9	Has difficulty seeing to read ordinary newspaper print	0.5

Table 3.1. The classification system used to rate the severity of visual impairment (HMSO 1988)

This demonstrates that the selection of participants that are recruited for the study should be carefully considered. For example, participants who could see well enough to read a newspaper headline, may also be able to identify control shapes visually, which would help to inform the user of the function, and mode of operation of the control. It was therefore recommended that participants with vision at or above the severity score of 8 in table 3.1 should be recruited for the study.

There are established methods for the systematic assessment of the abilities of disabled people to perform tasks. Occupational therapists have established a structure for such assessments called AMPS (Assessment of Motor and Process Skills) (Baron K.B. 1994. Cooke, K.Z. 2000. Chard, G. 2005). The AMPS protocol aims to assess the abilities of disabled and elderly people to perform activities of daily living such as making a hot drink, cooking a meal and washing clothes. The AMPS method is used by occupational therapists to determine if elderly and disabled people are capable of living independently, and also to determine the suitable level of support services if these are required. The AMPS method uses a list of predefined tasks that have been broken down into assumed task stages by the authors of the method. The first stage of the AMPS method is a discussion between the occupational therapist and the person being assessed to determine which tasks can be realistically performed. The person being assessed is then asked to perform each of the selected tasks. The person being assessed would be given an instruction such as "make a cheese sandwich" with no other instructions being given until the completion of the task unless the participant struggles to know what to do next. The method used by the person being assessed is compared to assumed process stages. An example of this process can be seen below.

AMPS Task: Make a cup of tea

Assumed process stages

1. Fill kettle (the kettle should be empty)
2. Plug in kettle (the kettle should be unplugged)
3. Turn on Kettle

4. Retrieve cup from storage
5. Put tea bag in cup (or tea pot as appropriate)
6. Fill cup (or tea pot)
7. Retrieve milk from storage (if used by participant)
8. Add milk and sugar as appropriate

The list of tasks have been designed to represent different levels of complexity in both the motor (manipulate an object, lift an object, grip a handle, carry an object, and reach to interaction points) and process (cognitive) skills (sequences of task, notes feedback, use successfully, complete the task). This allows for the exploration of why the participant may stray from the assumed task stages. The reason for deviation may be because of a coping strategy (such as sliding the filled kettle along the work surface to avoid lifting it) that is used to overcome some aspect of their disability, or it may be an indication that the process skills of the participant are lacking. Any coping strategies used by the participant are recorded by the occupational therapist at the appropriate stage.

The AMPS method demonstrates that by breaking a task down into assumed task stages, and noting the coping strategies used by the participant, a deep understanding of the interactions that are being performed can be obtained. The notion of coping strategies is an important one for the study design. Disabled people often demonstrate coping strategies when performing activities of daily living. It was anticipated that visually impaired people would also demonstrate coping strategies that could be illustrative.

3.3.2 Study design

It was proposed that visually impaired people would be video recorded whilst interacting with an unfamiliar electronic product. In doing so, the visually impaired participants would be able to demonstrate which controls convey function and operational feedback based upon their shape and motion characteristics. It was also proposed that by observing visually impaired people whilst they interact with their own equipment, that coping strategies, or learned behaviours, that allow non visual use may be demonstrated. It was therefore proposed that after interacting with different electronic devices in everyday life, and therefore different control designs, visually impaired people would have preferences for certain control coding techniques that they find information rich, leading to the selection of products on the basis of interface design issues.

Loughborough, in Leicestershire is the home of the RNIB training college. This college trains visually impaired people to live independently and gives training that allows visually impaired people to enter the work force. Visually impaired people at the RNIB college in Loughborough interact with electronic products on a regular basis, from browsing the internet using audio feedback on personal computers, to using washing machines. The RNIB College provided a number of willing participants for the study.

The initial step in designing the experiment was to explore a methodology that would allow visually impaired people to express the skills that are used when interacting with controls. A study design that followed the basic structure of the AMPS process was defined i.e. breaking tasks down into assumed task stages, and observing coping strategies that are used by the participants.

3.3.3 Selection of the electronic equipment

The lessons from the literature, and need to examine both familiar and unfamiliar product interactions with visually impaired people were combined into four criteria for the selection of the test equipment as follows;

1. The device should contain functions that are similar in operation to the those found in an automotive environment
2. The device should contain both stereotypical and non-stereotypical control layouts and modes of operation
3. The device should use as many different control types as possible
4. The device should be portable to allow it to be easily taken to user trial sessions in the homes of the visually impaired people

With these criteria in mind a product search was performed online. It was noted that portable electronic HIFI devices often contain controls such as rotary dials, sliders and push buttons, the same type of controls that are found in current automotive interiors. Initial discussions with the students at the RNIB College confirmed that all students owned a piece of HIFI equipment. A portable HIFI was therefore sought that contained both stereotypical and non-stereotypical control motions, whilst also utilising a number of different control types. The portable HIFI selected for the study is shown in Figure 3.9.

Figure 3.9. The portable HIFI equipment used in the experimentation

The following section describes the functions and interface design of the selected equipment and the reasons for their inclusion in the tasks that were given to the subjects.

3.3.4 The task list derived from the analysis of the controls including in the test device

The selected device provided three main functional groups (CD, Radio and Tape modes) that allowed scenario tasks to be generated as per the AMPS process. These tasks were then broken down into the assumed task stages. These functional groups defined the following tasks and assumed task stages based upon the design of the selected device.

CD Scenario: Task 1. Turn the HIFI on

This is done using the control shown Figure 3.10. The protrusion level of the power button is larger than the surrounding buttons.

Figure 3.10. The power button on the selected portable HIFI

CD Scenario: Task 2. Open the CD drawer

The control for this task has a textured surface as shown in Figure 3.11

Figure 3.11. The button used to open the CD draw

CD Scenario: Task 3. Select CD mode

The control for this function is a three option slider switch with detents for each of the options as shown in Figure 3.12.

Figure 3.12. The slider switch used to select from the three modes of the portable HIFI

CD Scenario: Task 4. Play the third track of the CD

The 'Skip Up' button needed to be used to select the third CD track as shown in figure 3.13.

Figure 3.13. The push buttons used to select the CD track

CD Scenario: Task 5. Reduce the volume

The rotary control shown in Figure 3.14 was used to reduce the volume.

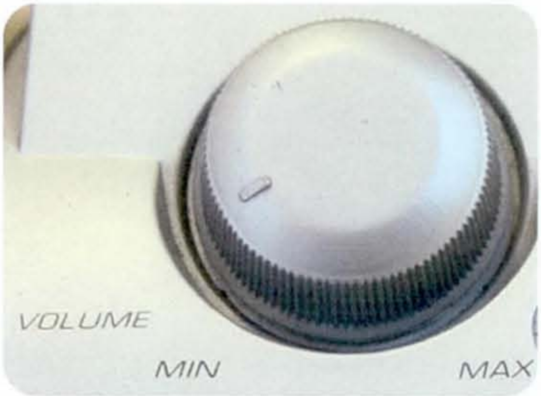


Figure 3.14. The rotary control that was used to change the volume

Radio Scenario: Task 6. Select the radio mode

The radio mode is selected using the three option slider switch shown in figure 3.12.

Radio Scenario: Task 7. Tune in a radio station

The rotary control used to tune the radio station is in the mirrored position of the volume control on the device. The only method of differentiation between these controls is the tactile marker that is placed on the volume controls as shown in Figure 3.15

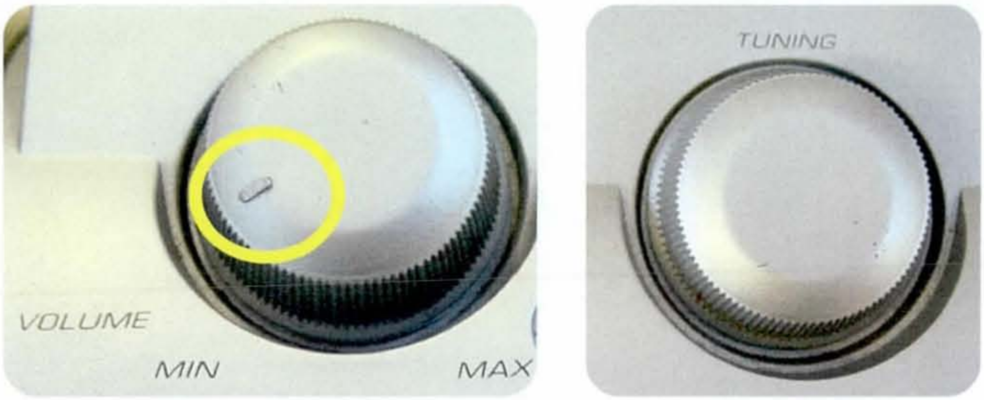


Figure 3.15. The rotary control that was used to change the volume, and the same shaped and sized radio tuning control

Tape Scenario: Task 8. Select Tape mode

The tape mode is selected using the three option slider switch shown in Figure 3.12.

Tape Scenario: Task 9. Eject the tape holder

This is performed using the second button from the right in Figure 3.16.

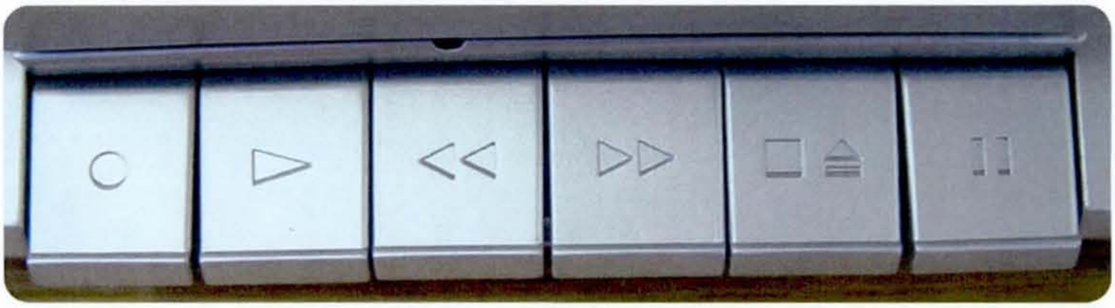


Figure 3.16. The cassette player controls

Tape Scenario: Task 10. Insert a cassette into the cassette tray

The participant is required to insert a tape into the cassette tray using the correct orientation of the cassette.

Tape Scenario: Task 11. Fast forward the tape and then play the tape

The participant was required to use the third control from the right to fast forward the tape, and the second control from the left to play the tape. These tasks required the participants to use all of the control types that are built into the selected portable HIFI.

3.3.5 Experimental procedure

The AMPS process requires the participants to work in silence once a task has been assigned to avoid inadvertent support of the task through conversation with the experimenter. This is particularly important when assessing the cognitive skills of the participant. It was decided that this was inappropriate for the study with visually impaired participants as it was considered important to analyse the preconceptions of the participants regarding the controls that would be associated with certain tasks. It was proposed that each participant would verbalise their expectations of the control types that are associated with the given tasks before each task was performed. The interviewer asked each participant to discuss which control type that they expected before each task was performed, and discussed the tactile interaction that allowed the correct control to be found. The interviews were video recorded to allow the transcription of the data after the study had been completed. A recording sheet was generated that allowed the recording of the success or failure of the control interaction, and any coping strategies used. An example of a task stage, and the information that was recorded can be seen below.

Turn the HIFI on

Notes on coping strategies/ Differences to assumptions above / safety implications
Expected control. Latching push button, or the first click of the volume rotary. He found the power switch almost straight away, and passed his finger from the power switch to the CD skip track buttons noting the difference in height. When he switched the device on he said "BINGO" when he heard the CD spin (as it does when the device is powered). The sound allowed the participant to determine that he had successfully turned the device on.

The procedure was performed with each of the task stages listed in section 3.3.4. This was followed by an examination of the electronic equipment that was owned by each participant. They were asked to demonstrate the use of the device, and highlight any tactile features that allowed non-visual interaction. Finally the adaptations made to the products used by visually impaired people by their support staff to enable easier use were examined. The final stage was added after a personal communication with Geoff Haynes, year tutor at the RNIB College in Loughborough. Geoff Haynes advised that students have their electronic products modified to help in the location of important controls. The full recording sheet including the data captured for each participant can be seen in Appendix 2.

3.3.6 Pilot study

In order to explore the issues surrounding the level of visual impairment, a pilot study using two participants was performed. One participant had complete visual impairment with an OPCS visually impairment rating of twelve; the second participant had a severity score of eight on the OPCS scale for vision (see Table 3.1). In this way the control interaction methodologies of blind and partially sighted participants were explored. The experimental procedure that was defined in section 3.3.4 was used during the pilot. After analysing the video recording of the two trials a difference was noted between the methodologies that were used by the two subjects. The participant with some level of vision used a methodology that included the use of the limited vision available to her. The participant spent much longer than her counterpart exploring the device by attempting to determine the overall layout using a combination of the tactile and visual senses. The participant with no vision explored the device with a more methodical approach, and spent approximately half the time on the initial examination of the device, with no apparent detriment to performance in the tasks that followed. It was considered important to explore the use of limited vision further in comparison to the subjects with no vision at all. Both groups were included in the sample used in the study.

The pilot also raised another issue, because the participants were allowed to explore the shape of the device before tasks were given, they had already formed some preconceptions on the shape and therefore the function of some controls. In order to allow the observation of the behaviour associated with the first exploration of an electronic device the participants were not allowed to explore the device before the tasks were given during the main trial.

3.3.7 The sample frame

Table 3.2 shows the level of visual impairment, age and gender of the participants that were selected for the study.

Participant number	Gender	Age	OPCS severity score of visual impairment
1	Female	17	10
2	Male	19	12
3	Male	21	9
4	Male	42	8
5	Female	23	8
6	Male	19	8
7	Female	29	8
8	Female	21	8
9	Male	24	12
10	Female	24	12

Table 3.2: The level of visual impairment in the sample recruited for the study

Many participants were unable to name the medical term for their visual impairment making the use of OPCS scale particularly relevant. The sample included three participants with no vision, and seven participants with some level of vision. With all participants at OPCS vision impairment level eight or above, none of the labels on the test equipment were able to be read by the participants during the trials, and none of the button shapes would be distinguishable visually.

3.3.8 Summary of findings

The video recording of each trail was reviewed in order to capture the methodology used in the assessment of the product, the success or failure of the task, and the coping strategies used. Images were captured of the electronic equipment that was owned by each participant. The following sections discuss the main findings from the analysis of the video and the notes taken.

3.3.8.1 The interaction methodologies that were demonstrated

It was found that the initial inspection of the device was performed once the first task had been presented to the participant i.e. turn on the HIFI. There was a split in the methodologies used in this initial exploration of the controls depending on the level of visual impairment of the participant. Participants with no vision performed a very fast, but methodical examination of the device with the following stages;

Figure 3.17. Initially gauging the overall size of the device

Figure 3.18. An initial relaxed flat hand exploration of the top and front surfaces

Figure 3.19. Tracing the outlines of controls to determine their shape

Figure 3.20. Testing the mode of operation of different controls

Participants with some level of vision all attempted to use that level of vision, which generally slowed down the process of control identification when compared to the subjects with no vision. During the initial inspection all participants tested the shape and motion characteristics by running their hand over the surface to identify objects that were protruding from the surface, and then tracing the control shape with the finger, and determining control height. The success of this process and the level of comprehension that is obtained were illustrated by the following example. On a number of occasions the participant would inadvertently leave the volume setting high after exploring the control motion. When the CD mode was selected as per the CD Scenario, Task 3 the first reaction of the participants was to quickly reduce the volume from the HIFI. In all of the three cases where this happened the participant quickly selected one of the two large rotary controls on the top of the device, and rotated them anticlockwise. The volume control was selected in two of these occasions, in the other the radio tuning control was incorrectly selected. This highlighted the strength of the stereotypical associations that are inferred from control shape and motion.

When exploring the device six of the ten participants mistook the microphone grill for an active area due to the textured surface that is created by the holes. This suggests that the subjects were searching for a textured surface to indicate an interaction point. The phrase 'tactile noise' was coined by the PTI team and was seen as something to avoid in the design of tactile control interfaces i.e. avoid the use of textures on surfaces that are not interaction points. The participants indicated that different levels of protrusion of controls from the surface of the device gave clues as to the function, where there were two protrusion levels adjacent to each other. The power switch was identified using this cue by the majority of participants.

None of the participants could identify the shape of the indented symbols on the cassette player buttons. Most participants stated that protruding symbols are better due to the fact that one could trace the finger tip around the shape improving identification. Nine of the participants could remember the order of cassette button function from previous experience illustrating the use of stereotypical control layouts as a beneficial control coding technique.

3.3.8.2 The task completion data

Table 3.3 shows the tasks that were successfully and unsuccessfully performed by the participants.

					Participant					
Tasks	1	2	3	4	5	6	7	8	9	10
Task 1:Turn the HIFI on	Done	Done	Done	Done	Done	Done	Fail	Done	Done	Done
Task 2: Open the CD draw	Done	Done	Done	Done	Done	Done	Done	Done	Done	Done
Task 3: Select CD mode	Done	Done	Done	Done	Done	Done	Done	Done	Done	Done
Task 4: Play the third track of the CD	Fail	Fail	Done	Done	Fail	Done	Done	Done	Done	Done
Task 5: Reduce the volume	Done	Done	Done	Done	Done	Done	Done	Done	Done	Done
Task 6: Select the radio mode	Done	Done	Done	Done	Done	Done	Done	Done	Done	Done
Task 7: Tune in a radio station	Done	Done	Done	Done	Done	Done	Done	Done	Done	Done
Task 8: Select Tape mode	Done	Done	Done	Done	Done	Done	Done	Done	Done	Done
Task 9: Eject the tape holder	Done	Done	Done	Done	Done	Done	Done	Done	Done	Done
Task 10: Insert a cassette into the cassette tray	Done	Done	Done	Done	Done	Done	Done	Done	Done	Done
Task 11: Fast forward the tape and then play the tape	Done	Done	Done	Done	Done	Done	Fail	Done	Done	Done

Table 3.3: A table of results for the success and failure of the tasks performed in the study

The three failed attempts to find the third CD track in Task 4 were associated with confusion that arose from the non-standard circular array of controls shown in Figure 3.21.

Figure 3.21. The circular array of controls that caused confusion for participants

Two participants pressed the PROG button during the exploration of the product, which set a mode that is used to edit the playlist order for a CD. When this mode was activated the device would not respond until the user performed the correct action to select CD tracks. This stopped the two participants from proceeding in the selection of track number three from the CD. Both participants stated that they expected the circular array of controls to follow the standard pattern of play at the top, stop at the bottom, with skip track buttons in the left and right quadrants. As can be seen in Figure 3.21, the left and right quadrants of the circular array contain a blank button on the right had quadrant, and two CD related buttons in the left hand quadrant.

The only other two task failures were associated with participant number 7. This participant only used her own HIFI to play tapes. She could not find the power button during the experiment, and was expecting the power button to be on top of the device. She spent some time operating the controls on the top surface of the device and needed to be prompted to explore the front surface where the required control was located. When performing the 'fast forward cassette' task, the participant stated that she could not remember the order of the controls and was therefore unsure if she was fast forwarding or rewinding the tape when she heard the auditory feedback of the tape spooling.

3.3.8.3 The control types that provided feedback to the user

The recording sheets used in the study (see Appendix 2) captured the control type that was expected by each participant for each task before the task was completed. Some participants stated a number of options for the possible control type for a particular function, and some only mentioned one type, based upon their previous experience. The control types that were most accurately predicted by the participants were the rotary controls for the volume and tuning of radio stations. The analogue nature of the function indicated a control that can be varied in an analogue manner. The other controls that were successfully predicted by the participants were sliding switches for the selection of mode, and push buttons for the selections of discrete on/off options. As is suggested by the literature (see section 2.5.2.) the selection of control types depends on the function that is to be controlled. The visually impaired participants all predicted viable options for the controls types that were expected for each task. For example, participant number three suggested a rotary control for the volume function (turning clockwise to increase), and then provided another option, namely, two buttons mounted vertically and placed next to each other with the top button increasing the volume, and the bottom button decreasing the volume.

3.3.8.4 The examination of the equipment owned by the participants

A range of devices where demonstrated by the participants. These products, and the way that they had been adapted in some cases were highly illustrative. Figure 3.22 shows a device that was owned by three of the participants (5, 7 and 8, who had independently selected this model). The small portable HIFI contained large buttons that were shape coded using standard symbol designs for play, stop, fast forward, re-wind and record. Participant number 5 stated that she found this design easier to use than any other HIFI she had owned previously, with the symbol shaped buttons being especially useful when she first obtained the device and started learning how to use it. All participants expressed a preference for shaped buttons that described function.

Figure 3.22. A portable HIFI that was owned by 3 of the 10 participants

Other participants owned much more complicated HIFI equipment such as the device shown in Figure 3.23. Three participants (3, 4, and 9) owned static (non-portable) devices that contained many more buttons, and functions than the device shown in Figure 3.22. All three participants wanted to have a good level of sound quality with which to listen to their music, and were not prepared to accept the reduced sound quality available from portable devices. All three participants stated that they struggled with the more complex devices when they first purchased them, and that many of the functions that were available in these devices were not used as they required the user to read information from an LCD display. The functions that were not well understood or used by the participants who owned static HIFI systems included options for changing the graphic equaliser settings and building play lists, which required the user to navigate sub menus. The visually impaired users were unable to do this.

Figure 3.23. A portable HIFI that was owned by 3 of the 10 participants

Some products were demonstrated that had been adapted by the support staff at the RNIB college to improve ease of use. The remote control shown in Figure 3.24 has been adapted to remove most of the buttons that are included in the device.

Figure 3.24. Only 20 of the original 46 buttons remain after the customisation of the remote control, the remaining controls are highlighted by the yellow boxes

Participant number 10 stated that she would often press the wrong button on the remote control before it was modified, which would require her to power off the TV from the plug socket if she was in a mode she did not understand without the use of vision. This did not occur after the remote control had been modified. Only 20 of the original 46 buttons remain after the customisation of the remote control, the remaining controls are highlighted by the yellow boxes in Figure 3.24. Another remote control was demonstrated by participant number seven. The remote control shown in Figure 3.25 was used to control a portable HIFI. The participant only used the light grey buttons in the middle of the device that controlled the volume, and allowed the selection of the required CD track or Radio station. He had no idea of the functions that were operated by the dark grey buttons at the top of the device.

Figure 3.25. A remote control device that was demonstrated during the user trials. Only the light grey buttons in the middle of the device were used

Other adaptations to devices included the addition of tactile markers. For example, the washing machines that were used in the hall of residence of the RNIB College had been modified by the addition of stick on rubber markers. These markers indicated the dial positions of three popular wash cycles. The students are trained in the use of the coding when they arrive on campus.

3.3.8.5 Coping strategies that were exhibited by the participants

The analysis of the coping strategies used by the participants highlighted a key method used by visually impaired participants. Three participants (4, 6 and 9) located their hand in a consistent way when interacting with their own electronic devices. This was done by finding a particular tactile feature, which was then used to locate other controls. An example of this was the use of a bevel in a speaker grill. When wanting to change the CD track or volume on a portable HIFI, the participant would touch the left hand side of the device and then run his thumb along the edge of the speaker grill. When the thumb hit the end of the speaker grill he could then reach the skip track and volume buttons in a consistent manner. The phrase 'Hand Control Reference Point' (HCRP) was coined to describe this method of interaction. The use of auditory feedback supported the participants in their use of the controls. For example, When the CD mode was selected the CD would spin momentarily, making a sound. When the users switched to the radio mode, white noise was heard from the speakers. This illustrated the need for feedback that confirmed that the correct selection had been made.

3.4 Discussion of the results

The study with visually impaired participants has highlighted a number of design issues that have the potential to influence the design of the PTI system. The experiment with the 'unfamiliar' portable audio equipment highlighted the association of particular functions with stereotypical control types, such as a rotary knob for controlling volume. The control designs that showed stereotypical control design characteristics were successfully used, and the non-standard control layouts caused problems for participants. The discussion with the participants regarding the equipment that they own illustrated the use of tactile features to aid control location and discrimination. It was also shown that reducing control clutter can be beneficial, and that protruding buttons that are shaped as symbols can help in the process of learning a new interface. Section 4.2 contains design recommendations that have been derived from the results of the study with a description of the issue that highlighted the recommendation.

3.5 Conclusions

The initial concepts were defined to allow the consideration of the level of modality of the PTI whilst also illustrating the possibilities for both active and passive tactile feedback. Subsequently, the study with visually impaired people highlighted further design issues that relate to tactile coding and modality. These findings were considered in the production of a design specification for an interface that uses tactile coding to reduce visual load as discussed in the following chapter.

4 Chapter 4: Building a design specification for the Prototype Tactile Interface

4.1 Introduction

This chapter brings together the recommendations from the literature and the study with visually impaired people to create a specification for the design of a tactile interface. The chapter compares the three initial concepts defined at the start of the previous chapter to the recommendations, and describes the selection of a design strategy for the PTI. This is followed by a description of the process that was used to select the functions that are included in the PTI. The chapter then describes the analysis that was performed to determine the possible mounting locations for the PTI device with a vehicle provided by Honda R&D. These issues are discussed in this chapter using the following structure.

- Design recommendations that have been inferred from the literature review and the study with visually impaired people.
- A comparison between the initial concepts and the recommendations
- Determining the location of the PTI interface components
- The function selection process

4.2 Design recommendations that have been inferred from the literature review and the study with visually impaired people

The review of the literature and study with visually impaired people has highlighted a number of design recommendations for the production of the PTI. These design recommendations are listed below along with their source.

Recommendation 1: The visual and tactile model of an interface should be linked

The work of Sathian *et al* (2002) demonstrated the link between the visual cortex and the processing of tactile inputs. It was therefore proposed that the visual and tactile coding of control layouts should be linked. It was suggested by the author that tactile features could be used to subdivide functional arrays of controls, with the tactile model of layout mirroring the visual model. This has been demonstrated by the car seat controls shown in Figure 2.14.

Recommendation 2: Tactile symbols have the potential to convey information to the user

A number of examples influenced the inclusion of this recommendation. These included the work on pin matrix display designs discussed in section 2.4.2.3 and the successful implementation of tactile coding in-car controls and the controls of large machinery discussed in section 2.5. The study with visually impaired people also highlighted the benefit of using button shape to indicate function as highlighted by the successful use of symbol based interfaces owned by three of the ten participants.

Recommendation 3: Subdivision of an interface using different locations exploits the kinaesthetic sense's ability to 'over learn'

The discussion of the physiological limits of the tactile sense in section 2.4.2 included the work of Kosslyn and Ochsner (1994). This suggested that over time the action of reaching to a particular location can be 'over learnt' by the user removing the need to use vision. The use of distinct locations for portions of the interface has the potential to be a strong coding technique, with long term reductions in the use of vision to locate controls. The study with visually impaired people also highlighted interface subdivision through the use of HCRPs.

Recommendation 4: Use the finger tip as the tactile interaction point

Section 2.4.1 of the literature review highlighted the finger tip as the part of the of body that should interact with tactile coding. The finger tip is the most sensitive accessible part of the body for both active and passive tactile explorations. This was combined with the observation of the finger tip being used in the study with visually impaired people.

Recommendation 5: Two surfaces that are to be distinguished from each other should have a change of level of 5mm or greater

Section 2.4.1 also discussed the thresholds for tactile discrimination of two surfaces. The section highlighted the need to account for the degradation in tactile discrimination with age by using 5mm of protrusion between two surfaces that are to be differentiated by older users. The study with visually impaired people highlighted that a change in control mounting height when compared to the surrounding controls can be informative. For example, the use of the power button as discussed in section 3.3.4.

Recommendation 6: The PTI should allow the control of as few functions as possible

This recommendation was derived from the study with visually impaired people. The examples of product adaptation to reduce function, combined with the long training times that were found by participants with complex HIFI systems, have demonstrated that the smaller the number of functions that are to be included in a tactile interface, the more likely it is that the user will not become confused between those functions.

Recommendation 7: The PTI device should use embossed symbols to allow the user to trace shapes or recognise a location on the basis of the edges that surround it

All participants in the study were unable to identify the cassette player controls using the indented symbols on the buttons. Instead they remembered the order of the buttons on the cassette player, or used trial and error to find the correct control. All stated that they preferred embossed symbols which could be traced by the finger, as demonstrated by the device in Figure 3.14.

Recommendation 8: Tactile reference points should be employed that allow users to identify controls by their relative location whilst supporting the hand during control interactions

Three of the visually impaired subjects used HCRPs when interacting with their own audio equipment, locating the hand in the same starting position each time, using a tactile feature of the device control panel as a reference point.

Recommendation 9: 'Tactile Noise' or the use of textured surfaces that are not related to control identification should be avoided

The term tactile noise was derived from the confusion that was fostered by textured surfaces on the portable HIFI that was used during the testing. Figure 4.1 shows the microphone grille that is built into the design. The texture of this grille was often mistaken for an active control area, and was most commonly mistaken for the eject CD button shown in Figure 4.2. This highlighted the need to avoid 'tactile noise in the design of the PTI. The use of textures should be planned carefully.

Figure 4.1. A microphone grille that was often mistaken for the eject CD button

Figure 4.2. The button used to eject the CD

Recommendation 10: Supplemental feedback that confirms that the correct control selection has been made should be included in the device

The main form of feedback that demonstrated task success was found to be audio feedback in the study. It was anticipated by the author that the use of tactile coding could provide state of the system feedback. The study highlighted the importance of feedback from the system.

Recommendation 11: The PTI should be visible to the driver

The link identified between the tactile and visual processing centres of the brain (see section 2.4.2.1) indicate that the interface should be visible to the user to aid the conceptualisation of the layout.

Recommendation 12: Design a non-modal interface where possible

The accidental use of the PROG button (see section 3.3.8.2) during the study highlighted the difficulty in performing modal control interactions without vision. This suggests that the PTI device should be non-modal where ever possible. An example of this low modality would be to use a separate control for every function.

Recommendation 13: Exploit the stereotypes generally held by users to convey information

The study with visually impaired people demonstrated that stereotypical control shapes and layouts can convey information to the user (see section 3.3.8.4). The non stereotypical use of the circular array of controls discussed in section 3.3.8.2 was shown to be counter intuitive and confusing for participants in the study.

Recommendation 14: The components of the tactile interface should be within easy reach of the user

It was presumed that if the user is required to change the posture of the body to reach a tactile interaction point (leaning forwards or sideways) that the user would tend to look where they are reaching. It was also noted that a reaching location that requires the user to lean to allow reach has the potential to cause discomfort if the posture is held for a significant period of time.

4.3 A comparison between the initial concepts and the recommendations taken from the literature and the study with visually impaired people

4.3.1 Introduction

The three initial concepts that were described in section 3.2 are compared to the design recommendations in the following sections.

4.3.2 The implications of the recommendations on concepts 1 and 2

Figure 4.3. Concepts 1 and 2

Concepts 1 and 2 were both highly modal, using pin matrix display technology to present information to the user regarding the current system mode. These concepts relied upon the user of the interface being able to interpret the currently selected mode by the tactile icon that is displayed on the active pin matrix display. Recommendation 12 suggests that a modal strategy, inherent in the use of a pin matrix display should not be used. Concepts 1 and 2 also included locations that were potentially not viewable going against recommendation number 11. The exclusion of concepts 1 and 2 is also supported by the need to use stereotypical icon designs as suggested by recommendation 13. The discussion of functions that have strong symbolic stereotypes in section 4.2.13 highlighted the potential of a pin matrix display to provide state of the system information of HVAC and SATNAV modes. However, when further functions were considered such as selecting a navigation destination, switching between CD and Radio modes, and selecting automatic air conditioning, there were no standard symbols that were considered to be easily recognised upon which to base the design of tactile symbols. These functions are labelled in a number of different ways by automotive manufacturers, with some using symbols, and some using English text, or abbreviated text. It was therefore considered unlikely that symbols could be designed to represent these and other functions that could be recognised by users without training.

The pin matrix display that was proposed in Figure 3.5 would be smaller than any other produced and therefore potentially challenging to prototype, and based upon the reasoning above, would not be able to provide sufficient levels of feedback to inform the user of the current mode in isolation. The recommendations derived from the study with visually impaired people included the need to use stereotypical control shape designs, i.e. control shapes that exploit the previous experience of the user. With reflection on the conclusions of the study with visual impaired people and the reasoning above, the use of pin matrix displays to provide tactile feedback to the user would only be effective in certain circumstances and was deemed unsuitable for the project.

4.3.3 The implications of the literature review for the initial concept 3 and the design of the PTI

The third concept that was proposed included features of a non modal design, (recommendation 12) with a conventional control for each function, with a combination of tactile and location based subdivision of functional groups and individual controls (recommendations 3 and 8). The design included ease of visibility and reach through its mounting location on the dash board (recommendations 11 and 14), and finger tracks that allow the selection of functional mode and individual controls. The design also included the use of protruding tactile symbols designed to be traced by the finger (recommendations 2, 4 and 7).

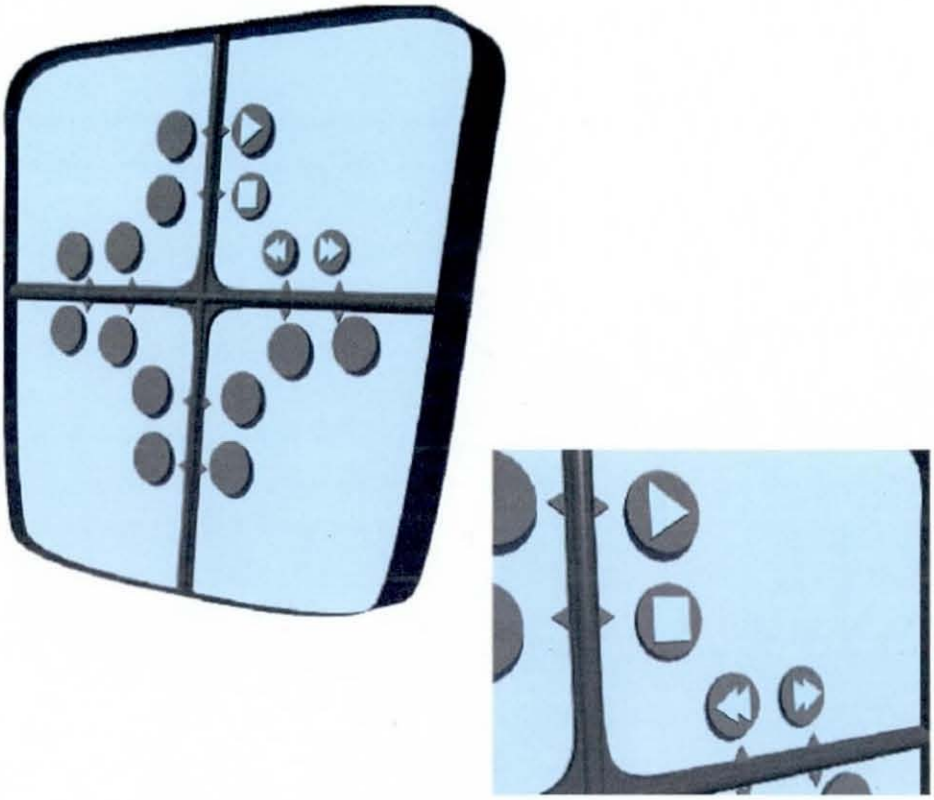


Figure 4.4. Concept 3

All other design recommendations can be satisfied by a more detailed version of concept 3. It was proposed that like concept 3 the PTI should use a combination of coding techniques to foster non-visual interaction. The interface design should be divided into functional groups in distinct locations and use stereotypical 'symbolic' control layout within each functional group with tactile coding matching the visual coding of each group.

4.3.4 Summary

The initial concepts have provided a focus for the discussion of design direction in terms of the use of active or passive tactile coding. The recommendations that have been derived and the discussion surrounding the initial concepts were used to define a structure for the design of the PTI as discussed in section 4.6.

4.4 Determining the optimum location for control interfaces within the 2001 Honda Civic

4.4.1 Introduction

The main industrial partner to the case study project, Honda R&D UK, provided the research team with a vehicle to which the final PTI controls were to be tailored. The year 2001 model Honda Civic was selected by Honda R&D as the test bed for the PTI. The 2001 Honda Civic utilises a relatively unusual gear stick location. This higher gear stick location, (shown in Figure 4.5 highlighted by the yellow circle) has been designed to occupy the prime reaching location in the car, as would be expected for a device that must be reached by all drivers. It was considered important that a full range of users should be able to reach the PTI location with comfort as defined in recommendation 14 in the previous section. It was anticipated that knowledge of the available reaching locations within the Honda Civic would help to define the form of the control mounting points.

4.4.2 Preliminary investigations

In order to examine the available reaching and viewing locations a number of users were asked to sit in the Honda Civic, adjust the seat so that they could effectively operate the primary controls, and reach to the main control panel above the gear stick without leaning.

Figure 4.5: The interior of the 2000 model Honda Civic with the gear stick location highlighted with the yellow circle

This was done with a woman aged 23 who had a stature that equated to 6^{th}%ile UK data (94% of the UK female population would be taller), a male aged 29 with 50^{th}%ile stature (50%of the UK male population are taller) and a male aged 30 with 99^{th}%ile stature (1% of the UK male population would be taller). This initial examination with users highlighted that most of the controls on the panel above the gear stick (the HVAC and ICE controls) could not be reached without leaning forward in the seat. This 'quick and dirty' analysis of the car interior illustrated that the main dash board was not appropriate for the location of the PTI. It was recognised that a structured analysis of the Honda Civic interior was required in order to locate suitable mounting locations.

There are a number of options available for the process of identifying possible control locations in a car interior. Further user trials could have been performed inside the Honda Civic, with a wider range of size variation in the anthropometric variables of stature, sitting height, buttock knee length, knee height and forward reach. It is established that accounting for the variability in these five anthropometric dimensions is important if car interiors are to accommodate all users with comfort (Porter 2001). However, it is difficult to accurately capture the reachable locations within a vehicle due to the confined space during user trials. Another option is the use of a human modelling CAD system. Human modelling CAD systems allow the creation of virtual environments including vehicle interiors, and the creation of virtual human models that are built using anthropometric data. These human models allow the representation of the size range of international populations.

Figure 4.6: The range of virtual human model sizes used to evaluate the adjustability ranges of a new road vehicle

These CAD based manikins can be postured, using realistic joint constraints and data that has been gathered on the range of joint angles that are exhibited by drivers (Porter and Gyi (1998)). SAMMIE (System for Aiding Man Machine Interaction Evaluation) is a human modelling system that was developed initially at Nottingham University. It is now developed and used in research, consultancy and teaching by the Design Ergonomics Group in the Dept. of Design and Technology at Loughborough University. Figure 4.9 shows example images taken from the SAMMIE system illustrating its use in the design of a car interior during 2005. The left hand image shows a 99^{th}%ile Dutch male human model (the tallest population on the planet) interacting with controls on the dashboard of the car. The left hand image shows a 20^{th}%ile Chinese female (the smallest female that was accommodated by the car design). The process that is used to perform an analysis of this kind is based upon the description found in Porter J.M. (2001).

4.4.3 The analysis tools available in the SAMMIE system

In order to explore the issue of reachable and viewable locations the CAD data for the interior of the Honda Civic as provided by Honda R&D was imported into the SAMMIE system. SAMMIE provides a set of analysis tools that relate to simulating reach and vision of interaction points.

The core of the SAMMIE human modelling system is the method used to constrain the joints of the human model. The SAMMIE system uses joint constraint data collect by Barter (1957), who performed a study that combined data collected from subjects during user trials, and cadavers. These data describe the range of motion of the major joints in the body, providing limits to the range of motion data for both loaded and unloaded conditions. The ability to produce realistic postures, based upon actual driving postures exhibited by users, adds to the level of fidelity that is achieved in the assessment of automotive interiors.

4.4.3.1 Posture, reach and vision

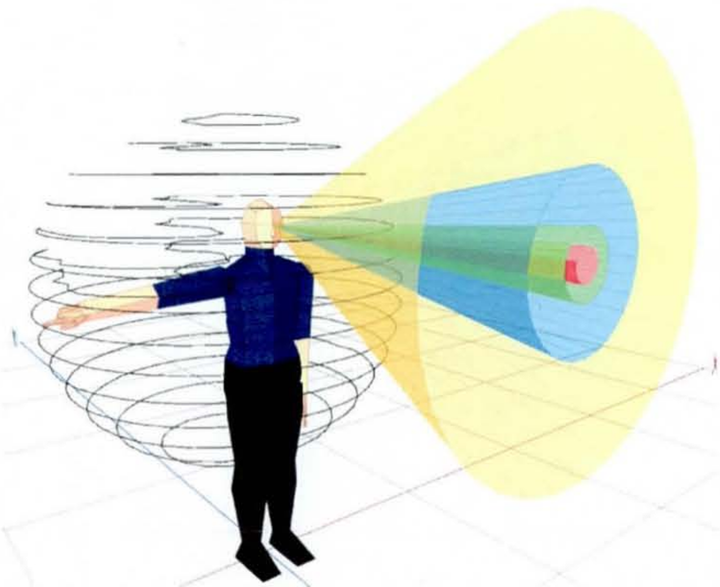


Figure 4.7: The reach contours and vision cones that can be used to analyse reach ability and view ability of interaction points in the SAMMIE human modelling system

Figure 4.7 shows the reach contours (the black spherical mesh) and vision cones that are used in SAMMIE to evaluate the reach ability and view ability of interaction points. The SAMMIE system allows the use of Reach Contours to identify reaching locations for controls. The volume of the reach contour is limited by the postures that are allowed by the joint constraints. It is also possible to perform tests where the actual posture required to reach an interaction point can be manually driven. The vision cones are used to highlight the areas that are visible for the user; there are a number of vision cone sets available in SAMMIE that represent different standards. The vision cone shown in Figure 4.8 is based upon data quoted by Deering (1998). The green central cone shown in figure 4.8 shows the area within which fine detail can be resolved by the eye. The very centre of this cone illustrates the area where the full resolution of the eye can be exploited. The edge of the green 2 degree cone represents the area where the resolution of the retina has reduced by 50% compared to the very centre of the cone. The blue, red and orange cones show the boundaries that equate to a 50% reduction in the resolution of the retina as shown in Figure 4.8.

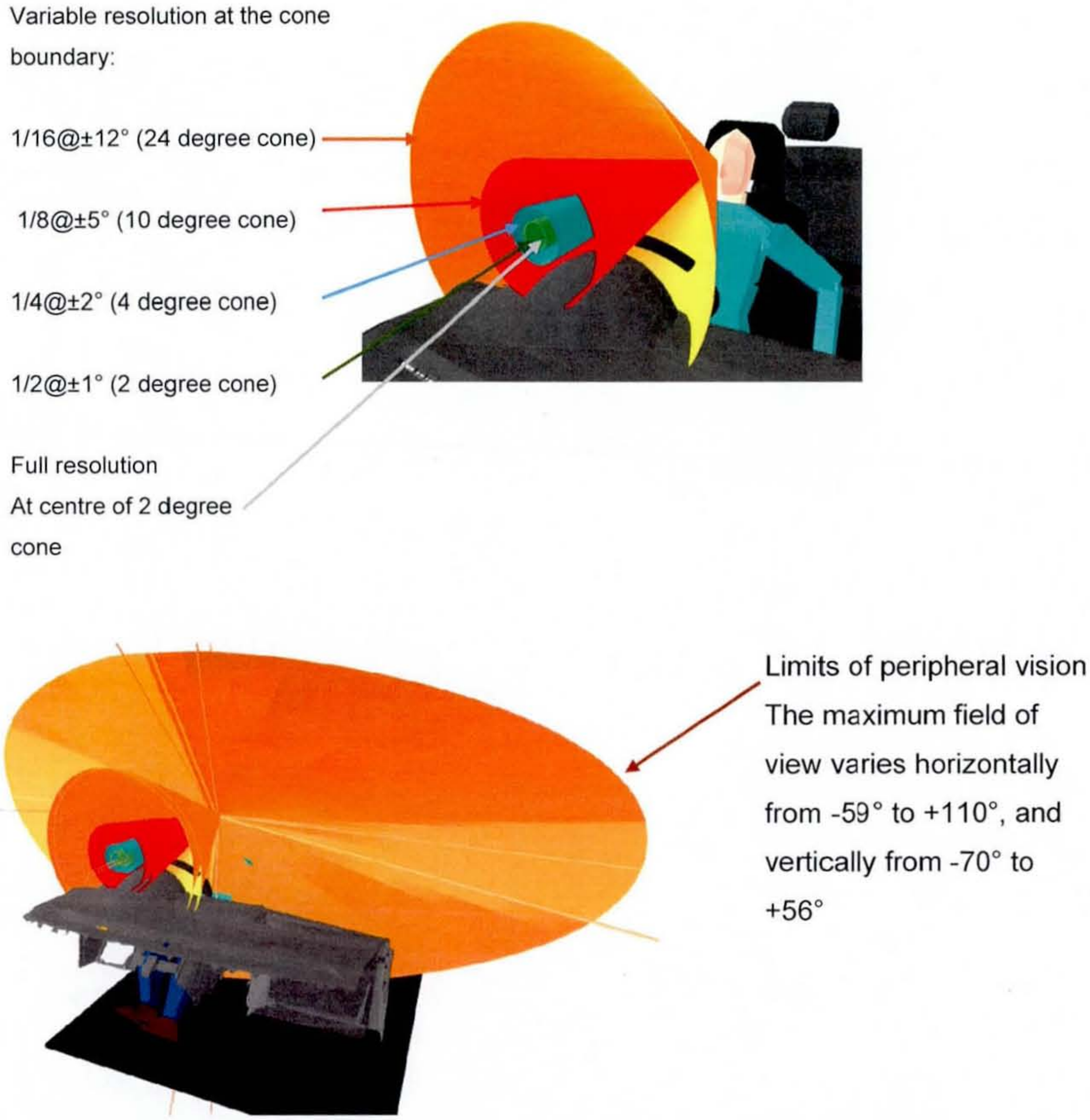


Figure 4.8: A vision cone set available in the SAMMIE CAD human modelling system based upon Deering (1998)

The assessment of the visible area that is possible through the use of vision cones is augmented with the 'humans view' tool. Figure 4.9 shows the assessment of a product design in progress using vision cones. The bottom image shows the view from the eye point of the human model or human's view. This allows for the detection of issues such as display obscuration.

Figure 4.9: The use of the human's view function to assess the exact area that can be seen by the human model

4.4.4 The SAMMIE evaluation of the Honda Civic interior

The following sections describe the method used to evaluate the reachable space within the Honda Civic interior, and the results that were found regarding potential mounting locations. Firstly, the digital human model sample is described, followed by the discussion of the protocol for the analysis of a car interior using a human modelling system.

4.4.4.1 The digital Human Model sample

The 2001 Honda Civic was designed to accommodate drivers ranging from 5^{th}%ile Japanese female to 95^{th}%ile US male. It was decided to include a 99^{th}%ile Dutch male in order to account for the largest males that may drive the car. The lower limit of stature of Japanese 5^{th}%ile female was imposed by the limitations of the driving package adjustability. The following human models were selected for inclusion in the study, with a range of human models between the maximum and minimum as recommended by Porter (2001).

- 5^{th}%ile Japanese female
- 50^{th}%ile UK female
- 5^{th}%ile UK male
- 50^{th}%ile UK male
- 95^{th}%ile US male
- 99^{th}%ile Dutch male

Figure 4.10 shows the stature range of the human model sample used in the assessment of the Honda Civic interior.

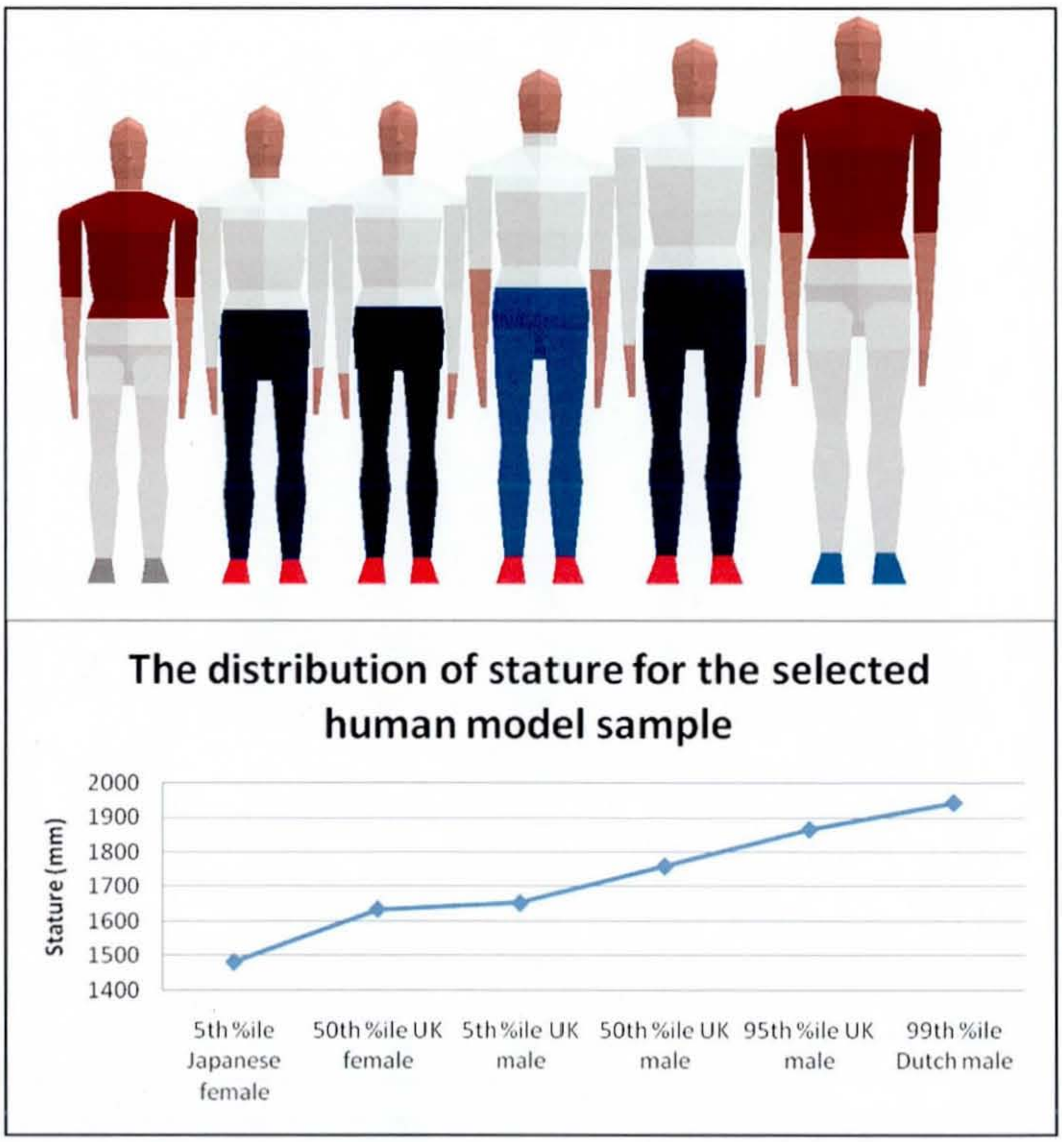


Figure 4.10: The distribution of stature in the human model sample used in the assessment of reachable space with the 2001 Honda Civic

4.4.4.2 Method

The SAMMIE analysis protocol used for this study contained the following stages.

Importing of CAD data of the car interior into the SAMMIE environment

This process involves converting the CATIA (a CAD tool used by automotive manufacturers) data provided by Honda R&D into WAVEFRONT object format. Any parts taken from the CATIA data that are required to move in SAMMIE (e.g. the seat and steering wheel) must be imported separately and adjustability ranges were setup to mirror those found in the real car. Figure 4.11 shows the interior model of the Honda Civic in SAMMIE.

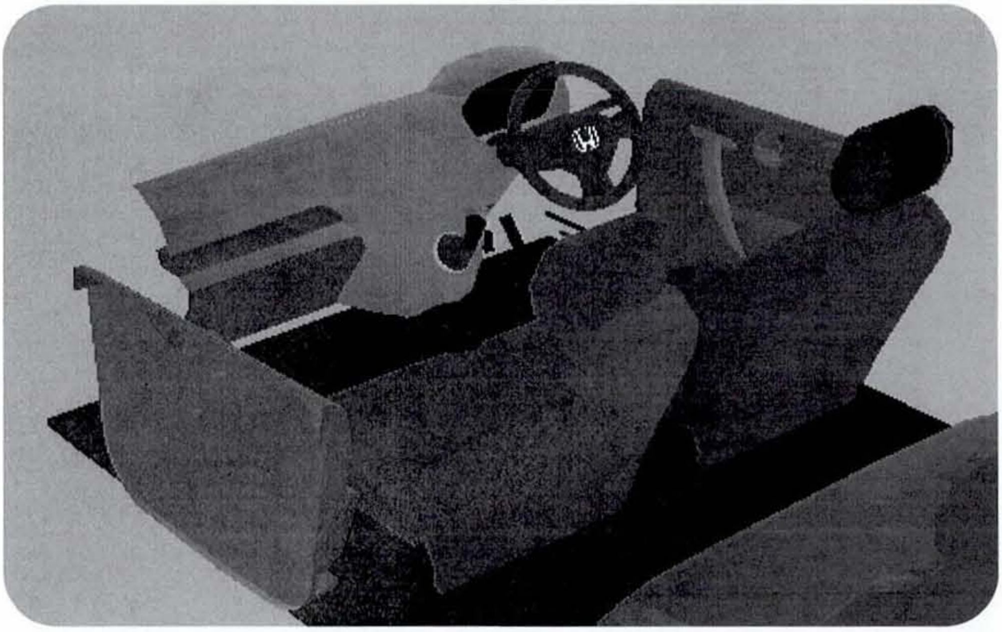


Figure 4.11: The interior of the 2001 model Honda Civic modelled in the SAMMIE human modelling system

Verification of the CAD data in the SAMMIE environment

This process involves loading the original CATIA data into an industry standard CAD package (Pro Engineer Wildfire) and creating check dimensions for various parts which are compared to the same dimensions created in the SAMMIE system.

Setting up 'modifications' to allow realistic movement envelopes for the seat and steering wheel

This process involves creating motion envelopes for the parts of the car that allow adjustability such as the seat and steering wheel. The definition of the motion envelopes was provided by Honda R&D.

Creating Human models that represent the population range

This process involves creating human models in the SAMMIE system as specified in the previous section. The anthropometric data used to build these models was sourced from Adultdata, a compendium of international anthropometric data (DTI, 1998). Adultdata is the most up to date anthropometric source that is freely available.

Adopting suitable driving postures for the human model population selected

The process of creating a posture and driver position within the Honda Civic model was driven by posture data from Porter and Gyi (1998), and seat compression data gathered by SAMMIE CAD Ltd. The postures that are possible with the constraints that are imposed by the adjustability of the seating package can be assessed by comparison to the joint range data. In order to determine how high the user population will sit in the car it is important to understand the amount that the seat compresses under the load of the driver. The process of determining seat compression uses the Society of Automotive Engineers (SAE) H-Point manikin (SAE 2006). The H-point manikin is a physical device that can be used to simulate the weight and size of drivers in the assessment of automotive interiors. The SAE H-Point manikin can be seen in Figure 4.12. The seat compression values for any seat can be determined by comparing the loaded and unloaded seat surface angles. The seat compression values that have been gathered through the use of an SAE H-Point manikin described seat compression for different weights to allow the prediction of how much a seat will compress under the load of a range of driver sizes. The weights applied to the standard SAE H-Point manikin can be tailored to match key percentiles. Figure 4.12 shows an overlay of the loaded and unloaded SAE manikin which shows how the position hip point marker (highlighted in green for unloaded and red for loaded) indicates the amount of seat compression. In the case illustrated in Figure 4.12 adding 40kg to the manikin caused the seat to compress by 32mm.

Figure 4.12: The SAE H-Point Manikin shown with a loaded condition superimposed over an unloaded condition. The green and red dots show the change in the Hip point due to seat compression under load

The seat compression values that were used were 35mm for small Japanese females, 50mm for average sized people and 80mm for large males in the range of 95-99th%ile. These figures are applied by placing the hip point of the human model lower than the seat surface in the SAMMIE model. For example the hip point of a 99th%ile male would be 80 mm lower than the position that would be adopted if the seat did not compress at all under load. Seat compression is an important factor to take account of the assessment process. How high the human model sits in the seat will affect reach to the pedals and steering wheel, and the eye point of the human, affecting vision of the interaction points, the road ahead and the vehicle displays.

Table 4.1 shows the method that is used to compare a posture that is exhibited in the Honda Civic, to the data from Porter and Gyi (1998). The human model shown in Figure 4.12 is the 99th%ile Dutch male, which was comfortably accommodated by the Honda Civic interior. The other human models in the sample were also suitably accommodated.

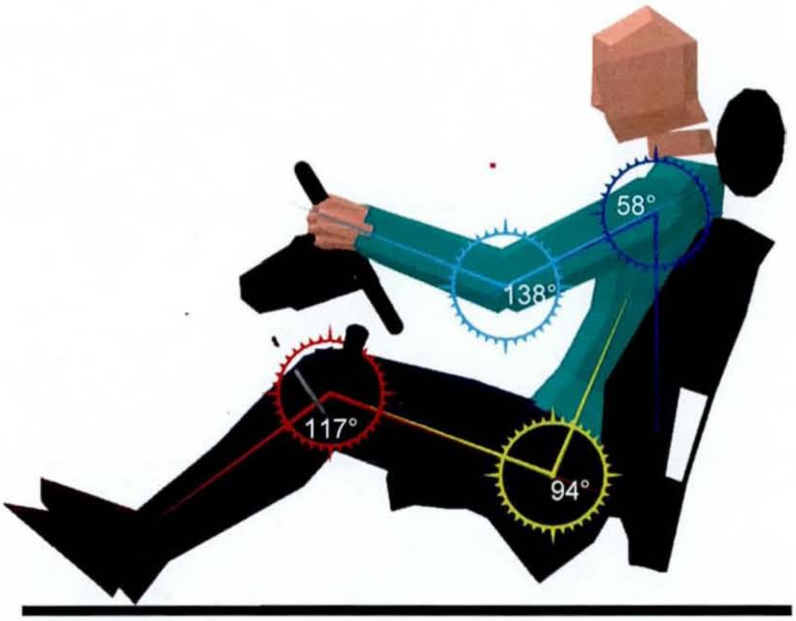


Figure 4.12: A 99th%ile Dutch male in the Honda Civic Interior

99th%ile Dutch Male	Data from SAMMIE	Male Joint Angle Range	Male mean Joint Angle	Difference between the Mean values and the Posture adopted
Trunk thigh angle	94	90-115	101	-7
Knee angle	117	99-138	121	+4
Upper arm flexion	58	19-75	50	+8
Elbow angle	138	86-164	128	+10

Table 4.1: Data from Porter and Gyi (1998): The table shows that a comfortable posture has been adopted for the 99th%ile Dutch Male

With each human model suitably postured in the Honda Civic interior the tests to identify reachable mounting locations could begin. Recommendation 14 was implemented during this process, i.e. the human model was not allowed to lean forward or sideways to improve reach.

Using reach contours to assess the reachable areas

For each human model reach contours were generated for finger tip reach, associated with the use of push buttons, and thumb tip reach, associated with the use of rotary dials and sliders. Initially the control panel above the gear stick was assessed. This was followed by an assessment of the rest of the interior of the car. The process is illustrated in Figure 4.16 with the 5^{th}%ile Japanese female reaching to the control panel. The white mesh in figure 4.13 shows the index finger tip reach, the yellow mesh shows the thumb tip reach.

Figure 4.13: The analysis environment in the human modelling system SAMMIE, showing the postures adopted and the reach contours that are used to assess the reach-ability of various locations

The results from this procedure can be seen in the following section.

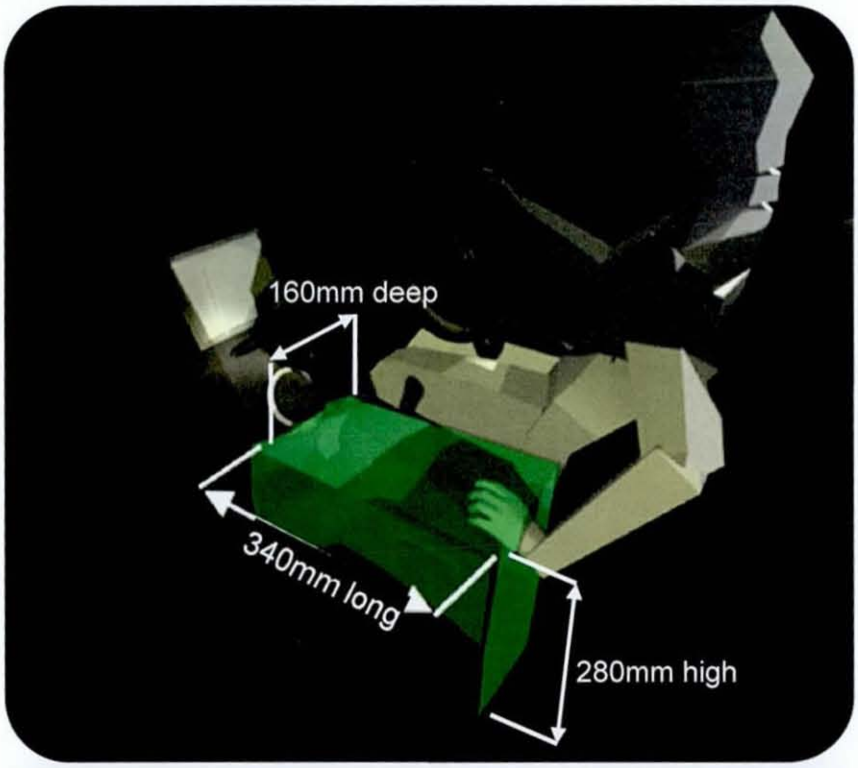
4.4.4.3 Defining the reachable and viewable locations within the Honda Civic

The results for the reach-ability of the main control panel can be seen in figure 4.14. The figure shows the area of the main control panel that can be reached (highlighted in green) for each human model that was tested. The analysis was performed for both finger tip reach (the left hand images) and thumb tip reach (the right hand images) as shown in figure 4.14. The figure shows that none of the human sample could reach the entire control panel with either finger tip or thumb tip reach. This confirmed that the control panel mounted above the gearstick was not suitable a location for the PTI.

Fig 4.14: The results of the reach test performed for each human model reaching to the control panel with finger tip reach and thumb tip reach. The green areas show reachable surfaces, the red areas show the panel sections that are out of reach.

A further analysis of the rest of the car interior highlighted three potential control locations within comfortable reach of the user. These were 1, behind the steering wheel, 2 mounted on the driver's door interior panel and 3, the area below the gear stick, and between the two seats. The raised gear stick position left the space between the seats empty. The unconventional design of the Honda Civic interior was therefore challenging in terms of space availability for additional controls as the main control panel was beyond comfortable reach. The need to be able to view the PTI in order to aid conceptualisation that was defined in recommendation 11 suggested that the locations behind the steering wheel and on the door interior panel would not be useful. The SAMMIE system was then used to determine the useable space that could be reached and viewed between the seats and under the gear stick. This was done by examining the rearmost reachable position in the space available between the seats. The foremost position was shown to be reachable by all human models in SAMMIE. This process was only performed using the 5th%ile Japanese female human model as this model sits in the foremost seating position and was therefore the worst case for defining the rearmost reachable space between the seats. A larger user would sit more rearwards in the car and would therefore be able to reach more of the space between the seats. The joint data and vision cones were used to define the rearmost reachable and viewable location as shown in Figures 4.15 and 4.16 respectively.

Figure 4.15: The use of the vision cones to identify the rearmost viewable location in the Honda Civic



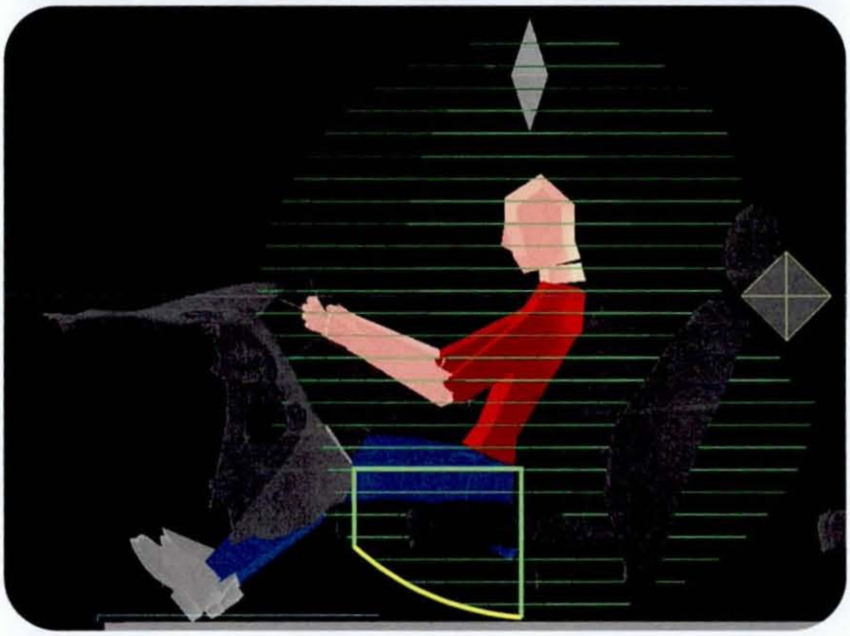


Figure 4.16: The volume of reachable space between the seats of the Honda Civic limited by the posture of the 5th%ile Japanese female and the reach contour as highlighted by the yellow line in the bottom image

All of the joint angles shown in the posture shown in Figure 4.16 were well within comfortable limits. The peripheral vision cone shown in Figure 4.15 was used to define the rear most viewable condition. The useable space for mounting controls was therefore defined as a volume that is 340mm rearwards of the gear stick base, 280mm high (limited by the height of the gear stick base to avoid using space that would be required by the passenger or driver) and 160mm deep (the space between the seats). The bottom image in Figure 4.16 shows how this cube was reduced by the worst case for forward reach, the 5th%ile Japanese female. This image shows how the reach contours limited the reachable volume (see the yellow line), effectively removing the bottom left corner of the cube. The interface designs that have been produced and described in the next chapter were tested using the SAMMIE system to ensure that they meet these spatial requirements. As with any assessment that is performed within a human modelling system, the results of this analysis were tested in user trials with physical mock-ups as described in the next chapter.

4.4.5 Summary

The SAMMIE system confirmed the findings of the user trial performed in the Honda Civic in that the existing dash board is not reachable without leaning forward in the seat. The analysis of the usable space within the Honda Civic has shown that the options for the location of the PTI were limited. The reachable volume that was identified was bounded by the region that is 340mm rearwards of the gear stick base, 280mm off the floor and 160mm between the two seats, combined with reach contours for the 5th%ile Japanese female.

4.5 The function selection process

The recommendations that were defined at the start of the chapter included the need to keep the number of PTI functions to a minimum, and to use a non-modal interface design. The function allocation process commenced with the creation of a list of available functions implemented in high end cars manufactured by Mercedes, BMW and Lexus. The function lists available in high end cars were taken as the starting point due to the 'trickle down effect'. That is, the prevalence for functionality that is installed in expensive cars to be incorporated into cheaper cars as the technology matures and becomes more cost effective. A good example of this is air conditioning. Available on a select few cars in the 1950's, it is now common to find air conditioning as standard or as an optional extra in most cars.

The resulting list contained over 100 separate functions. In order to explore which functions should actually be used in the PTI, brainstorming sessions were organised for the project team. The project team consisted of the author, a professor of design ergonomics, an ergonomics researcher and lecturer in computer science. Crucially, all of the team members had experience of regularly using satellite navigation systems, either through owning such a system, or by performing research into the safety of these systems in 'on the road' user trials. All team members had also been driving for over 5 years. The brainstorming sessions focused on scenarios that the project team members had experienced that required specific functions to be used. The full set of scenarios that were generated in the brainstorming sessions can be seen below.

4.5.1 Scenarios

4.5.1.1 Scenario 1: Airport hire car scenario

The 'airport hire car scenario' was defined as;

- You arrive at an airport early in the morning and it is cold and still dark
- You go to your hire car and get in. The windows instantly mist up
- Your first priorities are now to heat up the car whilst also demisting the windscreen
- You want to set a navigation destination so that you can get to your meeting
- You want to listen to the radio to find out the weather for later in the day

4.5.1.2 Scenario 2: The dirty air scenario

The 'dirty air scenario' was defined as;

- You are travelling down the motorway and you want to leave at the next exit
- You pull into the slow lane

- A HGV in front of you is producing black smoke
- You want to stop the smoke entering the vehicle
- You need to activate the 'recirculate air' option

4.5.1.3 Scenario 3: Sleeping children in the back of the car

The 'sleeping children in the back of the car' scenario was defined as;

- You have children in the back of the car who are asleep
- You want to listen to traffic reports but you don't want to wake them
- You need to control the sound output from the speakers so that you can hear the radio but the children cannot
- You need to change the sound output so that is only comes from the front speakers of the car

4.5.1.4 Scenario 4: Hot day scenario

The 'hot day scenario was defined as;

- You arrive at your car which is parked outside on a hot and sunny day
- You want to cool the car as quickly as possible
- You need to turn on the air-conditioning, set the temperature as low as possible and select the automatic mode of the HVAC system to ensure that the car cools as quickly as possible
- You also want to direct the airflow to your face and feet to allow you to cool down

4.5.1.5 Scenario 5: Favourite music

The 'favourite music ' scenario was defined as;

- Your favourite tune comes on the radio
- You want to increase the bass and treble of the sound output to better enjoy the tune

4.5.1.6 Scenario 6: Previous navigation destination

The 'Previous navigation destination' scenario was defined as;

- You are leaving your house so that you can drive to visit your family who have recently moved
- You are still unsure of the exact route to the new house
- You have used your SATNAV system to get their previously
- You want to set your SATNAV destination from a list of previously visited locations
- You then want to see a map view of the route that you will take
- You want to zoom the map view to show the final intersection of the route in more detail as you found it confusing the last time that you travelled this route

4.5.2 Selected functions

4.5.2.1 HVAC functions to be included in the PTI design

The following functions were selected for inclusion in the PTI device based upon the brainstorming sessions and scenarios discussed.

- Temperature (to allow the in-car environment to be controlled as per Airport scenario and the air conditioning scenario)
- Air flow direction to the face, feet and windscreen and combinations of these options
- An automatic mode that attempts to maintain the selected temperature
- Front screen and rear screen heating
- Re-circulate air within the car

4.5.2.2 Navigation functions to be included in the PTI design

The following functions were selected for use whilst the car is in motion.

- On/off
- Select map view on screen
- Zoom the map view in and out
- Select turn by turn arrows view on screen

- Select a previous destination from a list (including a method for navigating up and down the list)
- Increase/decrease the navigation voice volume

The following navigation functions were selected for use whilst the car is stationary due to the complexity of the tasks as illustrated by the literature.

- Add a new destination by city, then street, then address number
- Add a POI (Point of interest) as a destination e.g. a petrol station, supermarket etc

4.5.2.3 ICE (In-Car Entertainment) functions to be included in the PTI design

The following functions were selected for inclusion in the PTI based upon the brain storming sessions with the project team members.

- On/off
- Volume level
- Selection of radio or CD modes
- Auto radio frequency scan
- Manual radio frequency scan
- Mute
- Band selection
- Store radio channel
- CD
- Play
- Stop
- Skip track
- Increase decrease bass and treble
- Fade and balance the sound output

4.5.3 Summary

The function selection process resulted in the definition of 27 functions that were to be included in the design of the PTI. Table 4.2 shows the selected functions grouped into HVAC SATNAV and ICE categories.

HVAC	Navigation	ICE	
Temperature	On/off	On/off	CD
Air flow direction	Select map view	Volume level	Play
An automatic mode	Zoom the map view	Selection of radio or CD modes	Stop
Front screen	Turn by turn arrows view	Auto radio frequency scan	Skip track
rear screen heating	Select a previous destination	Manual radio frequency scan	Bass and treble
Re-circulate air	Navigation voice volume	Mute	Fade
	Add a new destination	Band selection	Balance
	Add a POI	Store radio channel	

Table 4.2: The functions to be included in the PTI interface

All of the selected functions were regularly used or found to be useful in specific situations by the brainstorming session members. As with a number of design issues that were explored during the project, the time pressures that arose from attempting to create a tactile interface in three years led to a number of 'quick and dirty' design decisions. It is acknowledged that various techniques could have been used to define the PTI function list. These techniques could have included focus groups with drivers with a range of ages, questionnaires sent to drivers, and user trials performed in the cars with participants demonstrating the functions that are used. These techniques may have defined functions other than those defined above. However, the functions that were selected by the project team were considered to be suitable to test a range of interface designs.

4.6 Automotive control design using the tactile interface design recommendations

The design recommendations have been subdivided into those that relate to the design of controls and those that relate to the overall form and operation of the device. The following sections discuss the PTI design direction that was inferred from these design recommendations.

4.6.1 The design recommendations that relate to the design of controls of the surrounding mounting surface

The following design recommendations relate to the form controls and the surrounding mounting structure.

- Recommendation 1: The visual and tactile model of an interface should be linked
- Recommendation 2: Tactile symbols have the potential to convey information to the user
- Recommendation 4: Use the finger tip as the tactile interaction point
- Recommendation 5: Two surfaces that are to be distinguished from each other should have a change of level of 5mm or greater. Differences in protrusion level of the controls from the mounting surface can provide coding that indicates and function.
- Recommendation 7: The PTI device should use embossed symbols to allow the user to trace shapes or recognise a location on the basis of the edges that surround it
- Recommendation 8: Tactile reference points should be employed that allow users to identify controls by their relative location whilst supporting the hand during control interactions
- Recommendation 9: 'Tactile Noise' or the use of textured surfaces that are not related to control identification should be avoided
- Recommendation 10: Supplemental feedback that confirms that the correct control selection has been made should be included in the device
- Recommendation 12: Design a non-modal interface where possible
- Recommendation 13: Exploit the stereotypes generally held by users to convey information

The following design process was inferred from these recommendations: The design of the PTI should be based around the subdivision of the defined function list into the standard groups that are evident in car interiors (ICE, HVAC and SATNAV). Each functional group will have a distinct location with a

single control per function as per recommendations 12 and 3. The main feature of each functional group will be a symbolic control layout that indicates the function of the whole array by exploiting the stereotypes held by users (recommendations 2 and 13). Each control should be able to be differentiated from the surrounding the structure by a level of protrusion of at least 5mm, and should use shape coding to convey function where a stereotypical model exists (recommendations 5 and 7).
Controls should be subdivided by tactile markers that indicate location when the finger is used to explore the arrays of controls. The interaction with the arrays should be supported by visual and tactile coding that is complimentary (recommendations 1 and 4). The controls surfaces should be easily distinguished from the surrounding structure to avoid confusion between structures that subdivide the array and control surfaces. The current state of each control should be identified using tactile coding (recommendations 9 and 10). Each functional group will then be located within the vehicle using the following recommendations and specifications.

4.6.2 The design recommendations that relate to the form and mounting structure of the PTI

- Recommendation 3: Subdivision of an interface using different locations exploits the kinaesthetic sense's ability to 'over learn'
- Design recommendation 11: The PTI should be visible to the driver
- Recommendation 14: The components of the a tactile interface should be within easy reach of the user

In addition to these recommendations the mounting location for the PTI was limited to the reachable and viewable space as described in section 4.4.4.3. The design process discussed in the following chapter was based upon these recommendations.

4.7 Conclusions

The chapter has illustrated the start of the design process by defining the recommendations that describe the key findings from the literature and the study with visually impaired people. The consideration of the initial concepts in light of the design recommendations suggested that passive tactile structures are appropriate for the PTI. This has been supplemented with a list of functions and the definition of the reachable space with the Honda Civic to provide further design constraints that must be accounted for. The strategy for the production of a PTI for the automotive environment has been derived from these sources. The following chapter describes the design process that produced a fully working PTI.

5 Chapter 5: The design and initial testing of the prototype tactile interface

5.1 Introduction

This chapter describes the design process that was undertaken during the case study project. The design process used to create the Prototype Tactile Interface (PTI) described in this chapter used a wide range of design skills and resources including group brainstorming sessions, rapid prototype production, user trials with a driving simulator and the use of human modelling software to assess designs. The initial plan for the project was to produce two iterations of the PTI, however, time and resources allowed for the production of four design stages using rapid prototype technology. The following sections are included in the chapter;

- The first design iteration of the PTI
- The second design iteration of the PTI
- The third design iteration of the PTI
- The design of the supporting structure for the control arrays
- User trials to test the minimum useable size of the three functional arrays
- Prototype design for evaluation with a driving simulator
- Design changes based on the recommendations produced by the simulator trial
- Software design for the final prototype

The first three sections describe the three iterations of the PTI design process

5.2 The first design iteration of the PTI

5.2.1 The initial design of the HVAC control array

The functions that were included in the PTI HVAC array were defined in the previous chapter and are listed below.

- Temperature
- Air flow direction to the face, feet and windscreen and combinations there of
- An automatic mode that attempts to maintain the selected temperature
- Front screen and rear screen heating
- Re-circulate air within the car
- Air conditioning (AC) on/off

The aim of the design process was to incorporate these functions into an array of controls that could be explored using the left hand, as defined by the available reaching location between the seats. The combination of location coding and tactile coding should allow each control to identified using touch alone. The initial design that was produced can be seen in the Figure 5.1 below. As discussed, each functional array required a symbolic layout of controls that helped to indicate function. In the case of the HVAC array the symbolic central section contained the controls for directing airflow. This first design attempted to use a model of airflow direction that related to a plan view of the car.

Figure 5.1: The spatial model used in the first HVAC array iteration

Each of the controls would be a latching push button, which when depressed would latch in place with the top surface being 5mm lower than the adjacent controls, and flush with the mounting surface. The surface texture of the button will be different to that used on surrounding structure. This would allow the user to identify which control is on and which is off. The two analogue functions of fan speed and temperature were assigned to rotary controls with a clockwise rotation to increase the fan speed or temperature as per the stereotypical design recommendations. The approach of placing static push buttons within these rotary controls was implemented for the air circulation and air conditioning push buttons. These controls were placed on the right hand side of the array as the use of the left hand would allow the rotary controls and push buttons to be operated by the thumb.

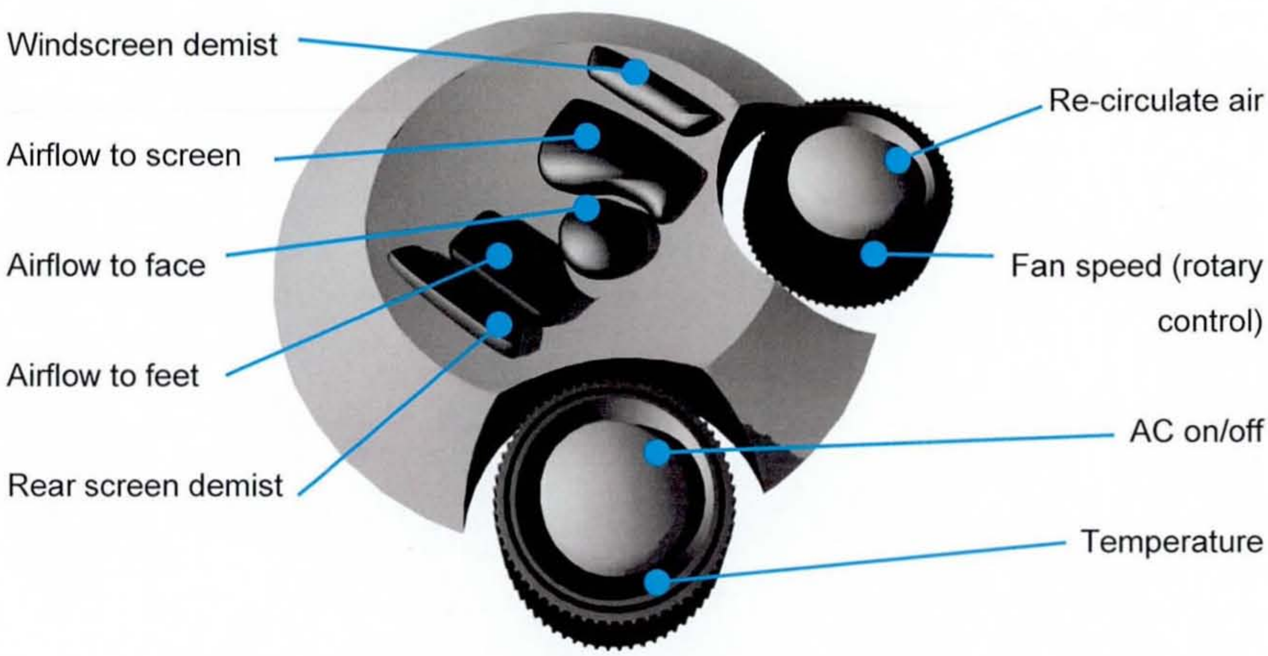


Figure 5.2. Design iteration 1: The first design iteration of the HVAC array

The initial design was tested amongst the research team and some confusion arose over the orientation of the airflow model i.e. if the plan view model was followed the feet would be above the head (see figure 5.1). It was evident that the arrangement of controls for the airflow direction did not match the planned location based coding. This was explored in the next design iteration.

5.2.2 *The initial design of the ICE control array*

The following functions were selected for inclusion in the PTI in the previous chapter

.

Radio

- Auto frequency scan
- Manual frequency scan
- Mute
- Band selection
- Store radio channel

CD

- Play
- Stop
- Skip track forward and back

Common functions for Radio and CD

- Increase decrease bass and treble
- Fade and balance the sound output
- Use of preset buttons to access stored radio stations or a six disk CD changer
- On/off
- Selection of radio or CD modes
- Volume

Figure 5.3. Arrangement of the play, stop, skip forward and skip back controls for a range of products. 1: Video cassette recorder controls. 2: I-pod controls. 3:Mp3 player controls. 4 Remote control.

As with the HVAC array, the aim of the design process for the ICE array involved identifying a stereotypical visual layout of the functions. A search was performed examining the products that use CD and radio controls and a number of control layout techniques were found. A layout that has been popular since the late 1980's is the 'play roundel' as illustrated in Figure 5.3. The common features of the control layouts shown in figure 5.3 are the circular arrangement of controls with the skip left and skip right buttons in the left and right quadrants of the circle. This model was considered a strong visual cue regarding the function of the ICE array and was therefore chosen for the central location that was used for the airflow controls in the HVAC array. The first design of the ICE array is shown in Figure 5.4.

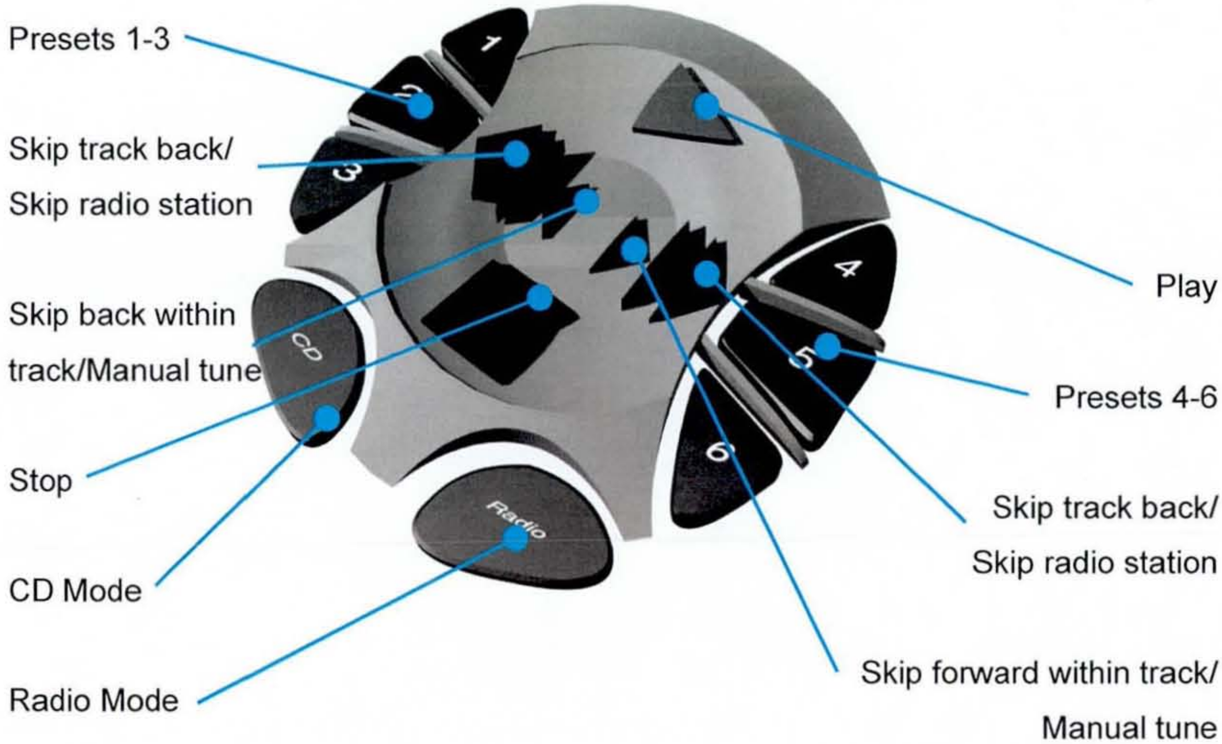


Figure 5.4. Design iteration 1: The first design iteration of the ICE array

The play and stop symbols were seen as the key to a symbolic layout that indicates function, and were included in the design as shown in Figure 5.4. The preset buttons for the selection of radio stations were divided using structures that sat 5mm above the surface of the buttons. The radio and CD functions were selected using the buttons mounted on the front edge of the array, and the volume would be changed by running the finger along the top edge of the central dish, using touch sensitive surfaces. The fade and balance would be altered by depressing the whole of the central circular potion. This would then allow the user to increase or decrease the fade, balance, treble and bass using the play and stop buttons.

The design was discussed with the project team members and it was noted that the low level of modality that was built into the design would make the use of symbols confusing when adjusting the fade/balance and bass/treble combinations.

5.2.3 The initial design of the SAT NAV control array

The following functions were selected for use whilst the car is in motion.

- On/off
- Select map view on screen
- Zoom the map view in and out
- Select turn by arrows view on screen
- Select a previous destination from a list (including a method for navigating up and down the list)
- Increase/decrease the navigation voice volume

The following navigation functions were selected for use whilst the car is stationary due to the complexity of the tasks as illustrated by the literature.

- Add a new destination by city, then street, then address number
- Add a POI (Point of interest) as a destination e.g. a petrol station, supermarket etc

The design of the SAT NAV array was more challenging than that of the ICE or HVAC arrays in terms of the definition of an symbolic layout. This was due to the relatively small number of SAT NAV systems that were found in cars at the time of the design process, meaning that people had little or no experience of satellite navigation. This meant that there were no stereotypical control layout opportunities that were so useful in the design of the HVAC and ICE arrays. In addition to this it was decided to attempt to incorporate a new technology into the SAT NAV array. As has been demonstrated in the literature review voice recognition technologies are not suitably robust at the time of writing. However, hand writing recognition technologies have the potential to allow the user to enter alpha numeric characters into a satellite navigation system. This was inspired by the use of handwriting recognition systems that were built into PDAs (Personal Digital Assistant). At the time of the design process handwriting recognition technologies used in PDAs generally required the user to learn a different form of the alphabet that used simplified symbols for certain letters of the alphabet (note the characters A, F and K) in the image below.

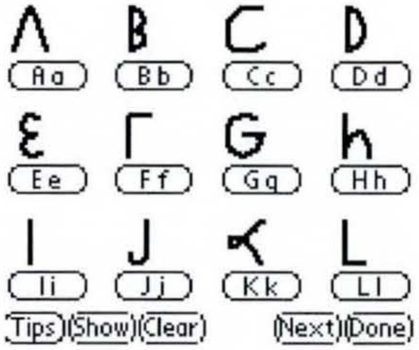


Figure 5.5: An example of the GRAFFITI handwriting recognition language that requires some special characters to be learned by the user

However, at this time (2003) a new handwriting recognition system was produced by A.R.T. (Automatic recognition Technologies). This system allowed users to draw both upper and lower case letters into a PDA as they would on paper, removing the necessity to learn new characters. ART worked in conjunction with Seimens to produce a prototype system that could be used in a car. This idea was expanded by the author to include the ability to draw characters onto a laptop type touch pad in order to enter alphanumeric characters into a navigation system. The need to do this was defined by the systems for alpha numeric data entry that were prevalent at the time, e.g. touch screens with a virtual keyboard as found in the Lexus models of the time, or selection of characters from a virtual keyboard using a joystick. These systems were thought to be time consuming to use based on the experience gained through their use by the research team, and were certainly not considered appropriate for use whilst the vehicle is in motion. This was due to the visual feedback that is required to allow the user to know which character is being selected, potentially increasing the 'eyes-off-road' time. The use of handwriting recognition technology presented the opportunity to allow the user to draw alphanumeric characters with the finger tip onto a suitably sized touch pad. The designs produced for the SAT NAV array therefore incorporated a standard Synaptics touch pad to allow for the possible inclusion of hand writing recognition technologies. It was decided that this functionality should be available only whilst the vehicle was stationary. The design of the SATNAV array shown in Figure 5.6 was subdivided into the controls that were available whilst the vehicle is in motion (in the centre of the array), and those available when the vehicle is stationary (the darker grey section on the left hand of the array. The centre of the array followed a stereotypical model for increase and decrease through the vertical orientation of the zoom map buttons. The map and nav buttons which allowed different display modes to be selected were arbitrarily assigned to the left and right quadrants of the array. The button used to repeat the current navigation instruction was mounted on the front of the array.

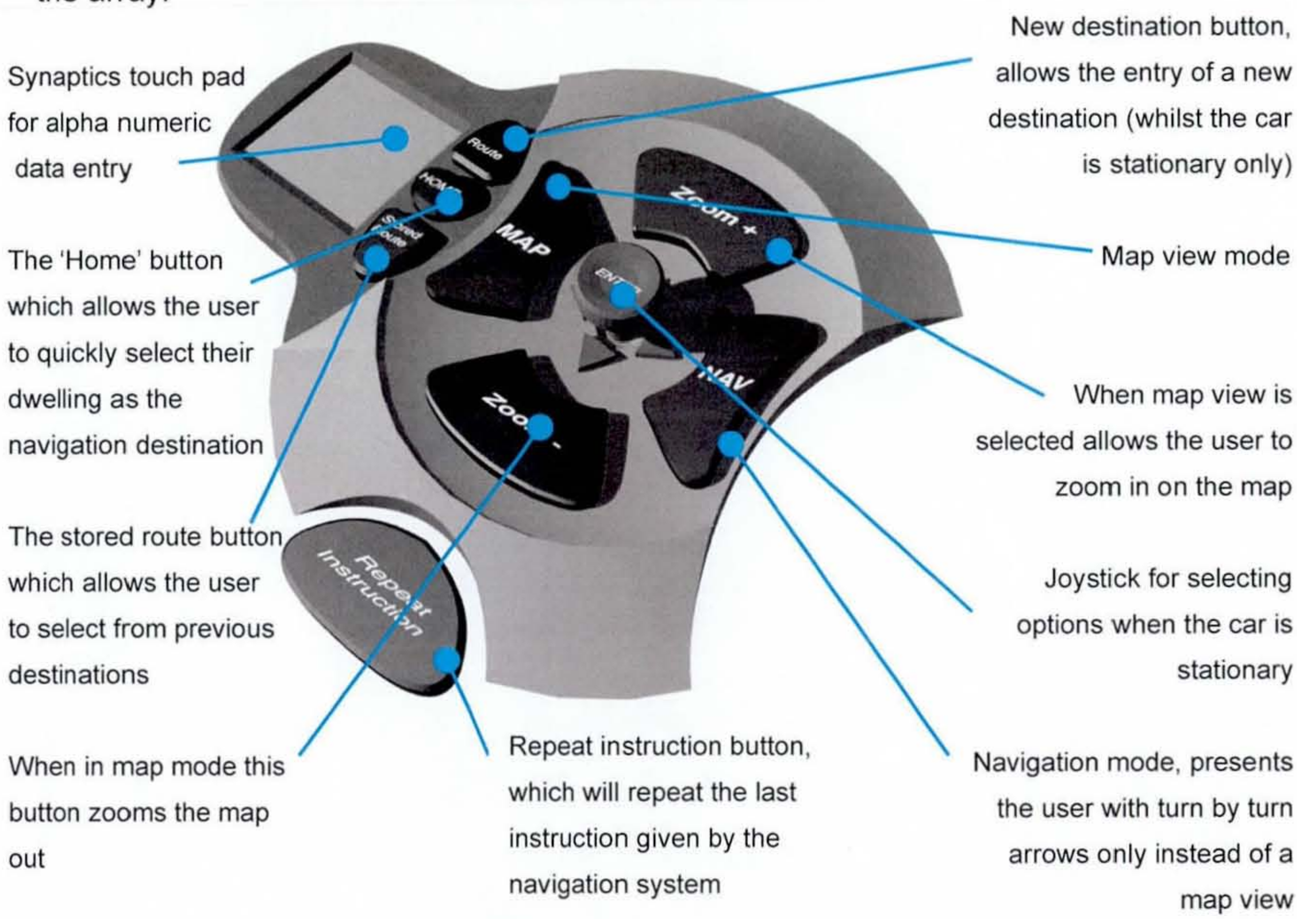


Figure 5.6: The first design iteration of the SATNAV array incorporating the Synaptics touch pad technology

5.3 The second design iteration of the PTI

Discussion amongst the project team had identified the need for improvement of each array. The following section describes the second design iteration that aimed to address these issues.

5.3.1 The second iteration of the HVAC array

The model for airflow direction shown in Figure 5.1 was found to be confusing based upon discussions with the research team. Another symbol was required to indicate the function of the HVAC array. Figure 5.7 shows the standard symbol for airflow direction and its implementation in a car control. It was decided that the symbolic feature for design iteration 2 would be the standard airflow symbol to allow recognition of the HVAC functional group.

Figure 5.7: The standard airflow direction symbol that represents airflow to the face and feet BS ISO 2575:2004 and its implementation in a car control design

The standard airflow options at the time of writing are;

- Airflow to windscreen
- Airflow to face
- Airflow to feet
- Airflow to feet and face
- Airflow to Windscreen and face
- Airflow to windscreen and feet

Many automotive manufacturers arrange these functions as options within a rotary dial. The problem with the use of devices such as multi option rotary controllers is the ability of people to remember the location of the option that they require. Each manufacturer that uses a rotary controller design uses different ordering and location coding of the airflow options. Also, there is no apparent use of an orientation model that might be expected, such as ordering the airflow options as illustrated in figure 5.8 below, with a vertical ordering of options reflecting the in car vertical coding of the airflow options.

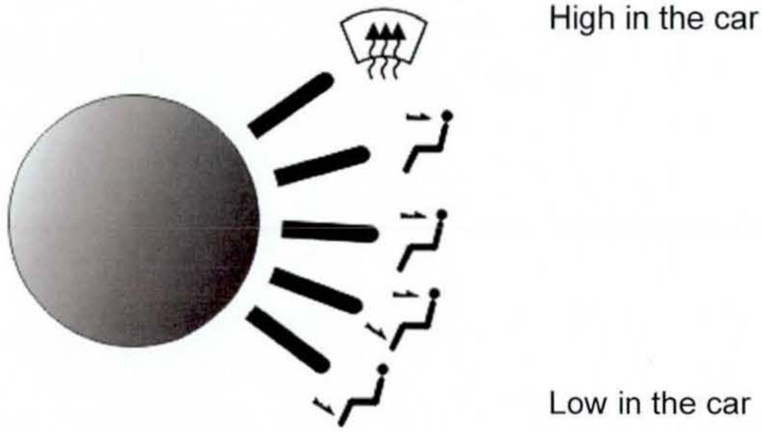


Figure 5.8. The concept of using space within the cap of a rotary control to mount a non rotating push button

Following the PTI design recommendations, it was proposed that each airflow direction should have a button, with the user being able to select any required air flow combination. It was proposed that the simplification of a multi selector rotary control to three push buttons would allow users to more easily conceptualise a model of operation. The other new feature that was incorporated into design at this stage was the concept of the bezel. Design Iteration 1 used the concept of a rotary control whose centre was a non-rotating push button. See figure 5.9 below.

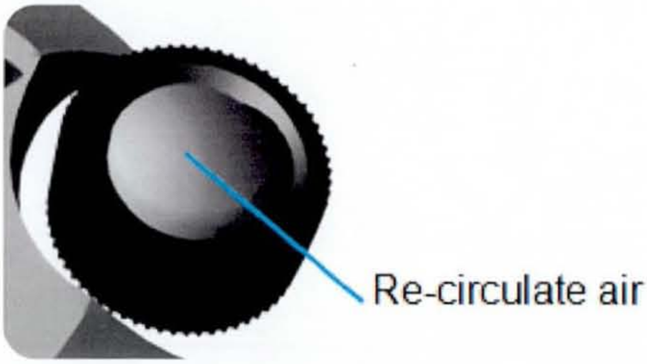


Figure 5.9. The concept of using space within the cap of a rotary control to mount a non rotating push button

In design iteration 2 this concept was expanded to include multiple controls within a static mounting surface, surrounded by a rotating ring (bezel) that could be used to increase fan speed. It was anticipated that this would allow differentiation between controls inside and outside of the bezel, as can be seen in Figure 5.10.

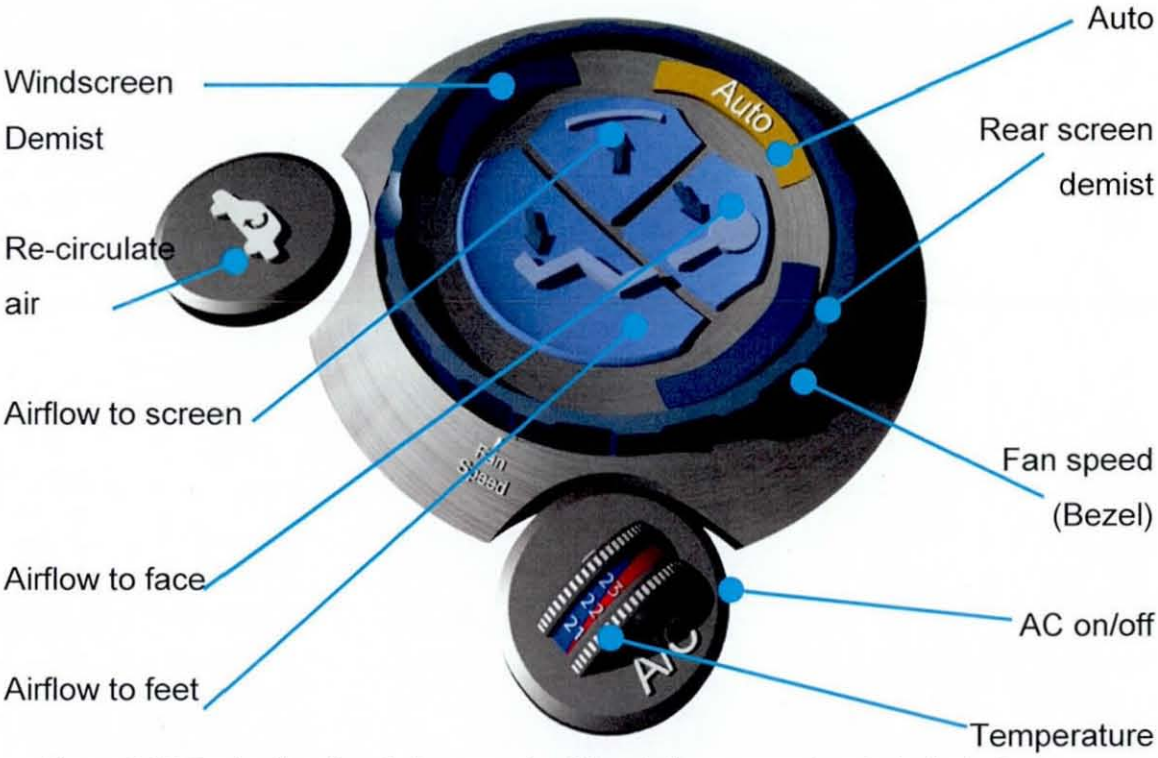


Figure 5.10 Design iteration 2: An example of the air flow concept controls that allow any airflow combination by depressing the buttons associated with the required air flow direction

The central airflow direction buttons used the ISO standard airflow symbol which protrudes from the mounting surface to provide tactile discrimination between the buttons. To the left and right of the air flow buttons are the push button controls that operate the front and rear screen demisters. These were placed to follow the spatial model setup by the direction that the ISO airflow model is facing i.e. the rear screen demist button is the right of the airflow symbol, and behind the head of the symbol. The push buttons for the re-circulate air and AC options were relocated to the front of the array, and the temperature setting rotary control was mounted in a location that fostered use by the left thumb.

5.3.2 The second interaction of the ICE array

The subdivision of the array using a bezel that was found in the second iteration of the HVAC array was also used in the ICE array. The rotary bezel controlled the volume of sound from the entertainment system. Figure 5.11 shows the second iteration of the ICE array.

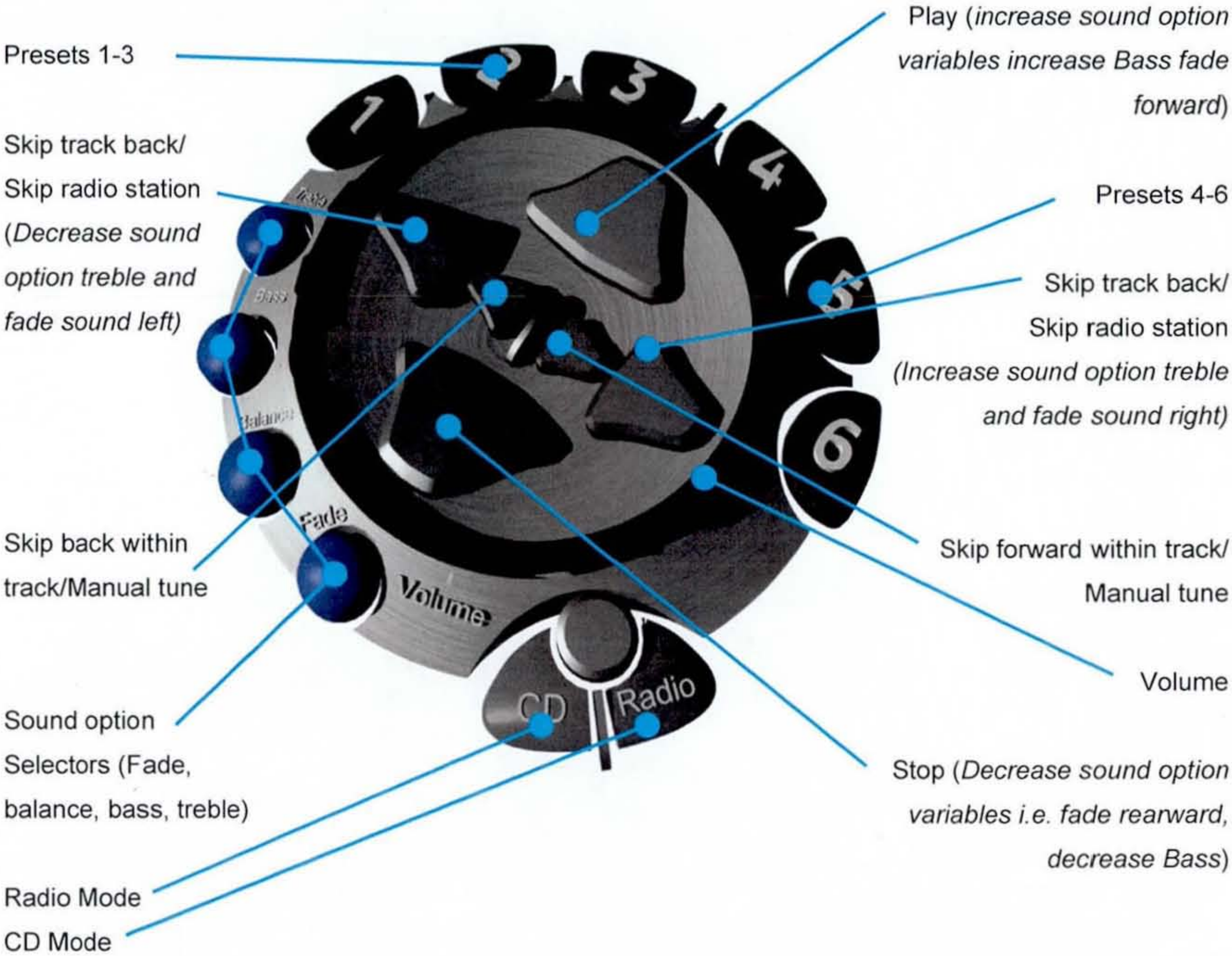


Figure 5.11. Design iteration 2: The second stage in the design process incorporating the bezel

This design iteration assigned the fade/balance/bass/treble selection to single push buttons around the edge of the array. The options buttons would only be operable whilst the vehicle is stationary. The new shape of the central buttons would be used to change these variables when selected. The buttons also performed the function of play, stop, skip forward and back as with the first iteration if no other options are selected. The symbol based central buttons shown in design iteration 1 were replaced by buttons that were more general in shape. It was presumed that this would cause less confusion when users were changing the sound options. The central buttons that are used to skip track, and skip within track still mirror the standard symbols for these functions.

5.3.3 The second interaction of the SATNAV array

Figure 5.12 shows the second design iteration of the SATNAV arrary. As with the previous two array designs the SATNAV array progressed to include the bezel concept, with the bezel controlling the volume level for the navigation instructions. The touch pad was relocated within the bezel and the zoom map and mode switching buttons were located around the edge of the inner surface.

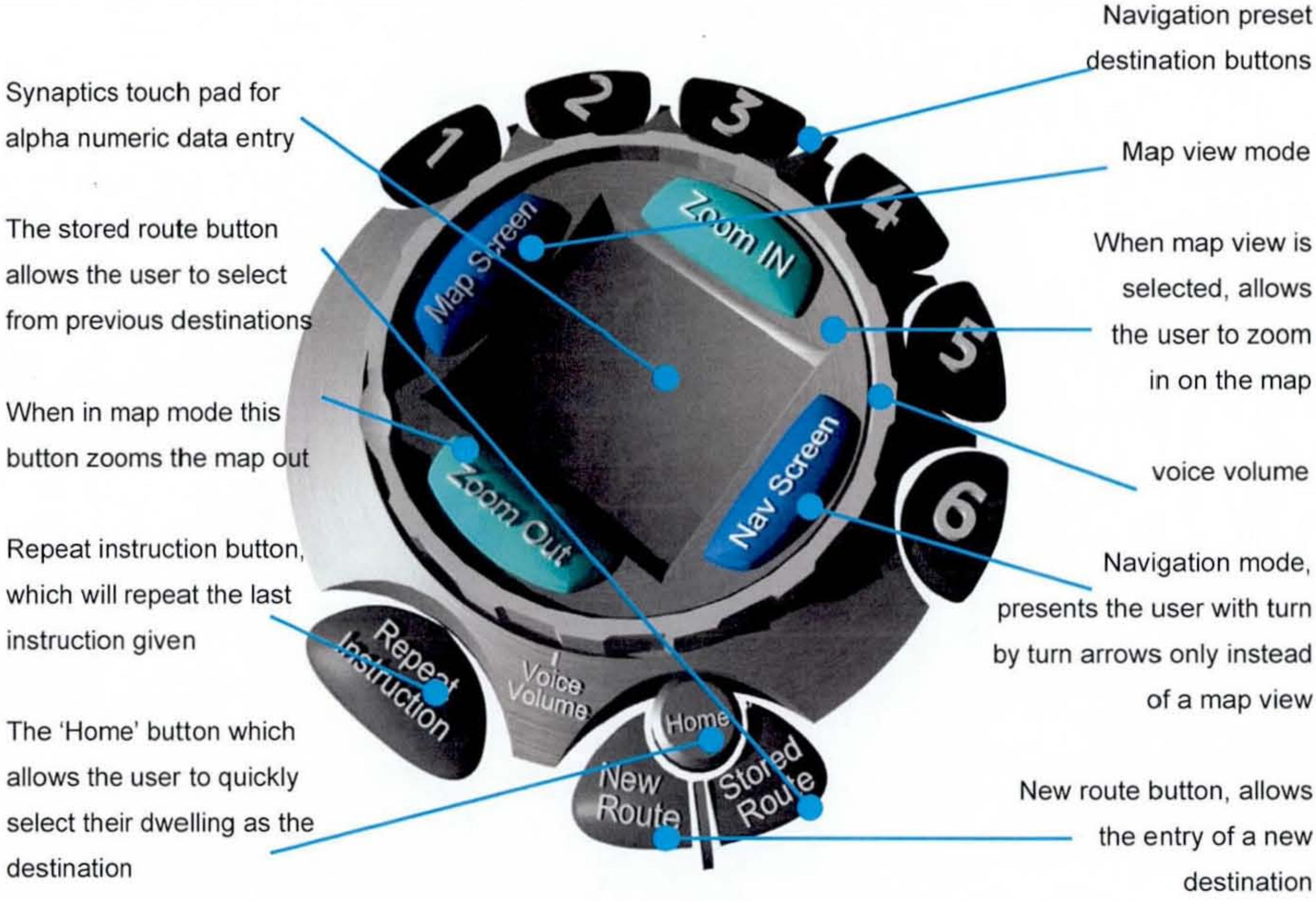


Figure 5.12: The second design iteration of the SATNAV array incorporating the concept of preset destinations

It was at this stage in the design process that a design cue was taken from the ICE array. It was decided to incorporate the idea of radio presets in the SATNAV array to allow the selection of 6 predefined destinations that could be assigned by the user. Using the model of usage that is prevalent with the use of radio presets, the user would press and hold a preset button to store the current navigation destination to that preset button. The repeat instruction button was located at the front of the array, and the new route, stored route and Home buttons were located where they could be accessed by the thumb.

5.3.4 A review of the second iteration

A review of the second design iteration was performed with the research team. The layout of each functional group was discussed in terms of the functions that it contained and the location of the buttons. The discussion relating to the HVAC array produced a consensus view supporting the further subdivision of the array, moving the auto, front screen and rear screen demist buttons outside of the bezel that controls fan speed.

The discussion of the SATNAV array focussed on the HOME button. With the presets being able to store regularly used destinations the need for separate HOME button was suggested as redundant.

It was also suggested that the centre dash area in the Honda Civic could be made reachable by the addition of shelf that could support the arrays that were designed in the second iteration.

This was seen as a valid option and a design was produced as shown in Figure 5.13. The design was analysed in the SAMMIE system and it quickly became evident that the shelf would need to protrude beyond the top of the gear stick shown in Figure 5.13. The shelf height and protrusion from the mounting surface that allowed reach by all users clashed with the space required to operate the gear stick.

Figure 5.13: The design of a mounting structure that improved the reach-ability of the dashboard within the Honda Civic

It was also noted that a potentially useful aspect of the first iteration had been removed from the second iteration. This was the concept of designing the location of some controls to foster the use of the thumb of the left hand. This idea would be re-instated in the third design iteration. The second design iteration was deemed appropriate in terms of the functions that were incorporated, and the layout of the controls. The next iteration in the design process focused on the addition of a hand rest, or HCRP, that would allow a consistent hand location for control interaction.

5.4 The third design iteration of the PTI

The work performed on the study to examine the use of electronic products by visually impaired people highlighted the benefits of Hand Control Reference Points (HCRPs). These HCRPs were used by visually impaired people to promote a hand location and orientation from which tactile discrimination could be consistently started. It was anticipated that a hand rest incorporated into the array would promote a consistent hand location for control interactions. It was proposed that by adding a structure in front of each array, that the hand could be supported. A new array design was created that incorporated a hand rest. This hand rest was located at the front of the array, with the presumption that the user would rest the heal of the hand upon it, and be able to reach the switch and controls with the fingers and thumb. Figure 5.14 shows SAMMIE being used to analyse one of the proposed designs.

Figure 5.14: The assessment of a built in hand rest at the front of the array mounting structure.

The location of the hand rest required all controls that previously located at the front of the array to be moved (the repeat instruction buttons, and select new and stored destination buttons on the SATNAV array. The options and mode switching buttons on the ICE array). The testing of the postures adopted by the SAMMIE human model highlighted that the thumb was resting at a point above the right hand side of the array. Based upon this a surface was added to the right hand side of the array, and the controls that needed to be moved due to the placement of the hand rest were moved onto this surface. Figure 5.15 shows the redesigned array for the HVAC functional group, and highlights other changes that were implemented to improve the tactile coding.

Each array includes a raised section that acts as a hand rest, and an additional surface on the right of the array to foster the use of the thumb to activate controls. As suggested by the research team feedback after design iteration two, all controls other than airflow direction were moved outside of the inner bezel surface for the HVAC array. The re-circulate air, Auto and demist rear screen controls were moved onto the surface at the rear of the array, following the same placement coding that was previously used in design iteration number two. The temperature and AC buttons were placed on the right hand 'thumb' surface. For the ICE array, the only changes to the control placement between design iteration 2 and 3 were the placement of the radio, CD and power buttons on the 'thumb' surface. The SATNAV array changes involved the re-positioning of the new and stored destination buttons, and an on/off button onto the 'thumb' surface. The changes to each array are shown in Figures 5.16, 5.17 and 5.18

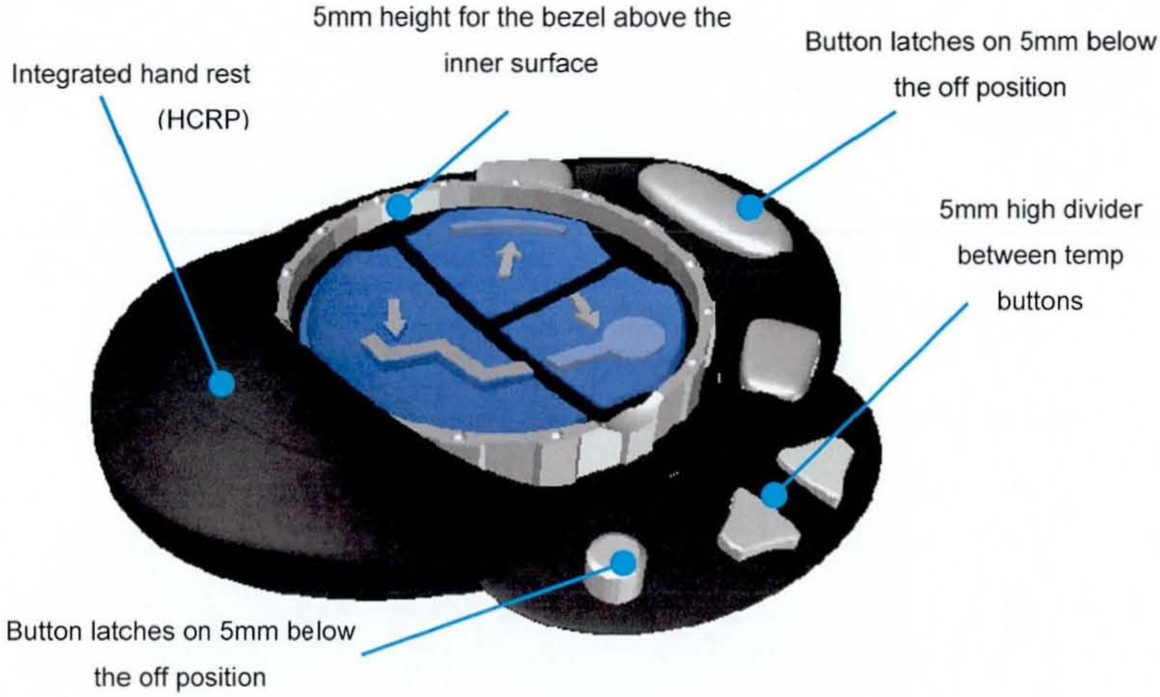


Figure 5.15 Design iteration 3: Design features following the recommendations

Other features illustrated by Design Iteration 3 were additional locations where changes in protrusion level were used. These were added to promote control identification and differentiation. Design Recommendation 5 specified a 5mm step height between two surfaces to allow discrimination by the elderly. The recommendation was therefore applied to the following areas of each array; (See figure 5.15)

- The protrusion level of a button above the mounting surface
- The vertical distance between the bezel top and the mounting surface
- Any controls which latch on and off must have a switch travel that is 5mm creating a 5mm depression when the button is latched on
- Tactile dividers were added between paired options such as preset buttons or temperature increase/decrease

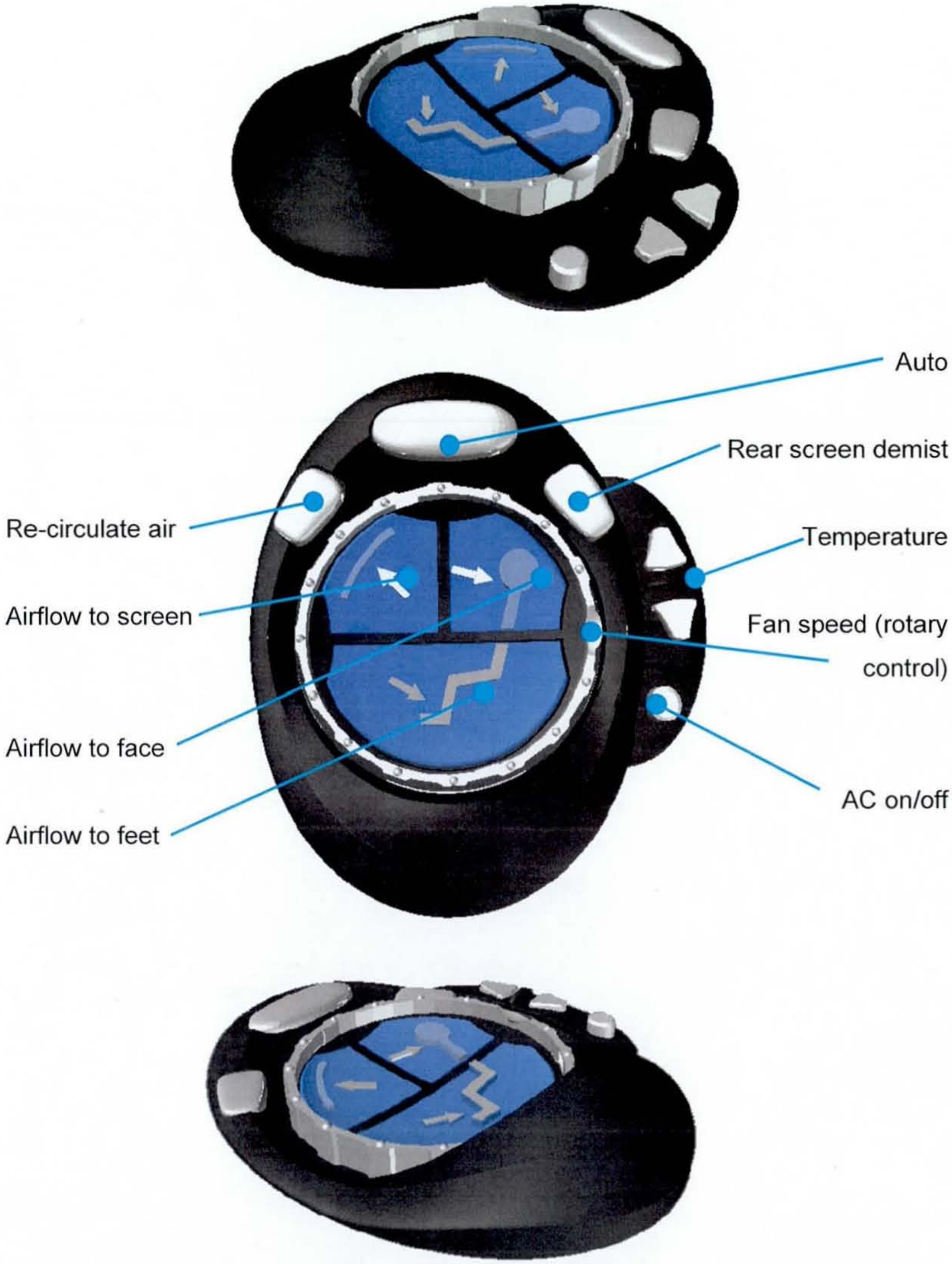


Figure 5.16 Design iteration 3 with more of the controls on the exterior of the fan speed bezel and incorporating a hand rest to allow consistent hand location

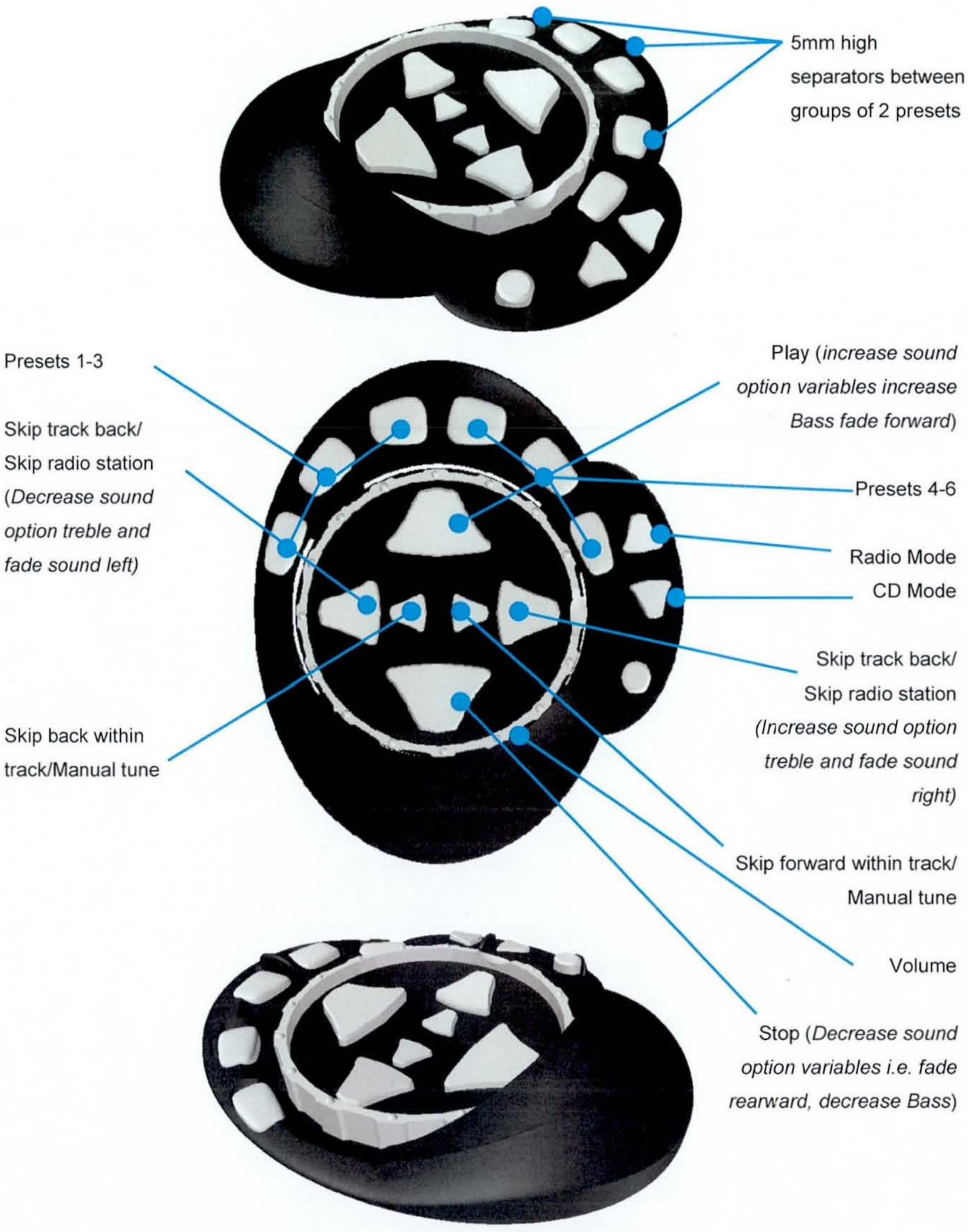


Figure 5.17. Design iteration 3: The third stage in the design process incorporating the hand rest and the right hand thumb operated controls

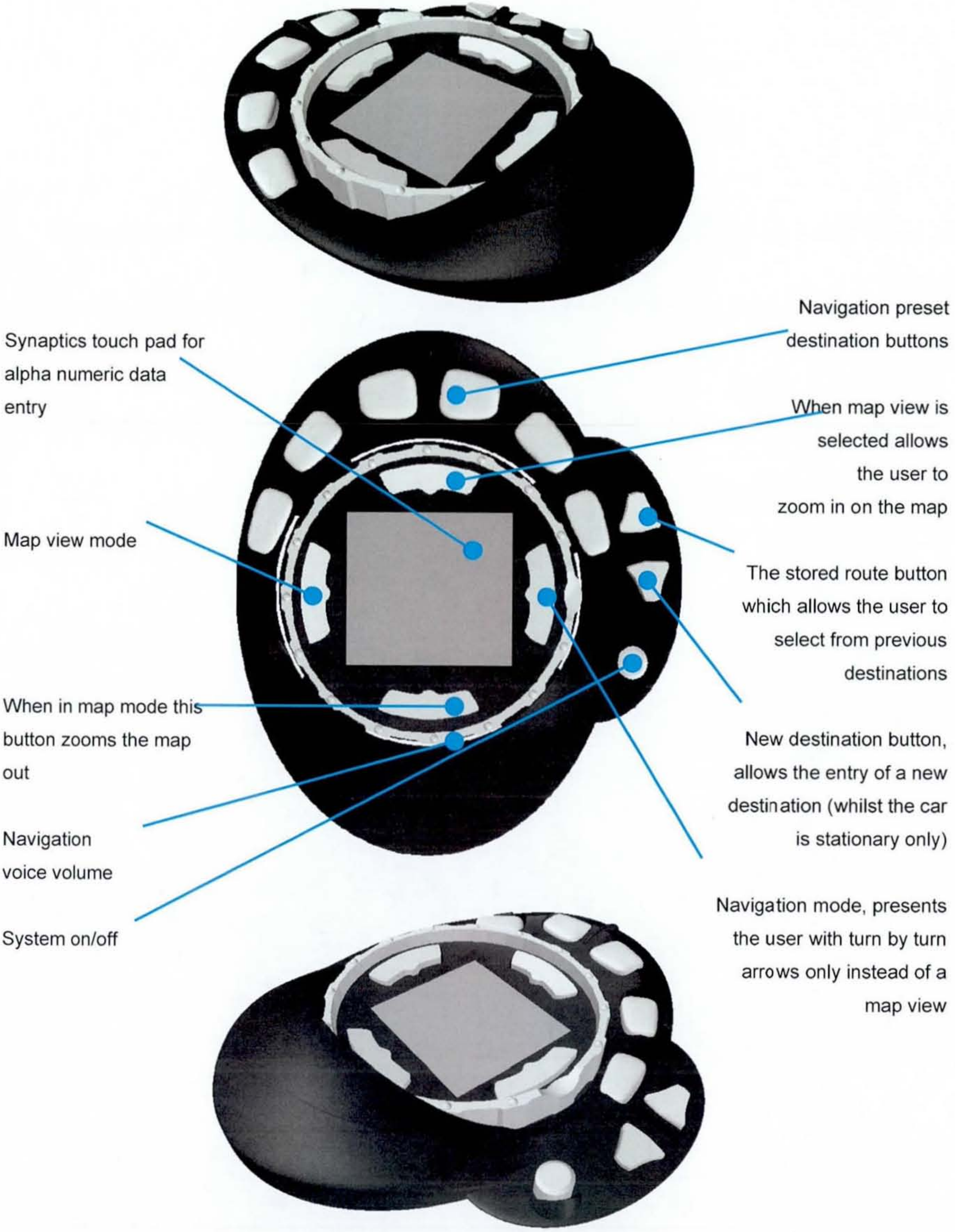


Figure 5.18: The third design iteration of the SATNAV array incorporating the hand rest and controls on the right hand side of the array for thumb use

A summary of the design changes made between each design iteration can be seen in Appendix 4. This concluded the initial array design process. With the form and control layout of each array defined it was necessary to determine the minimum usable size of each array due to limited space that was found to be available in the 2001 Honda Civic.

5.4.1 User trials to test the minimum useable size of the three functional arrays

5.4.1.1 Introduction

The requirement to define the minimum size of the three functional arrays arose from the limited reachable space that was found in the 2001 Honda Civic using the SAMMIE human modelling software (see Chapter 4). Before an attempt was made to design a mounting structure that could allow reach and vision of the three arrays by all users, it was considered necessary to assess the minimum useable size of the arrays. Variables such as the height and width of the hand rest, and the size of the controls were examined by producing models of different sizes for each of the array designs. It was also anticipated that the smaller the three arrays were the more mounting position options would be possible within the limited available space.

5.4.1.2 The sizing of the arrays based upon anthropometric data for the hand

The size increments of the arrays that were produced were defined using the SAMMIE system. The driving population that was defined for the assessment of the Honda Civic were used to provide variation in hand length. A relaxed posture was adopted for the hand as shown in Figures 5.19 and 5.20. The arrays were then sized so that the rearmost portion of the array was reachable with the palm of the hand on the hand rest. This produced the largest size of the array at 179mm from the front of the hand rest to the back of the array (length) and a smallest length of 135mm. An increment was also produced that lay between these sizes with a length of 157mm. These sizes were produced using SLA (stereo lithography) rapid prototyping technology to allow an examination of preferred size by a people with a range of hand sizes.

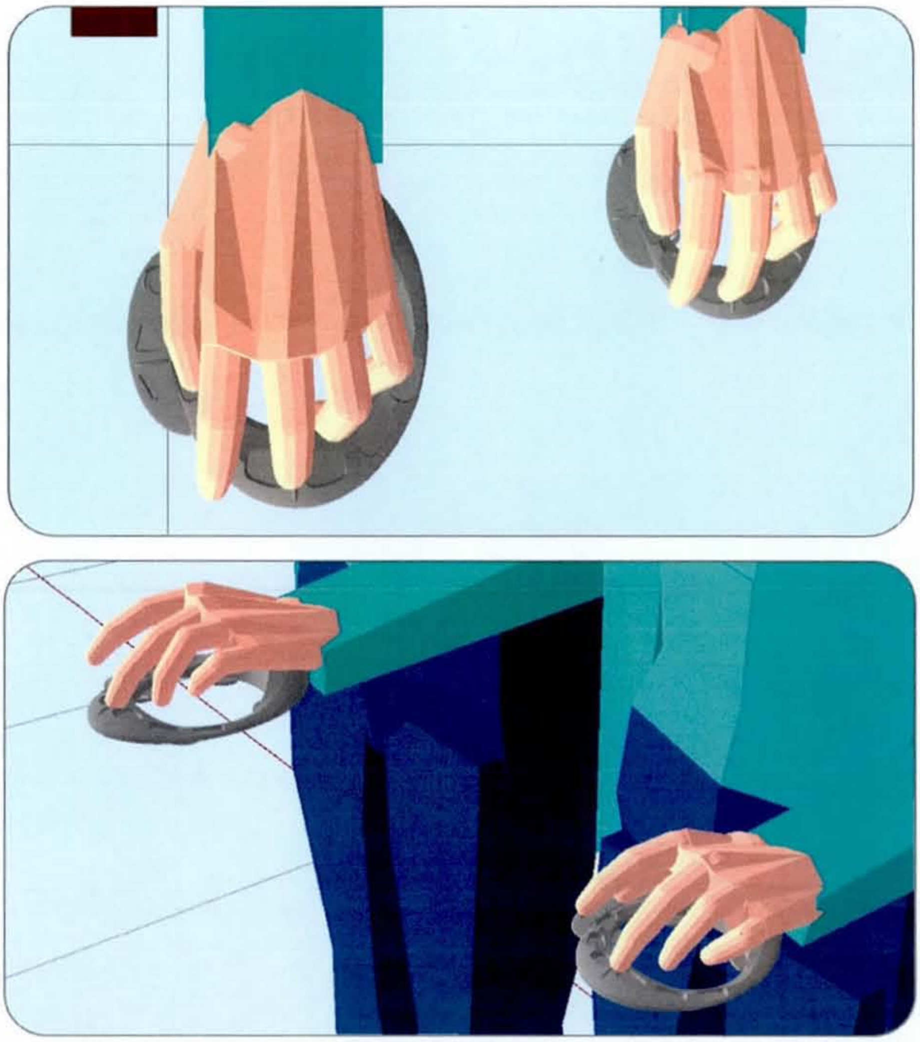


Figure 5.19: The size of the array that allows reach to the rearmost part of the array with the hand on the hand rest. 99th%ile Dutch male (left human model) and 5th%ile Japanese female array sizes are shown

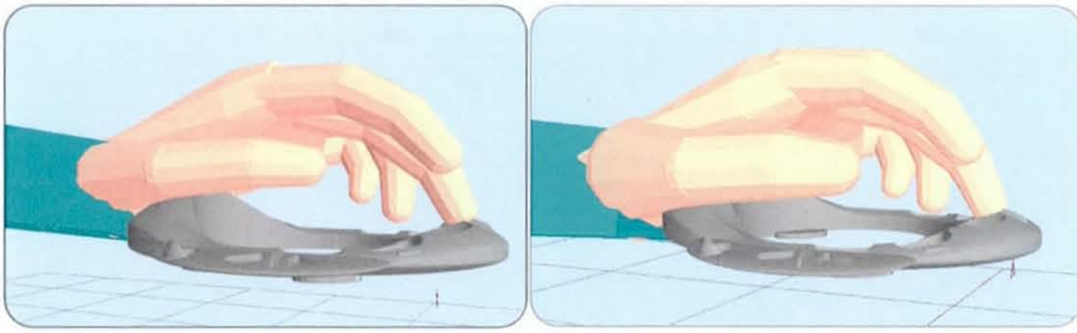


Figure 5.20: The left hand images show the hand of the 99th%ile Dutch male reaching to the divider between the third and fourth radio preset. The right hand images show the hand of the 5th%ile Japanese female reaching to the divider between the third and fourth radio preset (different sized arrays)

5.4.2 Participants

It was considered important to use participants that exhibited a large range of hand sizes in order to examine the suitable size of the arrays. Hand length dimensions were taken from the anthropometric data source ADULTDATA (1998) and these data were compared to the hand lengths of 20 possible participants. The aim was to select participants with hand length variability that matches the population that can drive the Honda Civic, i.e. 5th%ile Japanese female to 99th%ile Dutch male. Four males and four females were included in the user trial, with an age range of 22 years old to 52 years old. The table below shows the percentile of hand length for each of the selected participants. The data collected from the males was compared to hand data for the Dutch population, the female data was compared to Japanese female hand length data in order to reflect the previously defined population range that can drive the Honda Civic.

Participant number	Hand length %ile
Male	Dutch Data
1	97
2	85
3	42
4	21
Female	Japanese data
1	93
2	65
3	37
4	8

Table 5.1: The hand size of each participant that was selected for the array sizing trial

Of the 20 available participants screened for hand measurements the best range of hand measurements available were those shown in the Table 5.1. The difference in hand length between largest hand used (97th%ile Dutch hand length) and the ideal 99th%ile Dutch hand length is 7mm. The difference between the smallest hand used (8th%ile Japanese female) and the ideal 5th%ile hand length is 2mm. These differences were not seen as significant based upon the relaxed hand posture that was used in the SAMMIE test, i.e. it was presumed that the differences in hand length between the ideal 5th%ile

Japanese female to 99th%ile Dutch male and the hand lengths shown by the sample could be easily accommodated with a small change in hand posture.

5.4.3 Methodology

The methodology was designed to examine the size of the hand rest and the size of the control layouts independently. It was considered important to use a task based methodology that required the users to understand the function of each button to keep the study as realistic as possible. The participants were initially shown the poster in Figure 5.21 and the functional groups were explained in terms of function of operation.

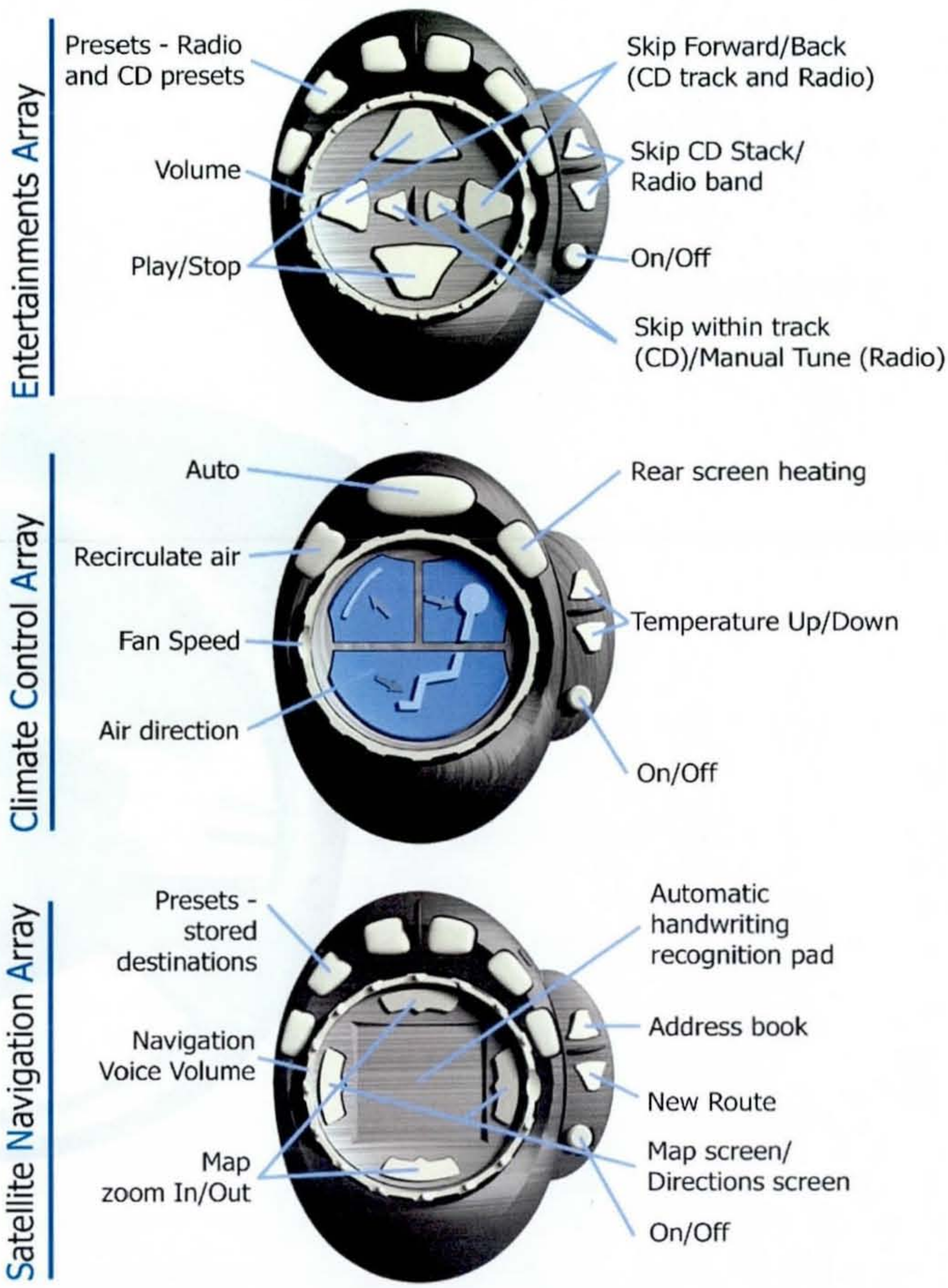


Figure 5.21: The poster used to demonstrate the BIONIC functions to the participants

The participants were then asked to locate the palm of the left hand on the integrated hand rest and were given instructions to locate and press the buttons associated with five tasks per array. The five tasks that were performed for each array can be seen in table 5.2. The left hand was used by all participants to reflect the useable space that was found in the SAMMIE analysis of the Honda Civic interior. Figure 5.22 shows the three sizes of each array ready for the user trial.

Ice array	HVAC array	SATNAV array
On/off	AC on	Address book
Volume	Increase Temp	Stored destination 1
Radio Preset 2	Airflow face	Map view
CD mode	Rear screen heating	Zoom Map
Skip track	Airflow windscreen	Navigation view

Table 5.2. The tasks performed during array size assessment user trials

Subjects were then asked to rank the three array sizes in terms of their preferred size of hand rest and the preferred size of the control mounting area.

Figure 5.22: Each of three arrays in three different sizes

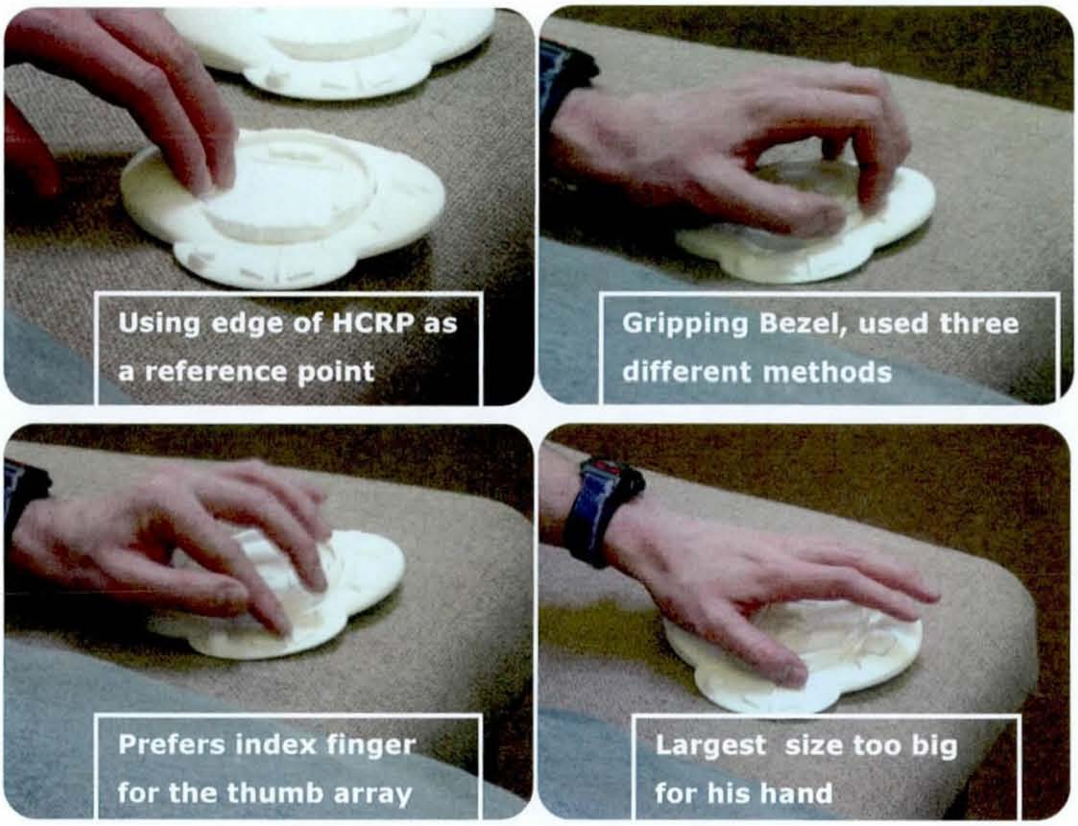


Figure 5.23. A male subject interacting with the arrays at a 75% scale and 100% scale

Each participant was then asked to explore the non-visual use of the array designs, by attempting to access each control without using vision. User comments were recorded during the testing and photographs were taken to illustrate the comments made by the participants as shown in figure 5.23.

5.4.4 Results

The following tables show the ranked order of preference for the hand rest size and array size with the most preferred having a table entry of 1 and the least preferred having a table entry of 3.

Participant	Preferred size of controls Largest Array	 Middle Array	 Smallest Array
		Male	
1	3	2	1
2	3	1	2
3	3	2	1
4	3	2	1
		Female	
1	3	2	1
2	3	2	1
3	3	2	1
4	3	1	2

Table 5.3. The tasks performed during the user trials

Participant	Preferred hand rest size Largest Array	 Middle Array	 Smallest Array
		Male	
1	3	1	2
2	3	1	2
3	3	2	1
4	3	1	2
		Female	
1	3	1	2
2	3	2	1
3	3	1	2
4	3	1	2

Table 5.4. The tasks performed during the user trials

The most preferred array size was the smallest array in terms of control size, and the middle array in terms of hand rest size with all participants ranking these sizes as either 1st or 2nd favourite. All participants stated that they felt that they could also use a control array at the middle and smallest size comfortably. The user trial also provided some useful design information. The points highlighted by the participants are listed below;

1. The divider that should allow the user to locate preset 2 and 5 on the ICE and SATNAV arrays is too small and needs to be made more obvious

2. Vision to the Zoom out button could be blocked by the hand rest depending upon the viewing angle
3. More than half of the participants were not happy using their thumb for control interactions on the surface to the right of the array. Interacting with this area using the index or middle finger provided no problems for users.

5.4.5 Conclusions

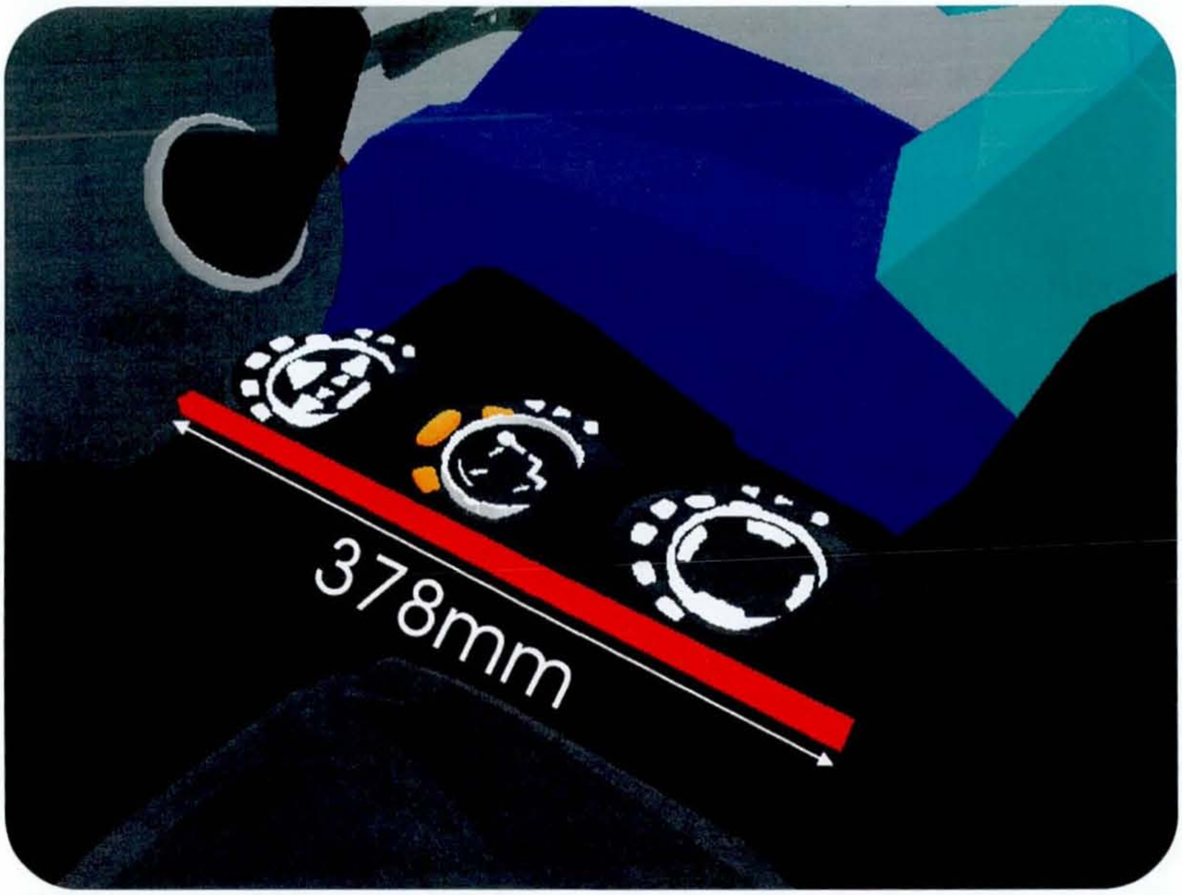
The user trials successfully identified a suitable size for the functional arrays, and provided some suggestions for the design of the tactile discrimination within the arrays. The next stage of the design process attempted to define a mounting structure that allowed reach and vision to the control surfaces within the limited reachable space available in the 2001 Honda Civic.

5.5 The design of the mounting structure to hold the three functional arrays

The design of the mounting structure for the three arrays was aided using the SAMMIE human modelling system discussed previously. The CAD data for the three arrays were imported into the SAMMIE system as shown in Figure 5.24. The imported CAD models of the arrays allowed an exploration of orientations and positions of the arrays within the reachable and viewable location defined in section 4.4.4.3.

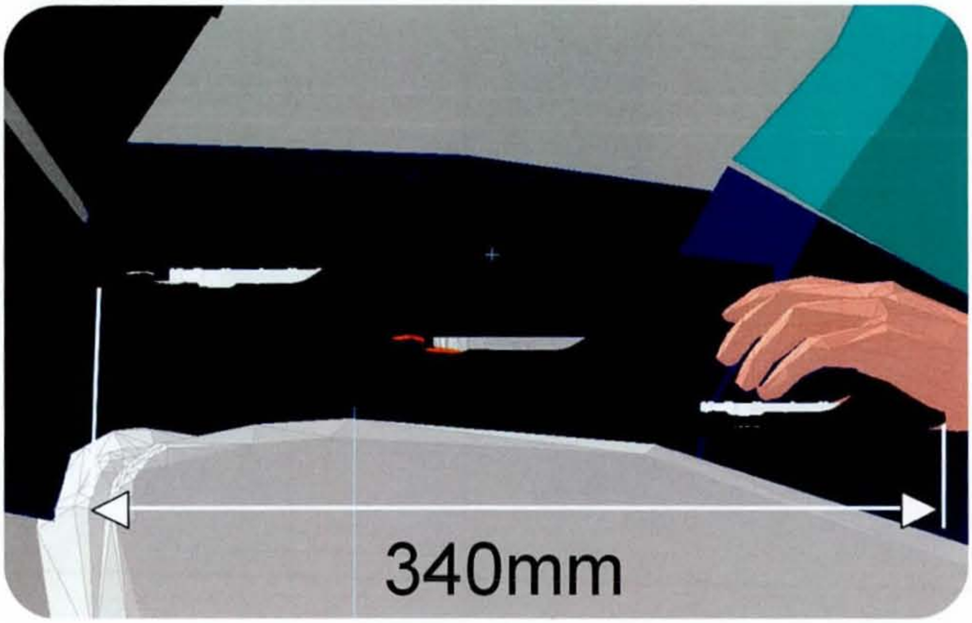
5.5.1 The rearmost viewable and reachable position as defined in chapter 4

By simply placing each of the arrays in a horizontal line (see figure 5.24) the rearmost point of the three arrays is 378mm. This is in excess of the 340mm limit that was set. it was determined that the array orientation shown in figure 5.24 would also result in inadvertent operation of controls on the array rear to the one being used, e.g. the preset buttons of the SATNAV array could be accidentally depressed when using the HVAC array.



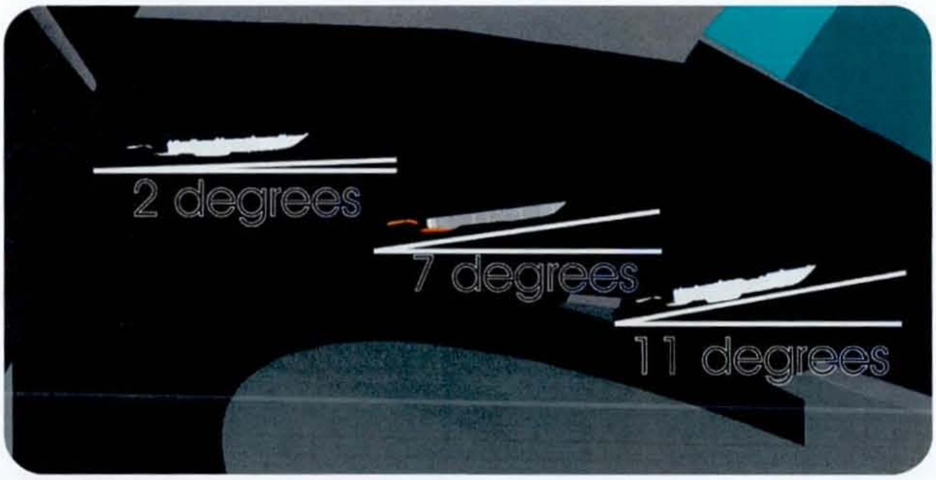
5.24. The rearmost viewable and reachable position as defined in chapter 5, being exceeded by a straight line orientation of the three arrays

The layout was experimented with by slightly overlapping the arrays, with the ICE array higher than the HVAC array and the HVAC array higher than the SATNAV array. This allowed the three arrays to be contained within the 340mm fore aft constraint, and allowed the use of the HCRP portion of the array without inadvertent operation of controls on the array to the rear of the one being interacted with. See figure 5.25 which shows that all three arrays were within the volume defined in section 4.4.4.3. i.e. below base of the gear stick, within the 340mm rearwards position, and between the two seats.



5.25. The orientation of the three arrays that fits within the defined 340mm rearwards limit, and does not allow inadvertent operation of controls

An examination of the wrist angles exhibited by users in this configuration caused concern. The wrist posture adopted by the 5th%ile Japanese female when reaching to the rearmost control array was shown to be uncomfortable by five degrees of wrist extension. It was discovered that by angling the HVAC and SATNAV arrays away from the user, that the wrist angle adopted when reaching to the controls of the rearmost array could be improved, allowing comfortable use for the 5th%ile Japanese female. Figure 5.26 shows the final configuration of the three arrays, with a mounting structure that supported this position. Figure 5.27 shows the improvement in wrist posture that is provided by angling the arrays.



5.26. The orientation that allows a comfortable wrist posture for the 5th%ile Japanese female

5.27. The improvement in wrist angle that is allowed by angling the arrays (top image, flat arrays. Bottom image, angled arrays)

In order to verify the suitability of the final design in terms of reach and vision an assessment was performed in the SAMMIE system using the extremes of population size for which the vehicle was designed (5th%ile Japanese female to 95th%ile US male).

5.28. A reach test to determine the suitability of the angled design for the full range of users in the Honda Civic (left column, the 5th%ile Japanese female, the right column the 95thUS male)

Figure 5.28 shows the reach test being performed for all of the arrays by the largest and smallest human model. All postures where within comfortable joint constraint values. Figure 5.29 shows the visibility of the arrays for the Japanese female with 5th%ile stature. The arrays were viewable by this human model using a combination of head, neck and eye movement all within comfortable limits.

Figure 5.29: The visibility of the PTI for the 5th%ile Japanese female human model using a combination of comfortable head, neck and eye movement

Figure 5.30 shows that the 99th%ile Dutch male could also comfortably view the arrays.

5.30. The visibility of the PTI for the 99th%ile Dutch male human model using a combination of comfortable head, neck and eye movement

5.5.2 *Summary*

The SAMMIE human modelling system was used to define a reachable and viewable volume of space within which the PTI should be mounted in Chapter 4. The selected PTI array designs were imported into the SAMMIE system and were orientated within the reachable and viewable space. An iterative design process was used, with various array placements being tested for postural implications. This resulted in an orientation of the three arrays that was reachable and viewable by 5^{th}%ile Japanese female, and 99^{th}%ile Dutch male human models. As with any human modelling CAD assessment, it was deemed necessary to test the design with a physical mock-up in a user trial. The next section reports the testing of the interface design in a driving simulator.

5.6 Evaluation of the prototype design using a driving simulator

5.6.1 *Introduction*

The following study describes the testing of a physical prototype of the PTI using a driving simulator, in order to examine reach and vision to the arrays and to test the symbolic array layouts. The primary aim of the simulator study was to compare the glance durations fostered by the prototype tactile interface controls, to the glance durations that have been reported in the literature for the same tasks. See table 5.5.

Task	Mean/median glance duration (seconds)
Turn on radio	1.1
Fan speed	1.35 to 1.95
Defrost	1.14 - 2.86
Zoom	1.1 to 1.25
Preset station	1.46
Change temperature	1.65 to 1.85

Table 5.5. The mean/median glance durations found in previous studies for tasks included in the PTI

The mean/median glance duration data from the literature review were therefore used as a mechanism to test the ability of the prototype tactile interface layout to convey function to the user. It was hypothesised that if the median glance duration for the PTI controls was within the range of glance durations shown in table 3.1, then the control would be no more dangerous than those fostered by existing controls and displays. If any of the controls require the user to employ larger glance durations than are shown in table 3.1, these controls, and the layout of the controls should be redesigned. The testing of the prototype tactile interface controls was performed with a physical mock-up of the interface that was produced using rapid prototyping techniques. In order to give a realistic task for subjects to perform whilst interacting with the controls, a driving simulator was employed. The following sections describe the sample of participants, methodology, analysis techniques and results from the simulator study.

5.6.2 Sample

Ten participants were selected to take part in the study, with equal numbers of males and females. It was specified that none of the subjects should have had previous exposure to the PTI design to prevent any previous conceptualisation of the interface supporting the control interactions during the study. The sample is illustrated in Table 5.6.

Subject	Sex	Age
1	M	57
2	M	51
3	M	36
4	M	32
5	M	21
6	F	48
7	F	46
8	F	25
9	F	21
10	F	19

Table 5.6. The sex and age of the participants in the simulator study

The mean age of the male participants was 39.4 years, and the mean age of the female participants was 31.8. All participants had held a full UK driving licence for at least two years. It would have been preferable to use some older drivers in the study, with the project aim to account for the effects of age in the design process, however, increasing time pressure on the project at this stage, forced the search for older participants to be stopped and the trials started with the available sample.

5.6.3 Methodology

The method involved producing a physical mock-up of the PTI. The low level of modality of the PTI, with a button for each function, allowed for an assessment on the basis of the glances needed to locate and operate each control. All of the controls had a simple on/off function with one depression accessing the desired function. In order to assess glance duration the following variables needed to be explored and defined;

- The production of the PTI interface mock-up
- The driving task to be performed
- The method for the capture of glance durations
- The method for the analysis of the glance duration data
- The data that the BIOINC glance durations would be compared to
- The experimental design

5.6.4 The production of the BIONIC interface mock-up

The production of the PTI mock-up for the simulator trials raised a number of design decisions. The aims of the simulator study helped in the specification of the mock-up design. The aims of the simulator study were to examine the layout of the PTI interface in terms of the glance durations that were elicited from control interactions. It was assumed that the longer the glance duration, the less well that a label, button shape and layout had conveyed the function of each control. It was inferred from this that the interface should look as much like a final product as possible, with suitable surface finish, colour and labelling. This would allow the participant in the simulator trial to get all of the benefits of the symbolic array design. It was also deemed necessary to give some form of feedback that allowed the participant to know that they had used a control. To this end, the copper diaphragms that are found in small electrical switches were placed under each of the BIONIC controls. When the copper diaphragms were combined with small pieces of foam, the buttons on the prototype would click when they were pressed, providing both tactile and auditory confirmation that a control had been activated.

The rapid prototyped parts that were received needed to be sanded, primed and painted before the labels could be applied. The colour scheme chosen for the controls and mounting structure was design to provide high contrast, whilst also highlighting the interaction points. The labels used on or around each button were based upon the ISO standard in car control symbols where they existed. If no symbol was available English words were used to label the buttons. Figure 5.32 shows the labels that were applied in detail.
Figure 5.31 shows mounting structure that was designed to hold the arrays in the defined location. The mounting structure was designed to support the arrays in the correct location when placed on the floor of the Honda Civic. The arrays were located within the driving simulator rig to replicate this location in relation to the seat position.

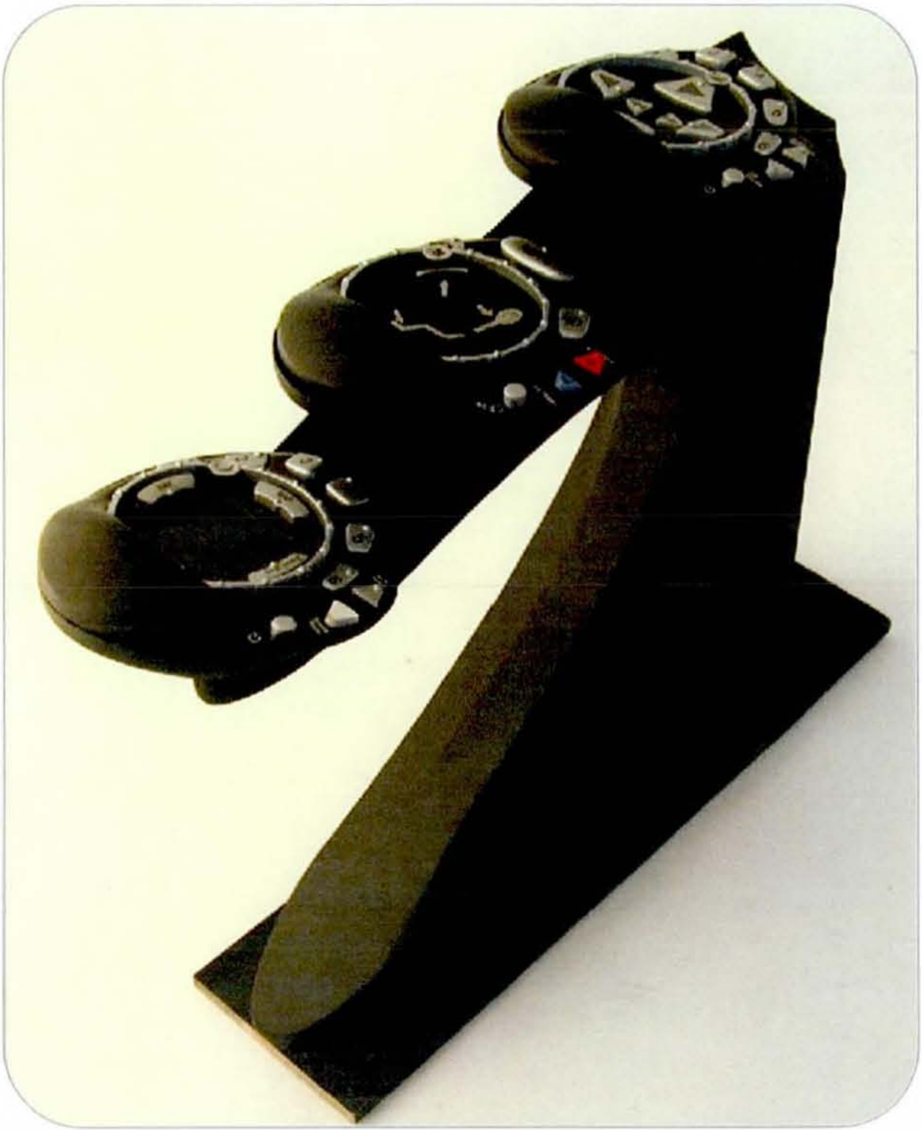


Figure 5.31 The PTI that was used during the simulator study, manufactured using SLA rapid prototyping technology, with tactile feedback for button depression detection

Table 5.32 A detail view of each PTI array, and the copper diaphragms used to create feedback to the user

5.6.5 The driving simulator route and task for determining driver attention

The simulator used for the study was the STISIM driving simulator. The STISIM simulator allows the user to design driving environments that can apply different workloads on the driver. Variables such as road curvature, road layout, traffic density, traffic light status, and the timing of pedestrians walking onto the street can be defined by the experimenter. The system also allows for the collection of data including the velocity of the car and the road position of the car, allowing the detection of lane departures that indicate excessive glance durations. After consultation with an expert in the field of driving simulator use (Dr. Gary Burnett, Nottingham University UK) it was decided to provide a level of road curvature that would not demand too much of the drivers attention. The literature has indicated that drivers will not generally interact with secondary controls under certain driving conditions, for example, steering through a curve in the road, or heavy traffic conditions

(Green 1999). This emphasises the need to design suitable driving conditions into the simulator. Also, a vehicle following task was introduced. This involved programming a white van that drove in front of the subject's vehicle during the simulation. This white van varied its speed, forcing the participant to change speed in order to maintain a safe gap. These tasks were considered suitably demanding by Dr. Burnett and by comparison to the literature (e.g. Tijerina, Parmer and Goodman, 1998). The route driven in the simulator was series of long winding curves joined by straight sections of road. The route required the user to pay attention to the road ahead in order to avoid leaving the assigned lane on the road.

5.6.6 The method for the capture and analysis of the glance duration data

Section 2.2.3.2 in the literature review discusses the methods for capturing glance durations in user trials. In the absence of an eye tracking system the alternative glance duration capture technique was the use of a video camera with post processing of the footage to extract glance durations. Figures 5.33 and 5.34 show the experimental setup that was used in the simulator study. A mirror was placed in a location that allowed the face and eyes to be clearly seen from the camera location. This allowed the video camera to also record the interactions with the controls and the view of the road shown on the screen of the driving simulator. The author would confirm that the correct control was being accessed during a task using the recording script that was also used to structure the assessment in terms of task order.

The glance duration video was digitised and processed in the video editing software Adobe Premiere. This software allowed a frame by frame analysis of the glance duration data, allowing each second of video to be split into 25 frames, allowing a resolution 1/25th of a second. The glance duration, or eyes-off-road time, was calculated by recording the frame number at the very start of the glance (when the eyeball moves away from viewing the road) to the very end of the glance (when the eyeball returns to forward viewing of the road).The glance durations were captured and processed with start and end points and these were used to determine the duration of each glance. The task being performed for each glance was also recorded. See section 6.4 for a detailed description of the data capture and analysis process. The data was then processed to give median glance durations which were compared to those found in the literature. The median (central value) of glance duration was used as opposed to the mean. The use of mean values in statistical testing of significant difference relies upon the assumption of a non-skewed 'Normal' distribution of the data (i.e. parametric data). This cannot be assumed for glance durations from a relatively small sample of 10 people. In addition, a 'Normal' distribution cannot be assumed for all data collected from a large sample of people. For example, if a study was performed in which the glance durations for a control selection task were gathered from thousands of people, there could be a skew of the data, with more people exhibiting longer or shorter glance durations than the mean. In this case parametric statistics would not be appropriate. This resulted in the use of the median glance duration, a measure that does not rely upon parametric assumptions, and the use of non-parametric statistical testing using the Wilcoxon signed ranked test.

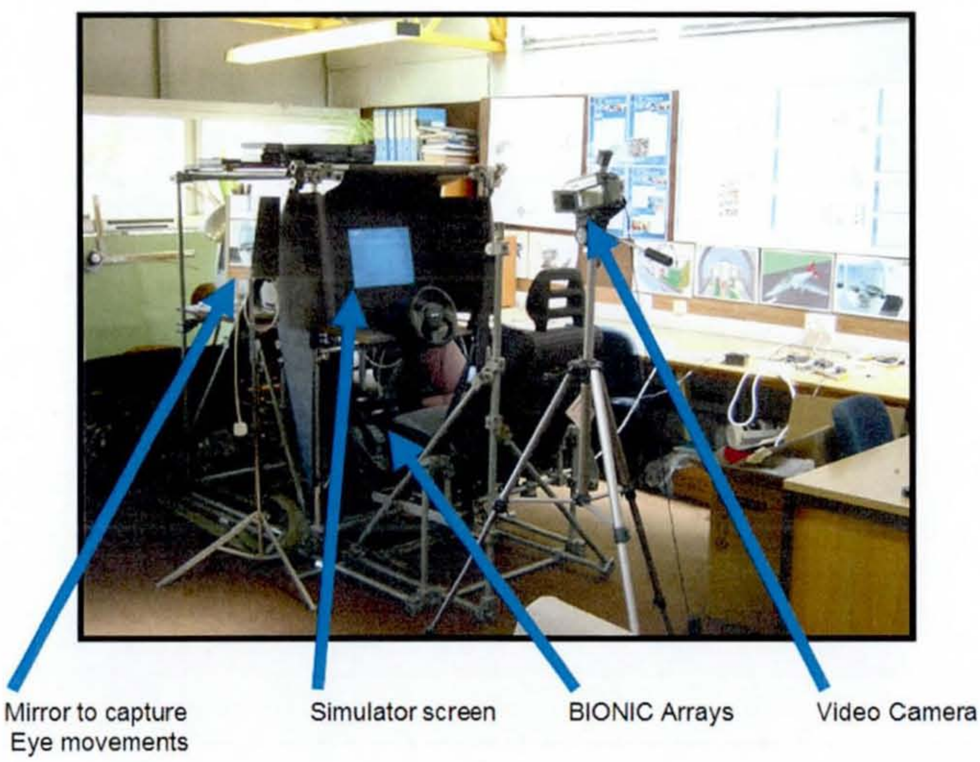


Figure 5.33. The simulator experimental setup using a mirror to capture glance durations

The video recording of the on screen activity allowed the author to determine if any of the participants accidentally crossed the lane markers on the simulated road. The time frame of any lane exceedances would be identified and the position of the participant at this point in the trial would be compared to the data produced by the simulator software that relates to road position.

Figure 5.34. The simulator experimental setup using a mirror to capture glance durations

5.6.7 Experimental design

The simulator study started with an explanation of the purpose of the experiment. The participants were not told that the PTI design attempts to encourage non-visual use. The experiment was divided into three distinct parts which were run concurrently over the period of 45 minutes.

5.6.7.1 Part 1: Guess-ability

The aim of the guess-ability section was to determine how well the PTI control layout conveyed the various functions. To this end, the participants were asked to sit in the driving simulator seat, with the simulator not running. They were then given verbal instructions to perform all tasks that were associated with the array controls. This was done using goal driven phrases such as "which control would you use to zoom in on the map?" and " Which control would you use to increase the fan speed?" This was seen as analogous to the first contact situation where the user needs to perform a set of tasks with an unfamiliar interface design as outlined in the scenarios in section 4.5. Any errors made by the participants were corrected, i.e. they would be told where the correct control was. This process generally took around 15 minutes. The order of presentation of the tasks was randomised for each of the three parts of the study design in order to account for order effects.

5.6.7.2 Part 2: Simulator run with vision

The second part of the study looked at the glance durations that were produced when the subject performed the driving task. The participants were told to keep a safe distance from the white van that was in front of them at the start of the simulator run. They were also told not to overtake the van. The participants were then asked to perform tasks that were associated with all of the controls.

5.6.7.3 Part 3: Simulator run without vision

The third part of the study looked at the success rates for control interaction without vision. The simulator run was the same as that performed in part 2, except that vision of the controls was blocked using a dividing wall as shown in Figure 5.35. This was done to explore if the tactile coding and symbolic layout can combine to allow non-visual use after a short period of exposure to the PTI.

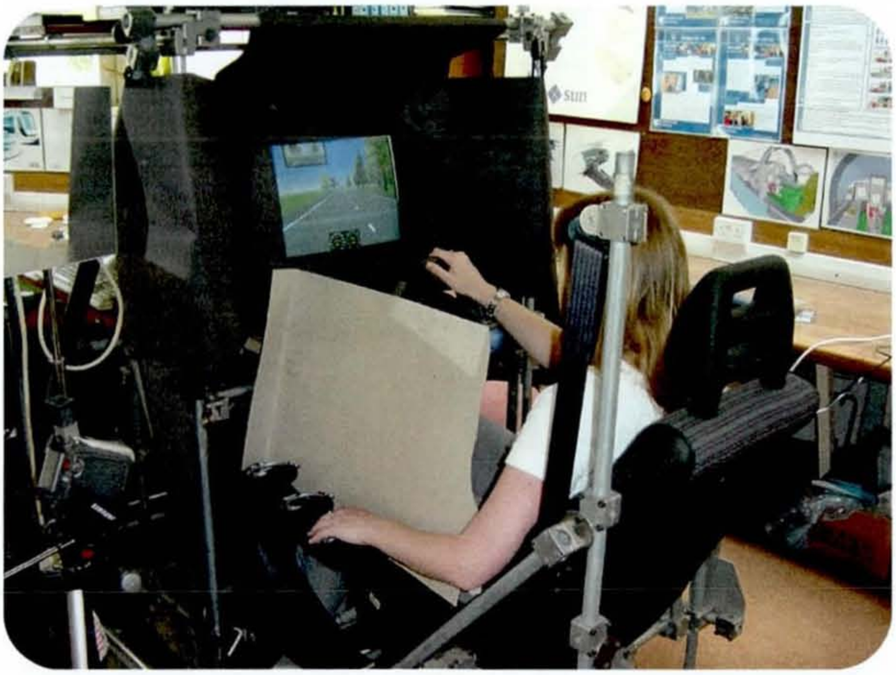


Figure 5.35. The panel used to obscure the controls from the participants

5.6.8 Summary

Section 4.4.4.3 specified metrics for recommended glance durations. The experimental method for the simulator study allows the number and duration of glances that are fostered by the PTI to be captured and analysed. These results were compared to the recommended glance duration limits.

5.7 Results for Part 1: Guess-ability

The guess-ability results were processed to determine the percentage of the 21 tasks that were performed successfully by each participant. The graph below shows the percentage of correct control identifications for each subject

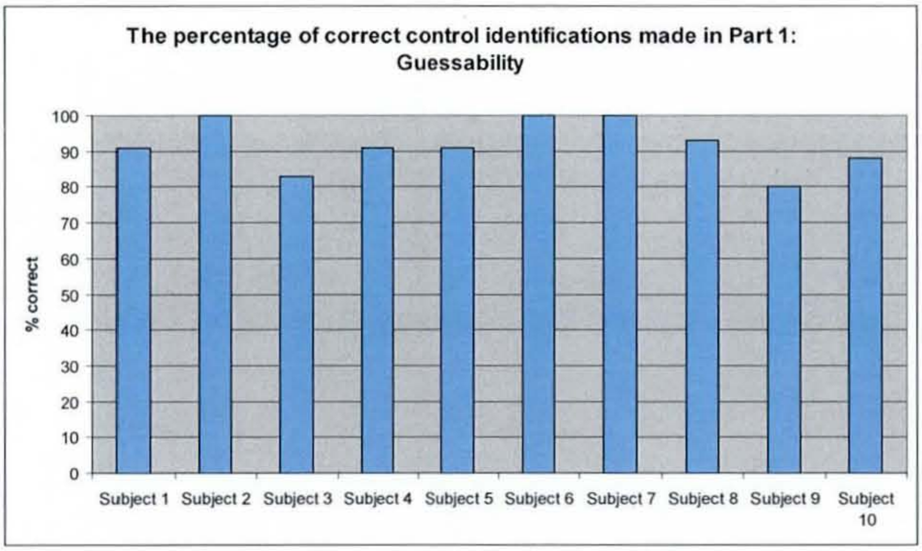


Figure 5.36. The percentage of correct control identifications made by each participant during the 'Guess-ability' stage

Three participants (numbers 2, 6 and 7) correctly identified all of the controls that were associated with the given tasks. Of the remainder five participants correctly identified the control in 19 of the 21 tasks (numbers 1, 4, 5, 8,10). The lowest accuracy was shown for participants 3 and 9 with 18 and 17 correct control identifications respectively.

5.8 Results for Part 2: Simulator run with vision

The results from the glance data analysis show how the glance durations elicited from the PTI compare to the glance duration values found in the literature. The initial analysis looked for median glance durations above 1.58 seconds for each task, as discussed in section 2.2.4. The Figure 5.37 shows the median glance durations for all of the PTI tasks. The only function which produced median glance durations above 1.58 seconds was Radio Mode. Therefore, on the basis of median glance duration, all but one of the control designs were within glance duration limits.

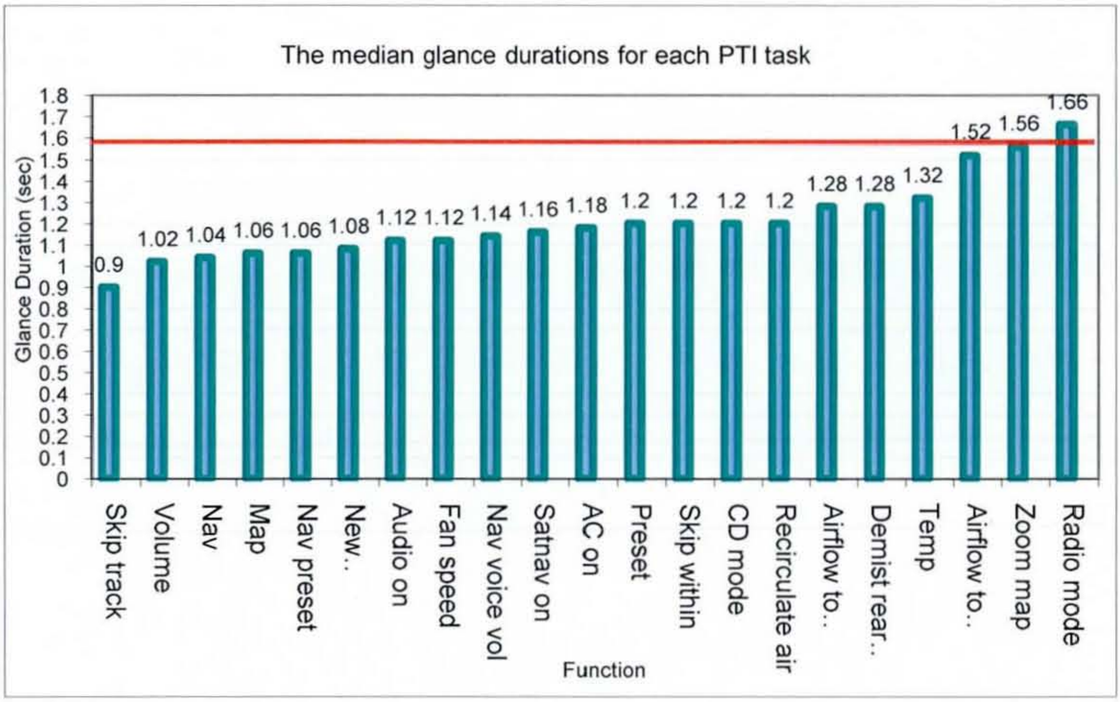


Figure 5.37 The median glance durations for each PTI task. The 1.58 second threshold is identified by the red line

Table 5.7 shows the median values for glance durations elicited by all tasks in each functional group. Based upon this the SATNAV array elicited the shortest glance durations, and the HVAC array elicited the longest.

	HVAC	SATNAV	ICE
Median glance durations	1.28	1.08	1.2

Table 5.7 The median of median glance durations for each array of the PTI

The results in table 5.7 were all below the 1.58 second threshold, however it was decided to examine which controls elicited the largest single glance durations in order to explore control design refinements. Table 5.6 shows the median, maximum and minimum glance durations for each task. The majority of the tasks elicited at least one glance duration that was beyond the 1.58 second threshold (one instance during the testing where a glance was above the defined threshold).

Task	Median glance duration	Max	Min	% of non visual interactions
Skip track	0.9	1.64	0.8	0
Volume	1.02	1.28	0.8	40%
Nav	1.04	2.36	0.92	0
Map	1.1	1.56	0.72	0
Nav preset	1.06	1.36	0.96	10%
New destination	1.08	2.32	0.8	10%
Audio on	1.12	1.84	0.92	0
Fan speed	1.12	1.36	1.08	30%
Nav voice vol	1.14	1.4	0.88	30%
Satnav on	1.16	1.76	0.92	20%
AC on	1.18	1.68	1	10%
Preset	1.18	1.84	0.56	10%
Skip within	1.2	2.04	0.92	0
CD mode	1.2	1.76	1	0
Recirculate air	1.2	1.24	0.84	0
Airflow to screen	1.28	2.1	1.16	10%
Demist rear screen	1.28	1.52	1.08	0
Temp	1.32	2.2	0.8	10%
Airflow to Feet & face	1.475	1.68	0.96	0
Zoom map	1.48	1.92	1	0
Radio mode	1.66	1.72	1.1	0

Table 5.8 The Median, Maximum and minimum glance durations, and the percentage of non visual interactions that were performed for each task

Each participant was asked to suggest any possible improvements to the design, and a number of these comments related to the functionality that exceeded the 1.58 second threshold. The majority of the comments made referred to the size of the text on the CD, RADIO, NEW DEST, ZOOM, MAP, and NAV buttons. Nine participants reported that the text was too small to read. This could account for the relatively lengthy single glances. Six participants mentioned the layouts of the MAP, NAV, ZOOM +, ZOOM – functions, were difficult to remember, and that the ZOOM out button was blocked from view by the hand rest in the SATNAV array. The other relatively high glance duration that matched comments made by the participants was the use of the on/off switches on each pod. It was suggested that these could "stand out" more by three participants. Three participants also said that they would expect to activate this control inadvertently in its current location.

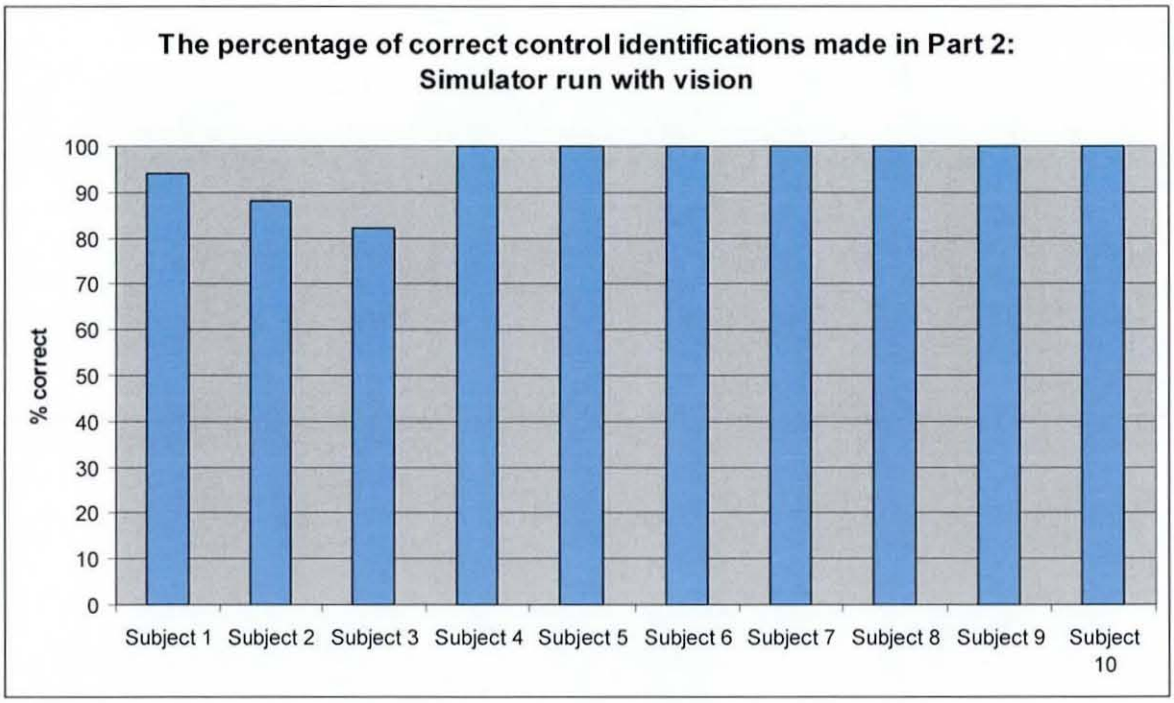


Figure 5.38. The percentage of correct control identifications made by each participant during the simulator run with vision stage

Figure 5.38 shows the percentage of correct control identifications made by each participant during the simulator run with vision. 96% of all tasks given were performed successfully.

Table 5.9 shows a comparison between the median glance duration data found in the study, and those reported in the literature for the same task. Only one task was found to elicit longer median glance durations than those found in the literature. The zoom task was associated with difficulty of reading the button labels as discussed.

Task	Mean/median glance duration from the literature	PTI median glance duration	
Turn on radio	1.1	1.1	Equal
Fan speed	1.35 to 1.95	1.12	Below
Defrost	1.14 - 2.86	1.28	Within
Zoom	1.1 to 1.25	1.52	Above
Preset station	1.46	1.2	Below
Change temperature	1.65 to 1.85	1.32	Below

Table 5.9 A comparison between the mean/median glance durations found in the literature compared to the median glance durations of the PTI

The raw glance data that was collected for the simulator run with vision can be seen in Appendix 3.

5.9 Part 3: Simulator run without vision

Figure 5.39 shows the percentage of correct control identifications in the final simulator run, without vision (the PTI arrays where blocked from view during the final run). 92% of the controls were identified correctly in this condition

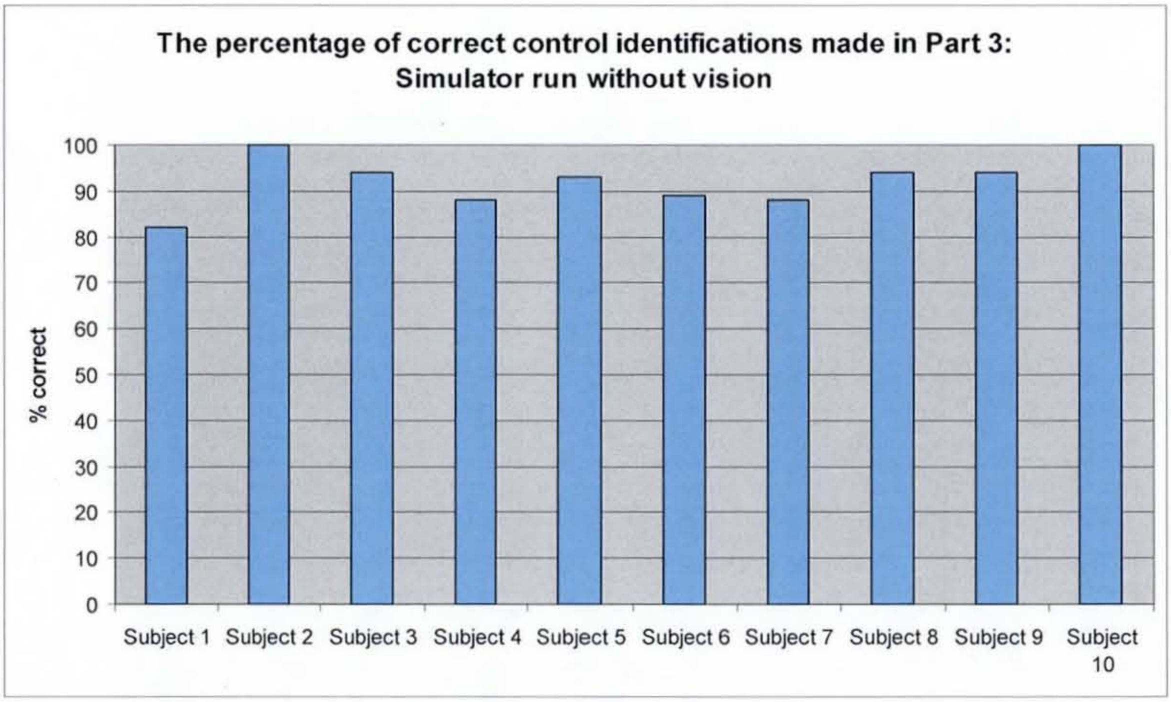


Figure 5.39. The percentage of correct control identifications made by each participant during the simulator run with vision stage

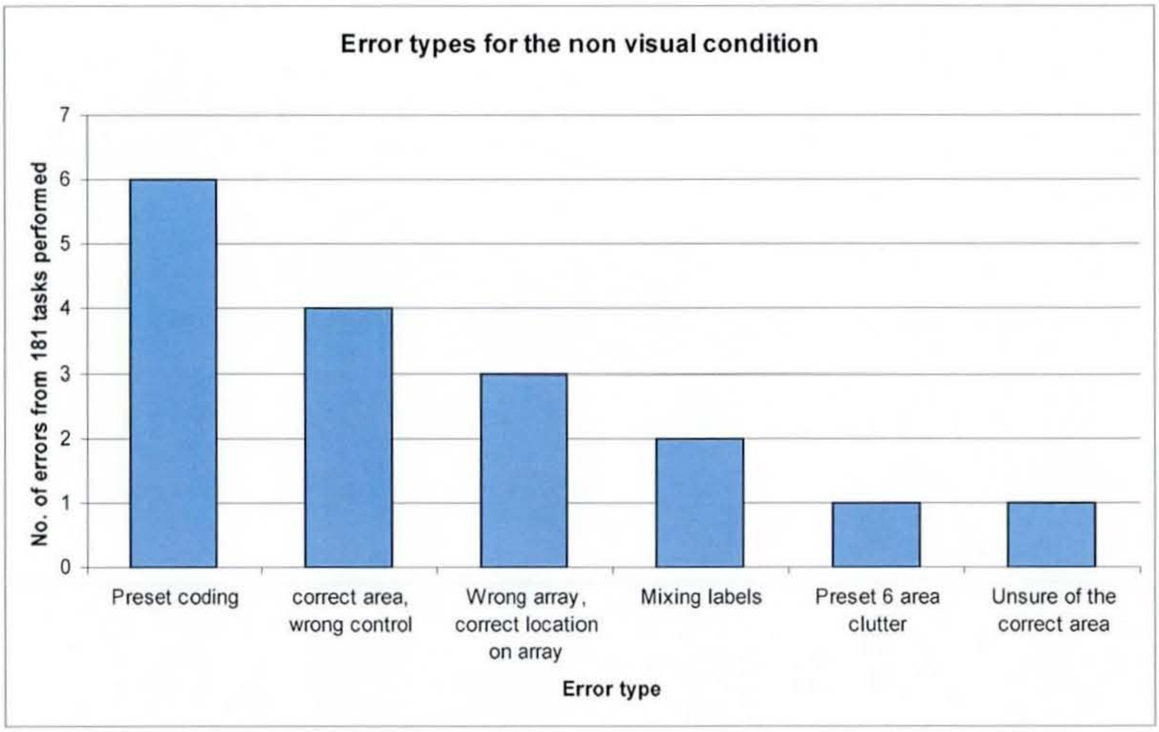


Figure 5.40 The percentage of correct control identifications made by each participant during the simulator run with vision stage

The errors that were made during the simulator run without vision are categorised in Figure 5.40. The majority of errors were made in the selection of radio presets, which matched the comments made by participants regarding the size of the dividers between the presets being too small. Other errors involved the users accessing a control next to the correct control (4 instances), the correct location in the wrong array (3 instances), mixing up cd/radio or map/nav (2 instances), and mixing up of the preset 6 and radio/new route buttons (1 instance).

5.10 Discussion

The simulator study has successfully verified that the PTI does not foster median glance durations that exceed those for common control and display interactions. The median glance durations that were found for each functional group were less than the 1.58 second threshold. The median glance duration for the HVAC, SATNAV and ICE arrays were 80%, 68% and 75% of the 1.58 second threshold respectively. Perhaps the most significant result of the simulator study was the percentage of control interactions that were performed without the need to look at the arrays. Of the 21 tasks that were performed 10 were completed without the need to look at the control by a least one participant. When performing the simulator run with vision the participants would have had around 15 minutes of exposure to the PTI design. The most successful control designs (fan speed, volume and navigation voice volume) allowed 30-40% of the participants to use the controls without taking their eyes off the road. It was not anticipated that users would engage with the tactile coding to this extent during a user trial of this duration. This was therefore seen as a positive result. The simulator study has also highlighted areas for improvement in the design of specific controls layouts. The errors that occurred in the trial have indicated that the subdivision of the preset buttons on the ICE and SATNAV arrays needed improvement, that labelling of the controls needed to be improved by increasing the size of the text used, and that the preset button number 6 was too close to the adjacent control on the ICE and SATNAV arrays. These issues are addressed in the following section.

The simulator trial required the users to identify and depress the control that is associated with a specific function. Whilst useful in terms of checking the layout of the controls and confirming that tactile coding is useful, the study did not simulate real control interactions such as changing the volume, CD track number or airflow setting where feedback from the system is required to complete the task. The following section describes the design and build of the final PTI which was a working prototype.

5.11 Final prototype preparation and software design

The aim of the final study that is described in the next chapter was to compare the PTI design to a baseline system to ascertain if a reduction of 'eyes-off-road' time can been achieved. This involved creating a working version of the PTI that could be integrated into the interior of the Honda Civic, whilst also hiding the OEM HVAC and ICE controls. The plan for the final study required a prototype design that operated with a high level of fidelity to allow a valid comparison with the base line system. The baseline system contained the standard HVAC controls in a Honda Civic and a combined ICE and SATNAV unit provided by Visteon (the Visteon VNR 9600). The remainder of this chapter describes the design changes that were made to the PTI on the basis of the simulator study results and the requirements for working prototype design.

5.11.1 Methodology

A methodology was developed for the production of the working PTI through consultation with research staff at Visteon, a project partner, and experts in the design of prototype test rigs. This involved producing a printed circuit board (PCB) for each functional array. Switches were mounted on the PCBs that matched the positions of the switches in the PTI that was used in the simulator study. These switches were then connected to a data logger which provided an input to a laptop computer. This computer read the signals from the data logger and displayed feedback to the user. The software that controlled this process was an in-car development tool called Altia. This system allows a large number of switches to be linked to the computer, with the software recognising that a switch has been activated, and displaying appropriate visual or auditory feedback. This process allows hi fidelity simulation of a product's software interface to be simulated.

5.11.2 The development of the PTI hardware

The production of the parts for the working prototype required a high degree of accuracy to allow the PCBs, switches, switch caps and the mounting surface to interact correctly and not cause switches to jam. The CAD software used to create the PTI that was tested in the driving simulator study was Newtek Lightwave, a piece of CAD software aimed at the production of realistic visual images of products. The level of control available within the modelling tools of Lightwave were not seen as suitable for the production of accurate parts that were to be rapid prototyped. Thus, the entire model of the PTI, including PCBs and wiring was re-modelled in the CAD package Pro Engineer Wildfire 2. This parametric CAD software allows for the fine control of the parts that are produced and allows the user to build 'assemblies' containing the separate parts that make a whole product. This supports the production of parts that interact correctly when manufactured. The system can then output these files in a format that can be manufactured using rapid prototyping technology.

The main design challenges that the final prototype design presented were;

- The need to design a structure that replicated the spatial constraints and array orientations of PTI version one, but also incorporating PCBs with working electronic switches that interacted with the switch caps

- The need to produce working array bezels that are able to convert the bezel rotation into the rotation of a variable resistor that controls fan speed

The complete remodel of the PTI in Pro Engineer initially involved the design of the PCB. In order to be consistent with the first PTI prototype, dimensions were taken for the location of each button centre. These button centres were then rebuilt in Pro Engineer to allow the switches to be placed on the PCB. The PCB model in Pro Engineer included accurate models of the switches that were identified for use in the design. This then set the constraint for the height of the portion of the switch cap that located onto the switch. This kind of logical progression allowed the design to be created in a way that allowed the PCBs to be enclosed by a structure that exhibits the desired attributes of the first prototype.

Creating a mechanism that converts rotation of the bezels that control volume and fan speed, into rotation of a variable resistor was a challenge. The mechanism that was designed used a gear on the base of the bezel that turned cogs which then directly drove the rotary variable resistor on the PCB. Figure 5.41 shows the structure of the PTI. Figure 5.42 shows the gearing used to convert the 90 degree rotation of the bezel into the required 320 degree rotation of the variable resistor.

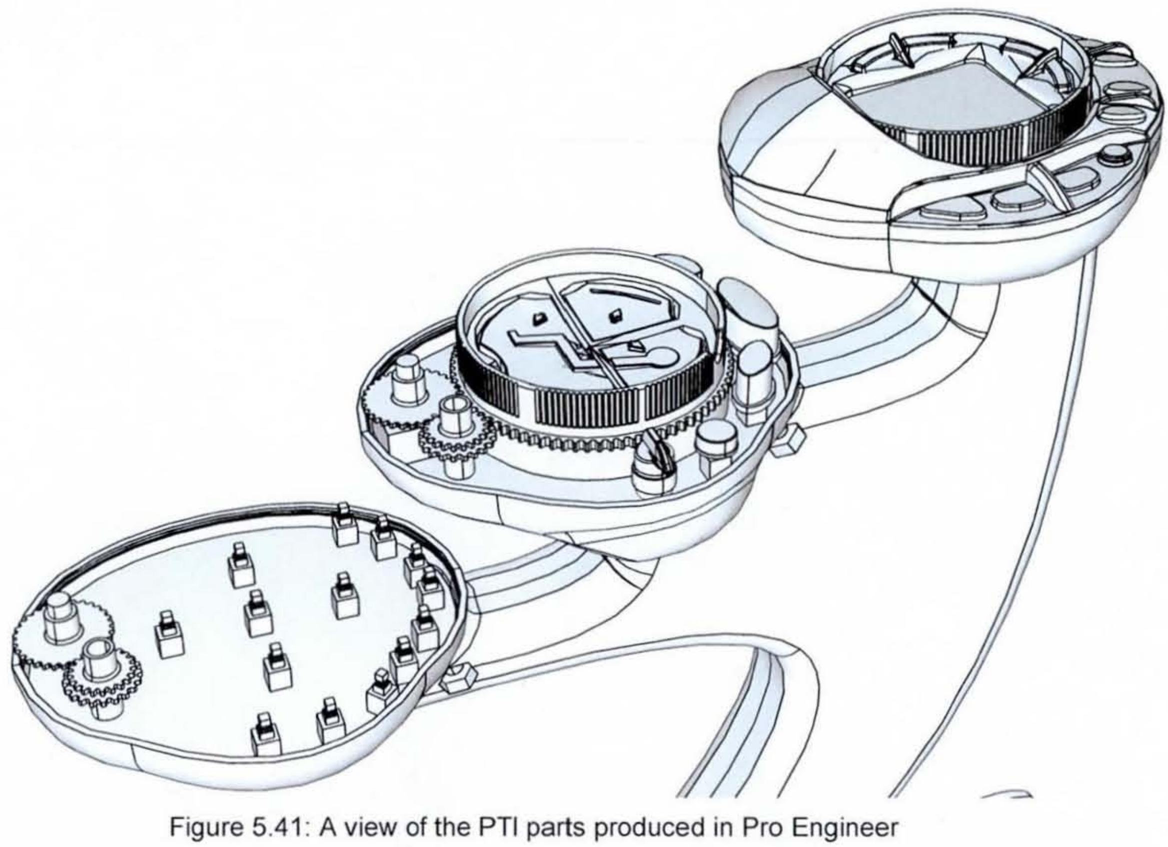


Figure 5.41: A view of the PTI parts produced in Pro Engineer

Figure 5.43 shows the shows an exploded view of an array with the surface upon which the bezel rotates highlighted in red. At this stage in the design process the CAD data for the parts of the final PTI were sent away to be rapid prototyped and the PCBs were built by the author. This was followed by the receipt of ABS (Acrylonitrile butadiene styrene) parts that were moulded from the rapid prototype parts. ABS is a thermoplastic that is used in the production of car interior components and therefore displays properties that are suitable for the intended environment. These parts were refined, painted and labelled by the author. The PTI was then assembled with the PCBs.

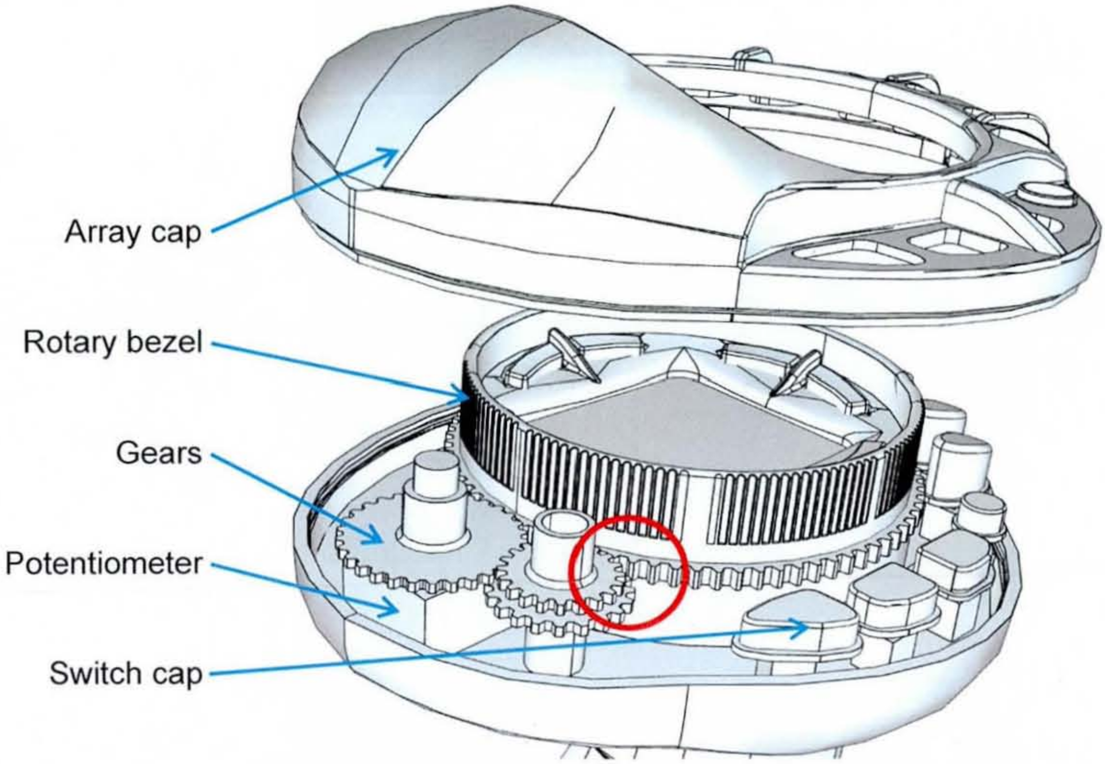


Figure 5.42: A view of the bezel interaction with the cogs that drive the potentiometer

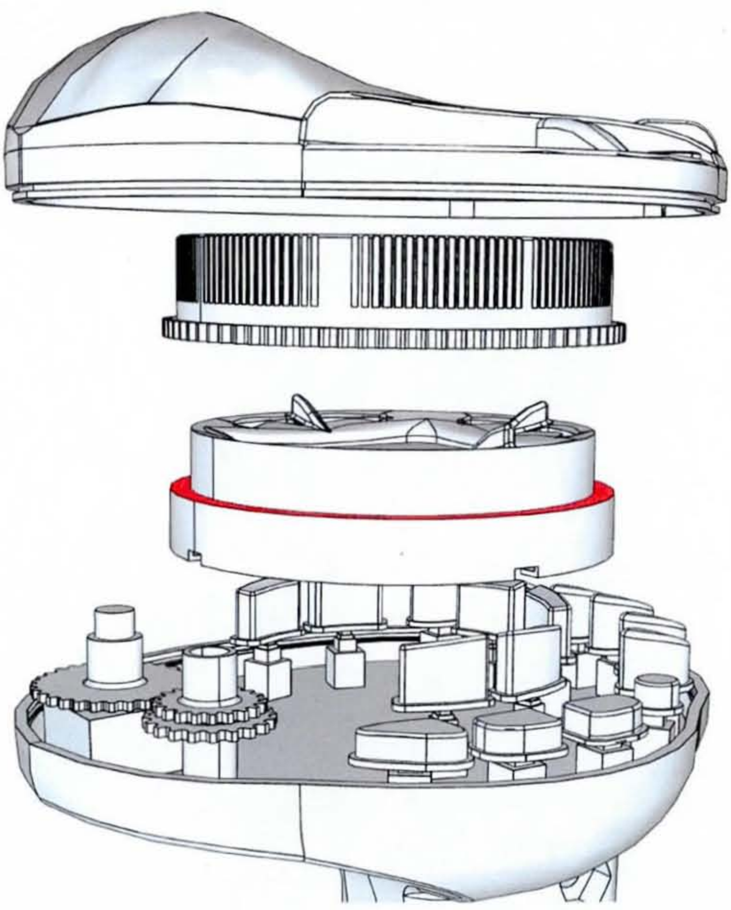


Figure 5.43: An exploded view with the surface upon which the bezel rotates highlighted in red

5.11.3 The PTI redesign based upon the simulator study results

Figure 5.44 shows the general design changes that were applied to each array. The changes that were identified in the simulator study were defined as follows;

- Improve the tactile markers that allow the Radio and Navigation preset buttons to be identified
- Rearrange the control layout to improve separation between preset button number 6 and the Radio button on the ICE array, and new destination button on the SATNAV array
- Change the position of the on/off button on the SATNAV and ICE arrays, and the AC button to avoid inadvertent operation
- Increase the size of text that is used on the arrays
- Hand rest size needed to be increased to match that of the medium sized array as described in section 5.54

The layout of the preset buttons on the ICE and SATNAV arrays was improved by grouping the 6 preset buttons into three groups of 2 and adding a 5mm high divider between these groups of two. It was anticipated that the location of divider (left of centre, centre and right of centre) would aid the identification of each group of 2 presets. The issue of the proximity of the 6th preset button and the control in the array designed for thumb use or 'thumb array' was solved by lowering the thumb array providing a separate mounting surface. A wider and deeper divider was also placed between the CD and Radio buttons on the ICE array, and the new route, stored route buttons on the SATNAV array. The issue of inadvertent operation of the power and AC buttons was addressed by moving the controls more rearwards on the thumb array. The issue of small text size was addressed by reducing the length of words and increasing the text size to match standard viewing distance recommendations as shown in Sanders and McCormick (1996). Finally, the hand rest size was increased to match that of the medium sized array as discussed in section 5.54. This increased the height of the uppermost part of the hand rest above the control mounting surface, and increases the breadth of the hand rest when compared to the original.

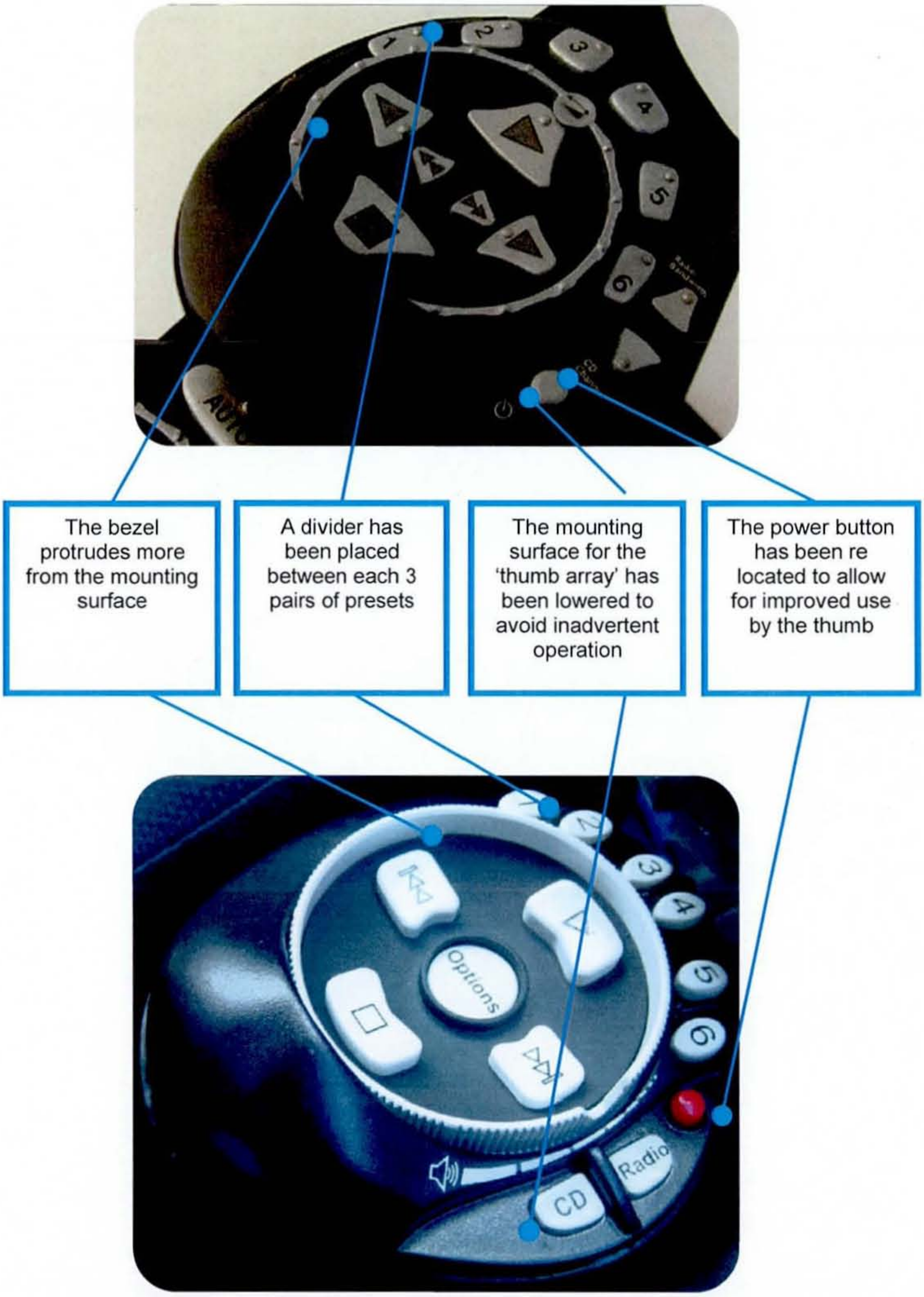


Figure 5.44. The design changes that were applied to all of the PTI arrays

5.11.3.1 Design changes for the HVAC array

The design issues identified for the HVAC array were as follows;

- The AC button needed to be differentiated from the power button found on the other two arrays
- The use of up/down button for temperature was not liked by the simulator study participants
- Participants in the simulator study were unsure how they would know that the re-circulate, rear screen heating, and Auto options were activated

The AC button was made larger as is shown in figure 5.45. This was done to help in the differentiation between the control arrays. It was presumed that during the initial contract with the array users would need support in the tactile differentiation between the arrays. By increasing the size of the AC button, and changing the temperature control to a rotary dial the HVAC array would provide a different tactile experience than the other two arrays. This also led to the placement of the HVAC array between the other two other arrays on the mounting structure. The use of the rotary control for temperature selection was suggested by the participants, and better matched the stereotypes that are prevalent in the literature.

The re-circulate air, auto and rear screen heating options were assigned to latch down switches in the array design. The aim was to indicate the on/off status of the switch using the change in height of the switch between the on and off positions compared to the surrounding surface. The curved nature of the surrounding surface made this difficult. The final design included a collar that protruded from the mounting surface that followed the shape of the three buttons. In this way, the user would feel the edge of the collar when the switch is in the on position, and the button surface when the switch is in the off position.

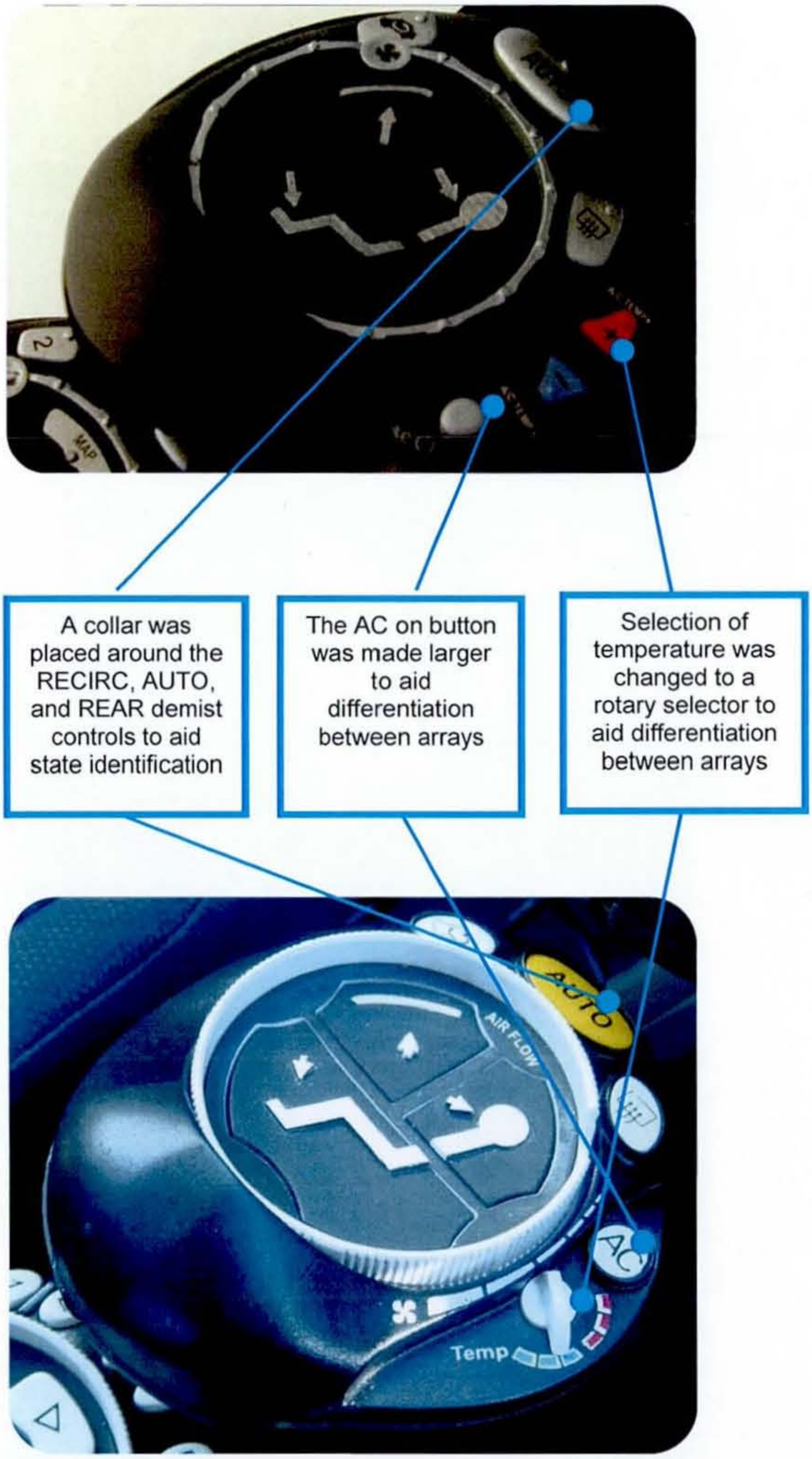


Figure 5.45. The design changes that were applied to the HVAC array

5.11.3.2 Design changes for the SATNAV array

The design issues identified for the SATNAV array were as follows;

- Three participants in the simulator study thought that zoom out button on the SATNAV array was hidden by the hand rest

- The system required a method that allows interaction with options such as destination selection

The two issues noted above combined to suggest a redesign of the of the panel inside of the bezel in the SATNAV array. The zoom out button was removed from the location and combined with the zoom in button on the right hand side of the array. The map button was then moved to the right of centre location at the top of the array as shown in Figure 5.39. This placed all of the controls associated with maps on the right hand side of the array. The opposite side of the array contains controls that were used to interact with the navigation system whilst the vehicle is stationary only. The operation of these controls is described in section 5.13.5. In addition to this a further control was added to the SATNAV array. A control that is used to repeat the active navigation voice instruction was placed at the front edge of the thumb array. This feature had been noted as useful during a meeting with the Honda R&D team. Figure 5.46 shows these changes to the SATNAV array.

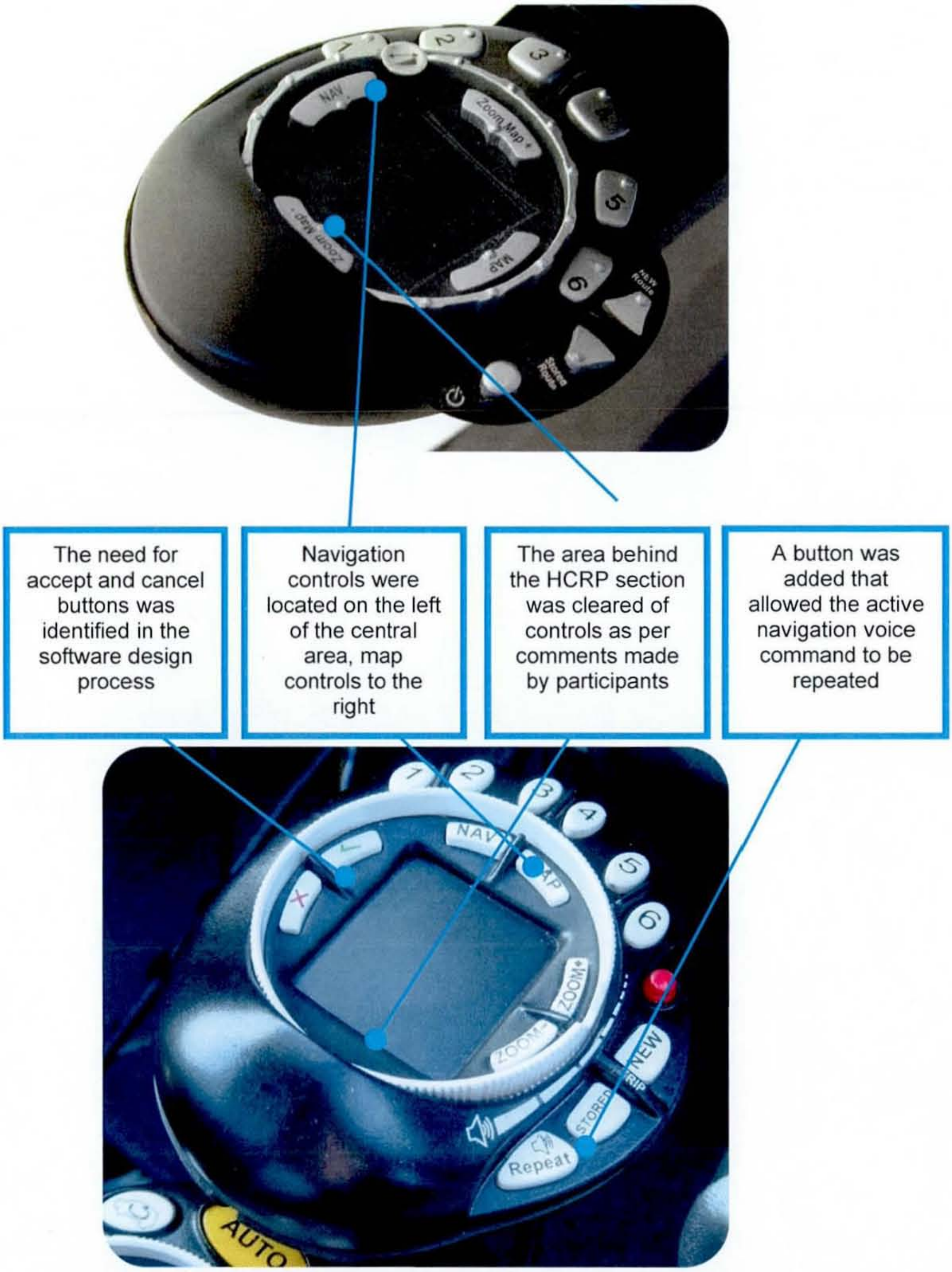


Figure 5.46. The design changes that were applied to the SATNAV array

5.11.3.3 Design changes for the ICE array

The design issues identified for the ICE array were as follows;

- The need to add a control to allow the selection of sound options for use whilst the vehicle is stationary was noted

- Four participants in the simulator study mentioned that they would prefer the skip track and skip within track buttons to be combined

The two issues above were addressed by removing the skip within tracks, and changing the operation of the skip track button. When this button was depressed and held the system would skip within the CD track, if the button was depressed and released the system would skip the track. This model is prevalent in the design of in-car radios. In place of the skip within track buttons, an extra push button was added that allowed the user to access the functions as described in section 5.13.4. Figure 5.47 show the changes to the ICE array.

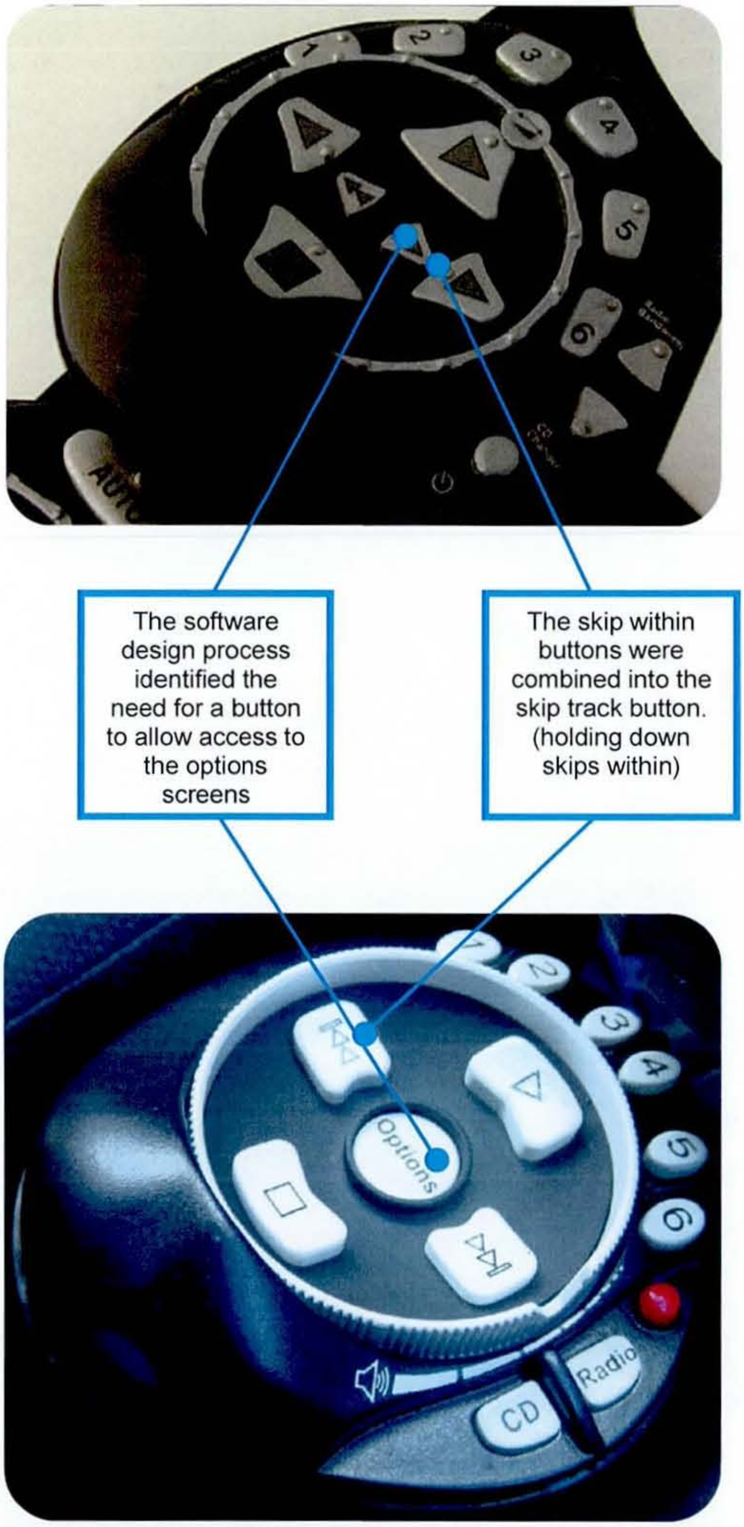


Figure 5.47. The design changes that were applied to all of the PTI arrays

5.11.4 CAD visualisations and photographs of the final

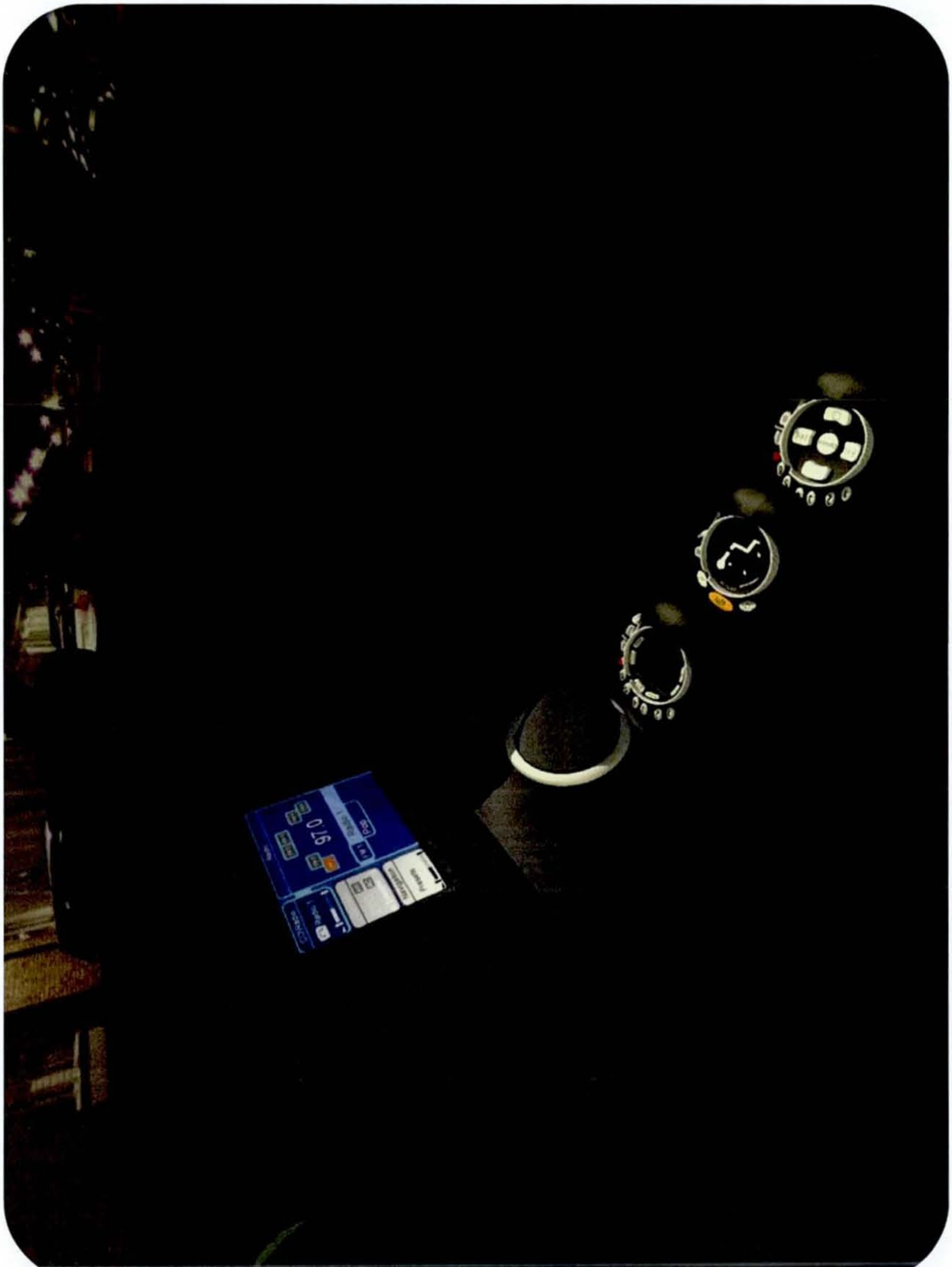


Figure 5.43 A CAD rendering of the final PTI produced before rapid prototyping

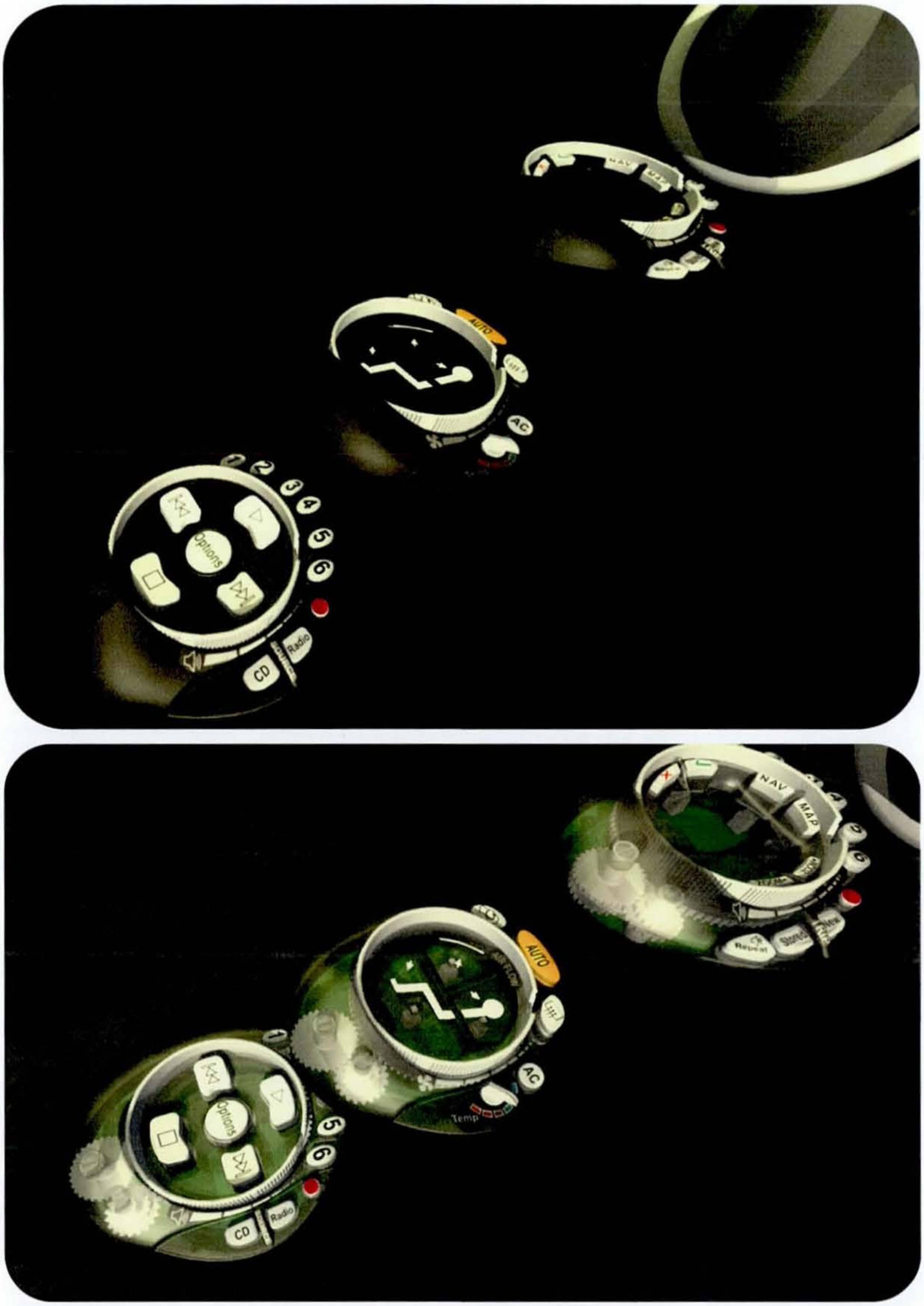
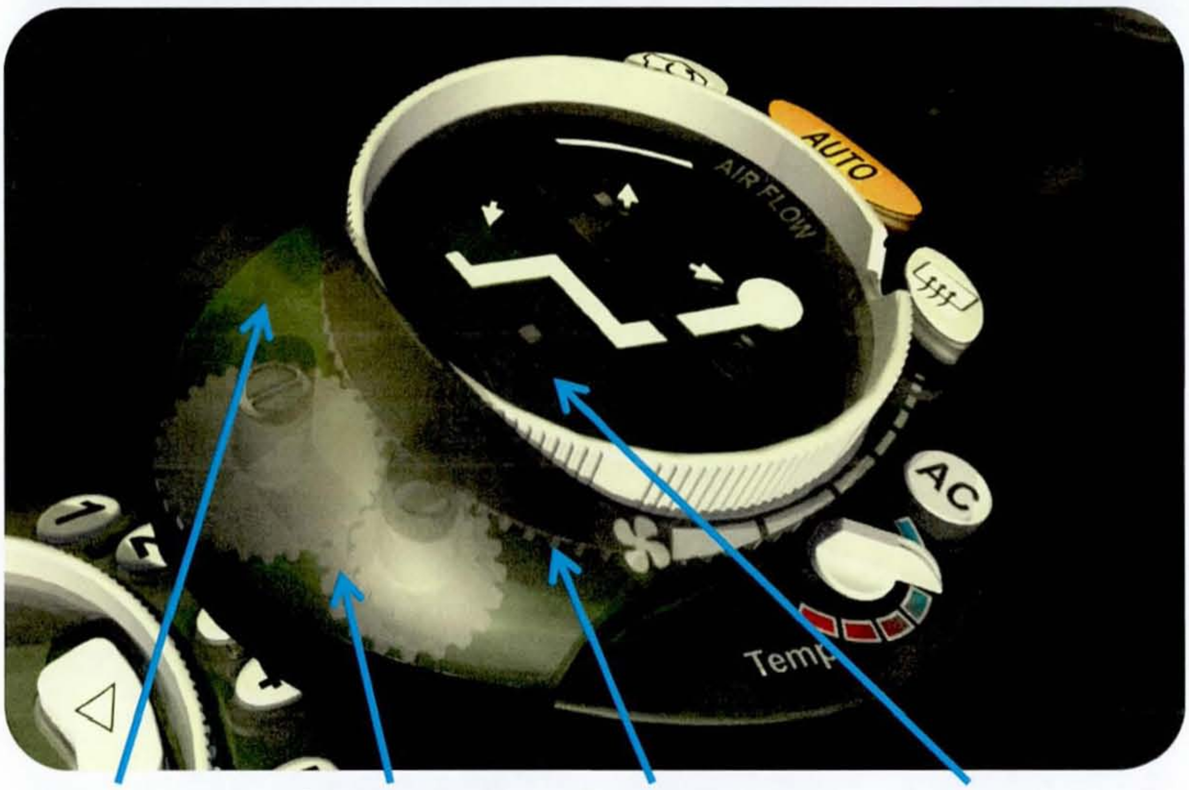


Figure 5.49. CAD renderings of the final PTI produced before rapid prototyping. Transparency has been applied to the array surrounds to allow a view of the internal structure in the bottom image



Printed Circuit Board

Gear connected to the rotary encoder for fan speed

Teeth on the bezel that drive the gears

Switch under the button cap

Figure 5.50. CAD renderings of PTI design features. Transparency has been applied to the array surrounds to allow a view of the internal structure

Figure 5.51. Assembly of the prototype parts (top four images). The final PTI interface in the 2001 Honda Civic, a full working prototype manufactured using rapid prototype technology

5.12 Software design

5.12.1 Introduction

The software was produced by the Visteon software team who required an exact specification of how the software would operate, including the pre-production of all graphics. The software design produced was communicated to the Visteon software team using a PowerPoint presentation. This presentation started with an image showing the three arrays in plan view, with hyperlinks over each button in the image. When the user clicked on the hyperlink associated with a specific button the slide show would display an image showing the effect of that button push in the software.

Figure 5.52. The final PTI software running on a 10 inch screen with a custom screen surround

The result was a piece of software that when used in conjunction with the PTI, and a dash mounted screen, provided a realistic experience for participants, with built in radio and CD content, and the direct control of HVAC functions. The screen surround was produced in Pro Engineer by the author and then rapid prototyped. It covered all of the existing baseline HVAC controls. The following section describes the design of the graphics and the software structure.

5.12.2 On screen graphics for the software interface

The primary aim for the software and screen was to provide navigation instructions to the user through the use of maps and turn by turn arrows. It was also anticipated that providing simple on screen feedback, that confirmed that a task had been completed would support users in the non-visual use of the PTI. As discussed in the previous chapter it was expected that the full benefit of the tactile coding would be achieved when the user had become fully acclimatised to the interface. In order to support this, it was decided that the software layout should follow the models used in the design of the PTI arrays, to further emphasise the symbolic image required to allow non-visual interaction. The software was designed with a main screen for each PTI array, and sub screens associated with sound options or navigation based tasks. The low level of modality shown in the physical PTI interface was therefore reflected in the software. Figure 5.53 shows the screens associated with each PTI array.

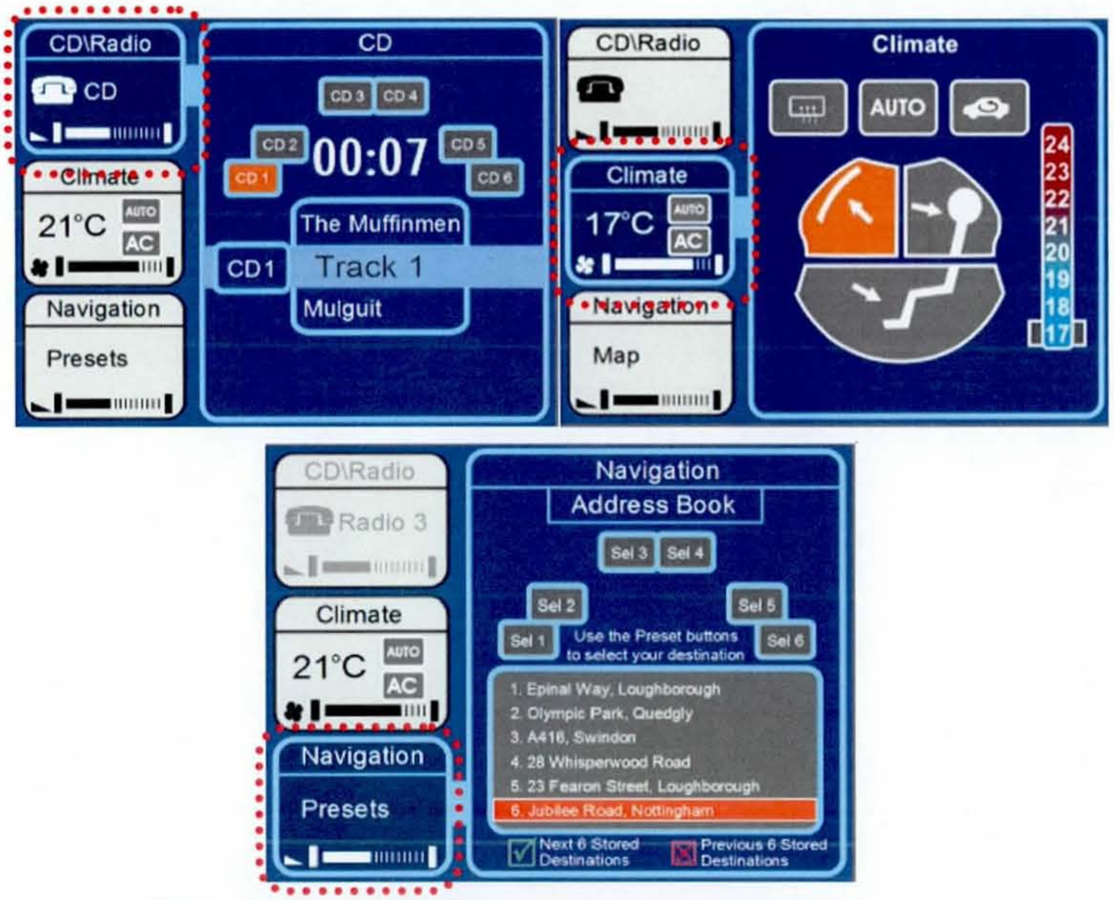


Figure 5.53. The HVAC PTI array and the associated software screen

The software incorporates a 'hot screen' for each functional group down the left hand side of the screen as highlighted by the red dotted lines in Figure 5.53. These display the main information that may be required regarding the state of each functional group at all times. For example, the hot screen associated with the ICE array shows the current radio station, in radio mode, and the current CD track when in CD mode. The hot screen associated with the HVAC array shows the current temperature and the state of the air conditioning function. The hot screen associated with the navigation array shows the current destination, next direction of turn and distance to turn. This was done to reduce the amount of screen switching that would be needed to gain basic information. The right hand panel of the software was designed to display information regarding the state of the selected functional array. The user would switch between the screen modes of the functional groups by either by using the on button of the ICE or SATNAV modes, or by depressing any button on the array, with the first depression performing the switch of screen only. The method of interaction with each screen is described in the following sections.

5.12.3 HVAC screen

Figure 5.54. The HVAC PTI array and the associated software screen. The coloured circles show the button on the array and the associated on screen display

The screen associated with the HVAC functions is the most simple of the three PTI arrays. It simply mirrors the layout of the controls on the HVAC array. Any control which is currently switched on is shown in orange on the screen.

5.12.4 ICE screens

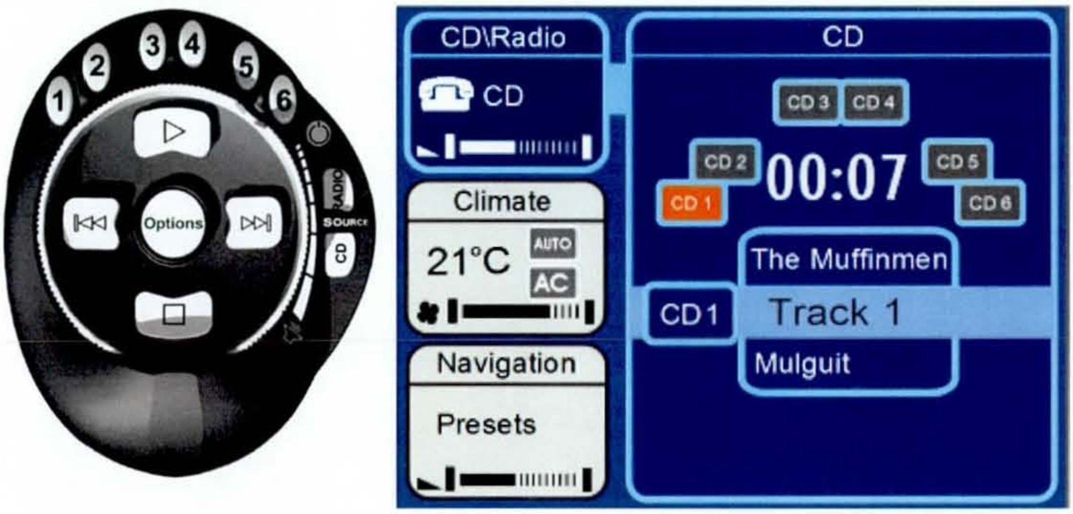


Figure 5.55. The ICE PTI array and the associated software screen

Figure 5.55 shows the layout of the ICE screen in CD mode. The presets shown on the array are also shown in the software. The presets are used to select radio stations in radio mode and to switch between disks in a 6 CD changer in CD mode.

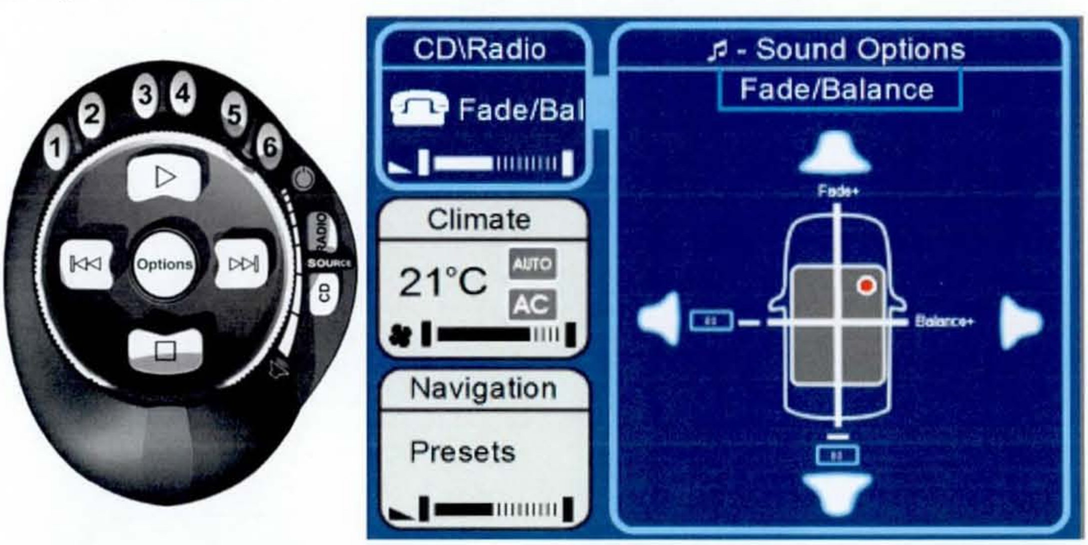


Figure 5.56. The ICE PTI array, the screen shown on the first depression of the OPTIONS button

Figure 5.56 shows the screen that is displayed when the options button is depressed once. This screen allows the fade and balance of the sound output to be modified. The plan view image of the car, in combination with the orange dot, allow the user to visualise where the sound source is currenlty focused. The user then uses the play, stop, skip forward and skip back buttons as cursor controls resulting in up, down, right and left movement of the orange dot, respectively.

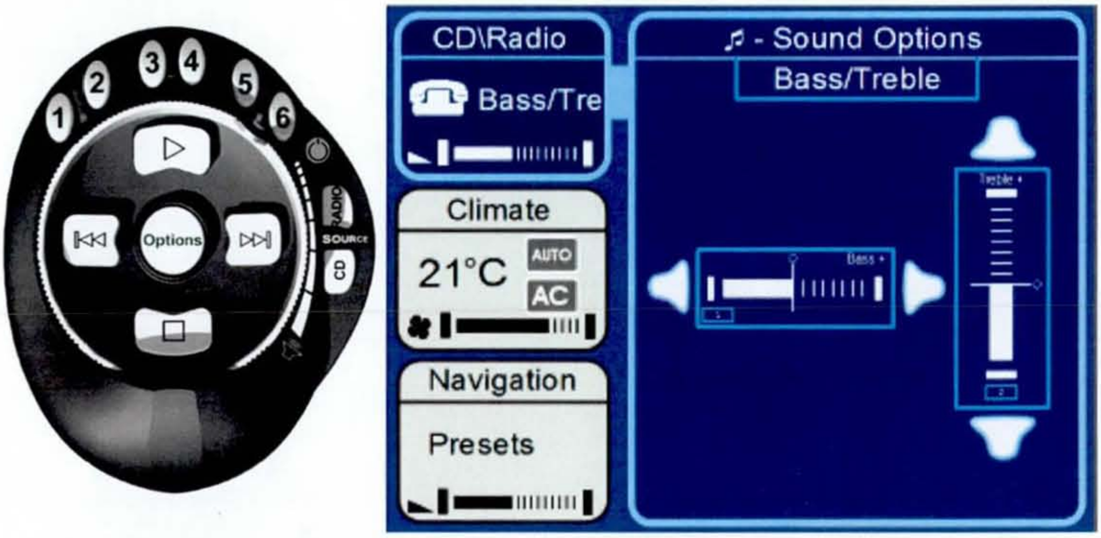


Figure 5.57. The screen shown on the second depression of the OPTIONS button

Figure 5.57 shows the screen that is displayed on the second depression of the Options button. This screen allows for the control of Bass and Treble sound options. The skip forward and skip back buttons are used to vary the bass, and the play, stop buttons are used to vary the treble. The third depression of the Options button returns the main screen.

5.12.5 Navigation screens

Figure 5.58. The SATNAV PTI array and the associated start screen

When the SATNAV system is turned on the first screen that is displayed shows the map. The zoom map buttons can be used to vary the map zoom from 4 miles to half a mile. The expected time of arrival (ETA), the distance to the destination and the direction of travel are shown at the bottom of the screen.

Figure 5.59. The screen shown on selection of the stored trip button. The trip cluster is highlighted by the dotted red circle

The stored trip button brings up the screen shown in Figure 5.59. The preset buttons are used to select from the on screen list of six previous destinations, in the order in which they were visited. Pressing the 'Tick' and 'Cross' buttons scrolls through the list of previous destinations.

Figure 5.60. The screen shown on selection of the NAV button

Figure 5.60 shows the screen shown on the selection of the NAV button, showing direction of turn, distance to turn and the destination address.

Figure 5.61. The screen shown on selection of the NAV button

Figure 5.61 shows the screen associated with the NEW TRIP button. This functionality was considered appropriate for use whilst the vehicle is stationary only. It was therefore not included in the testing performed whilst driving described in Chapter 7. The screen in Figure 5.53 was included to provide appropriate error feedback if the NEW TRIP button was depressed when the user was looking for the STORED TRIP button.

The software was run as a standalone executable on a laptop computer powered in the vehicle. The laptop/data logger combination took the signals from the switches in the arrays and the correct software screen was displayed. This fully working software interface could be tested using the screen shown in Figure 5.62. This software allows the ports of the data logger to be checked for good connections to the switches.

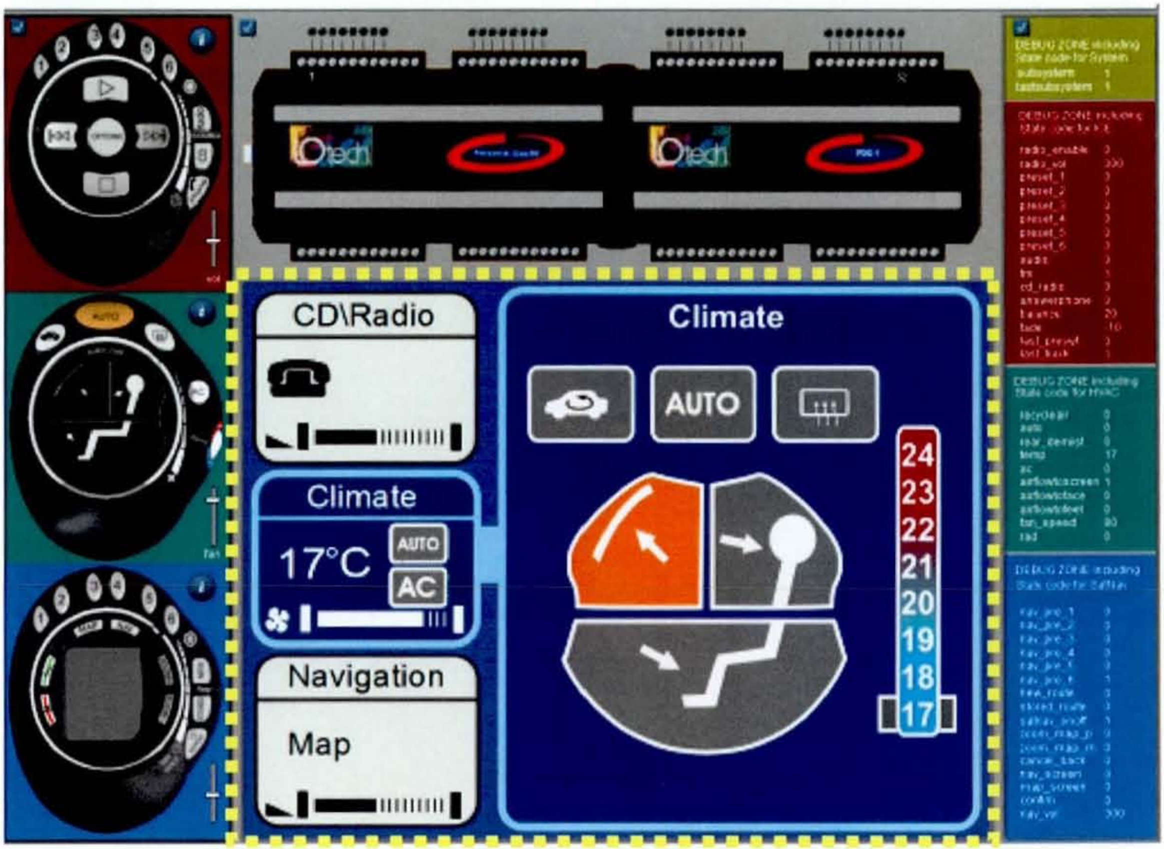


Figure 5.62. The test mode of the PTI software. The yellow dotted line shows the section that is shown to the user on the in car screen

5.12.6 Prototyping issues

The combination of the PTI, data logger and software interpretation of the hardware outputs produced an undesirable effect that needed to be accounted for in the design of the experimentation to assess the PTI in the planned 'on the road' study. This effect was produced due to scanning rate limitations of the data logger that was supplied for use in the project by Honda R&D. The data logger system scanned the outputs from the PTI every 100^{th} of second to determine if a control had been activated. During initial testing it was found that multiple rapid depressions of a PTI button would not all be detected by the system. This affected the tasks that required the user to make multiple button depressions such as selecting a CD track, or changing the fade and balance of the sound output from the ICE system. In order to account for this it was decided that only two increments of movement would be required for the fade/balance task, and that only two CD tracks would be required to be skipped in the CD track task. It was anticipated that this would reduce the need to perform multiple rapid button depressions.

5.13 Conclusions

The design recommendations that were derived in the previous chapter have been applied to an iterative design process. This process first considered the layout of each functional array and then considered the specific constraints that were found in the Honda Civic. The combination of virtual testing in a CAD based human modelling package and the testing of a prototype version in a driving simulator have illustrated that the majority of the PTI features were operated as anticipated during the design process. The glance durations required to locate a particular control in the simulator study, were found to be of the same order as glance durations associated with primary control and display use from the literature. This gave confidence that the final PTI would not elicit glance durations that were longer than those performed in the normal operation of vehicle. It has been shown that the PTI has the potential to reduce eyes-off-road time due to the number of control interactions that were performed without the vision at all. Other features were highlighted as being in need of improvement and these were addressed in the final design iteration. The final design iteration maintains the switch locations that were successfully used in the simulator, with the addition of improved labelling, a larger hand rest, and some minor modifications to the tactile structure. The following chapter describes the methodology used to assess the working prototype PTI in an on the road study.

6 Chapter 6: Final BIONIC experimental trials methodology

6.1 Introduction

The literature review defined the 'gold standard' of in car Human Machine Interface (HMI) assessments to be the use of an 'on the road' study design, with the capture of the glance durations that are used for control interactions. This involves testing of the interface in an instrumented vehicle being driven by participants on public roads. The following chapter describes the implementation of such a methodology for the assessment of the PTI.

The assessment of the PTI was performed to establish if the system was capable of reducing the 'eyes-off-road' time when compared to a baseline system using a 'repeated measures' study design. The testing of the PTI was performed by undertaking user trials in a 2001 model Honda Civic with two separate conditions. The two conditions were the PTI condition, as shown in Figure 6.1, and a baseline condition as shown in Figure 6.2. The base line condition consisted of a Visteon satellite navigation system which included navigation, radio, and CD functionality, combined with the standard Honda Civic controls for the HVAC functionality. The PTI condition consisted of the hardware and software combination as defined in Chapter 5.

The study was designed by the author with the support of the research team. As a project partner the Ergonomics & Safety Research Institute (ESRI) at Loughborough University was tasked to perform the user testing of the PTI system following the study design produced by the author. The structure of the chapter is as follows:

- The in car secondary tasks selected for comparison between the baseline and PTI systems
- Experimental design
- Results analysis methodology
- User trial issues

Figure 6.1. The PTI experimental system in the 2001 Honda Civic

Figure 6.2. The baseline experimental system in the 2001 Honda Civic

6.2 The in car secondary tasks selected for comparison between the baseline and PTI systems

The Visteon 9000VNR combined navigation and entertainment system was provided by Honda R&D to act as a baseline comparison to the PTI. The device incorporates a 4 inch screen with a combination of dedicated buttons and soft keys (buttons associated with on screen labels that change depending upon the settings selected).

A combined rotary controller and push button control is used for the volume and the system on/off respectively. A joystick is used to control the on screen interaction in combination with the soft keys. The image in figure 6.3 below shows the layout of the baseline device.

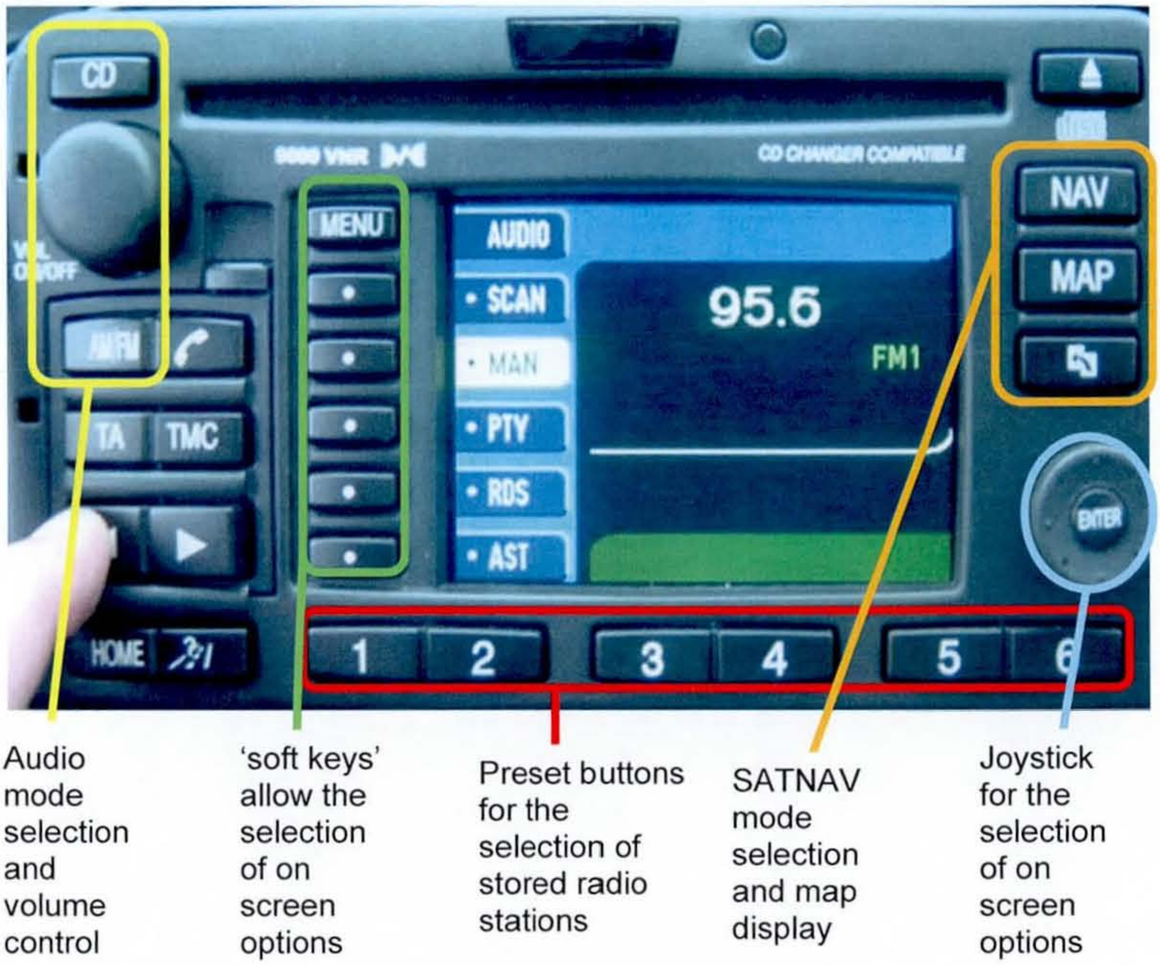


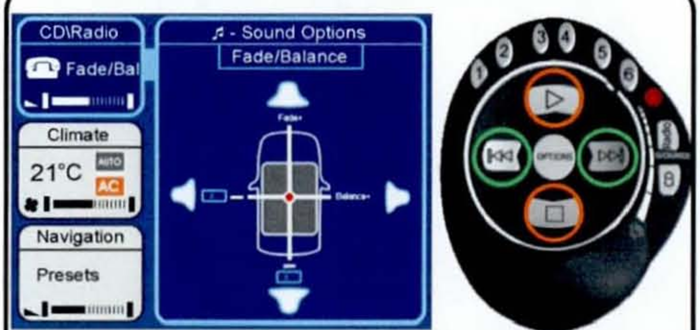
Figure 6.3. The Visteon 9000 VNR Navigation system control layout

In order to assess the 'eyes-off-road' time of the two systems it was necessary to select a list of tasks that could be performed on both. An analysis was performed between the 9000VNR and PTI systems comparing their functions and operation from which a number of tasks were defined that could be completed using both systems as shown in table 6.1. These functions were selected for use in the 'on the road' user trials. An example of this process is shown in figure 6.4, which examines the interaction needed to change sound options (fade, balance, treble and bass) on both systems. A step by step comparison of the operations required to perform the tasks that are common to both systems is included in the following chapter.

The yellow circle indicates the button that must be depressed in order to access the sound options

The yellow circle indicates the button that must be depressed in order to access the sound options

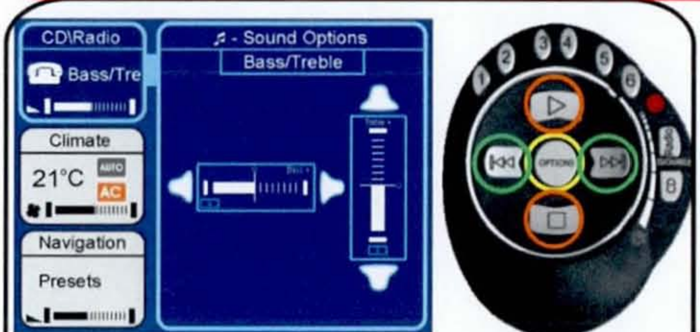
Accessing the sound options requires one button push on both systems



The orange circles indicate the buttons that should be depressed to alter the Fade. The green circles indicate the buttons that must be depressed to alter the balance

The fade and balance options must be selected by moving the joystick up and down OR by using the soft keys to select. The fade and balance is altered by moving the joystick to the left or right

The PTI allows direct manipulation of fade and balance at this stage. The 9000VNR requires the user to select the variable to be changed with either the soft key or the joystick. The PTI display shows an image of the car in plan view that exploits the spatial coding of the fade balance task.



Pressing the options button again allows the Bass and treble to be selected. The variables are altered as above

The Bass and treble options must be selected by moving the joystick up and down OR by using the soft keys to select. The Bass and Treble is altered by moving the joystick to the left or right

The PTI requires the user to press the options button again to access bass and treble options. The 9000VNR requires the user to scroll through the list of four options to access this functionality. Both systems require one more push of the options button to return to the main screen.

Figure 6.4. A comparison between the PTI and Baseline system in terms of the number of control interactions that are required to alter the sound options

Table 6.1 shows the tasks that were possible on both systems following the analysis.

System	No.	Task
ICE	1	Turn on the radio/cd player
	2	Select Radio mode
	3	Select preset radio station
	4	Increase the volume of sound
	5	Select CD mode
	6	Change the sound output to come from the front speakers only
	7	Increase the bass
	8	Select CD tracks
HVAC	9	Increase fan speed
	10	Change the airflow direction
	11	Turn on the Air Conditioning
	12	Re-circulate air
	13	Rear screen demist
NAV	14	Turn on the navigation system
	15	Select map view
	16	Zoom in on the map view
	17	Select a stored destination
	18	Return to the map screen
	19	Create a new destination

Table 6.1: The task list selected for the user trial

6.3 Experimental design

The aim of the experiment was to capture the 'eyes-off-road' time (consisting of glance durations and the number of glances) that are required to perform the same set of tasks on the two different systems. These glances could then be compared using statistical testing to determine if significant difference exists between the systems. During the research two experimental design methods were found to be appropriate for the assessment which were 'repeated measures' and 'independent sample' (Collican, H. 1999). The experimental methodology selected for this comparison was 'repeated measures'. This method uses the same sample of people in testing with both experimental conditions at separate times. This has advantages and disadvantages. The primary advantage of a 'repeated measures' approach is that of homogeneity of variance, i.e. there is no difference between the samples that will interact with both systems. If an 'independent samples' approach had been used it would have been necessary to balance two separate samples of participants for variables such as gender, age and level of education. A 'repeated measures' approach also requires a smaller sample than an 'independent sample' method due to lack of sample balancing. The main disadvantage of the 'repeated measures' approach is order effect. Each participant must be tested on each system at separate times, and will therefore be exposed to one system first. This exposure could educate the participant which could then affect the results of the testing of the second system. This can be balanced by ensuring that half of the sample are tested with the PTI first, and half with the baseline system first. It is a condition of the 'repeated measures' approach that the participants should be unaware of the aims of the experimentation. Other balancing tasks must be performed with the 'repeated measures' approach. The variability of human performance throughout the day, and days of the week must be accounted for by ensuring that each participant is tested at the same time of day, and day of the week. If possible a large period of time should be left between the first and second experimental sessions to reduce the order effect.

6.3.1 The balancing method used in the assessment of the PTI and baseline systems

The participants were required to attend the user trials on two separate days. In order to keep the trials as consistent as possible the participants were required to attend on the same day and time on two subsequent weeks, leaving a gap of seven days between experiments. The trials were balanced so that the same number of participants performed the first trial on each system. The trials were performed over a one month period. The trials were run with the PTI condition for one week, then the baseline system for two weeks, followed by a final week of the PTI system. This allowed two groups of eight participants to be tested, with each group performing the first trial with a different system as shown in table 6.2.

Group 1 (n=8)		Group 2 (n=8)	
Week1	Week 2	Week 3	Week 4
PTI	Baseline	Baseline	PTI

Table 6.2: The balancing scheme used during the user trials

6.3.2 The sample

Design Recommendation 5 defined in Chapter 4 referred to the difference in tactile sensitivity between younger and older people. The sample frame defined for the user trials included eight participants over 55 years old and eight aged 21-30. This was done in order to determine if there were significant differences between the 'eyes-off-road' time between the two age groups and to examine any differences in the interaction with tactile coding. The sixteen participants also had an even split of male and female. All participants had been driving for at least three years and had clean driving licenses. None of the participants had previous experience of the Visteon 9000VNR or the PTI system. Table 6.3 shows the age, handedness and gender of the sample members, with the participant number referring to the order in which the participants performed the study. As discussed in section 6.5 the data for the final five participants, highlighted in red in table 6.3, were not useable in the analysis. The results shown in the next chapter use the same participant numbering system as in table 6.3.

Participant number	Age	Gender	Handedness
1	27	Male	Right
2	25	Male	Right
3	29	Female	Right
4	26	Female	Right
5	63	Female	Right
6	65	Male	Right
7	61	Female	Right
8	29	Female	Right
9	61	Male	Right
10	23	Male	Right
11	27	Male	Right
12	62	Female	Right
13	59	Male	Left
14	64	Female	Right
15	60	Female	Left
16	28	Male	Right

Table 6.3: The age and gender of the sample members

6.3.3 Participant training

As none of the participants had experienced either of the test systems it was determined that a short training period was required to allow the safe control operation during the 'on the road' study. It was considered inappropriate and unrealistic to allow the participants to perform initial explorations of the two systems whilst in motion. It was anticipated that users would familiarise themselves with the basic operation of the secondary functions before driving a car. The training technique used was therefore designed to simulate the 'new car experience' of interacting with the controls for the first time with a set of tasks in mind. The participants were asked to perform all of the tasks that are shown in table 6.1 using a scenario structure i.e. each task was presented to the participants using goal based terminology such as "You have just entered the car, and the windscreen has instantly misted up. Please select the control that you would use to demist the windscreen". The participant would then be expected to find the fan speed and airflow to screen controls and operate them appropriately. Each task was given to the participant, who then had three minutes to perform the task by interacting with the system under testing. They were given advice on the correct interaction after this time. The training was given in a car park with the car stationary at the start of the of the test route.

6.3.4 The test route

The road trials were performed along a stretch of the A50 road from the junction of the M1 to the roundabout on the A38 (see figure 6.5). The route was driven by the author on a number of occasions at different times of day and traffic levels were noted on each occasion. The route was rarely congested apart from at peak times such as Friday afternoon. This provided the participants with a 22 mile route where a consistent speed could be maintained and tasks could be performed (as discussed in section 2.2.4.1). By ensuring that each participant drove the route at the same time of day and the same day of the week the traffic levels were as consistent as possible which helped in the balancing of the two experimental conditions. In order to provide consistency for the presentation of tasks landmarks (lay-bys) were used as markers that informed the experimenters when they should deliver a task to the user. Prior to setting off the participants were informed that they should only perform a task when they thought that it was safe to do so. At the start of the testing process the participants had spent approximately 15 minutes interacting with the secondary control systems and performing tasks during the training phase. In order to improve familiarity with both systems the participants were required to perform two experimental runs down the A50. The results from the second run were used in the final analysis.

Figure 6.5. The route driven by the participants during the user trials

6.3.5 *Experimental setup*

In order to capture 'eyes-off-road time' the Honda Civic used during the user trials was fitted with four lipstick cameras. These cameras were linked to a video processing box that combined the four camera views. This signal was then recorded with an in car video recorder. An example of the four combined views can be seen in Figures 6.6 and 6.7 which shows the camera setup used for the PTI and baseline conditions respectively. The cameras were orientated to provide a view of the user's face (top left in figure 6.6) the road ahead (bottom left in Figure 6.6) and two views of the controls being interacted with, including a close up of the main panel to allow the state of the system to be determined, and a wider view to allow observation of the interaction with the controls (top and bottom right in Figure 6.6).

Figure 6.6. The view of the PTI system provided by the four lipstick cameras mounted in the Honda Civic

Figure 6.7. The view of the baseline system provided by the four lipstick cameras mounted in the Honda Civic

6.4 Results analysis methodology

The results were analysed to provide 'eyes-off-road' time that consisted of the number of glances that were required to complete a task. The analysis of these results was performed by the author to allow a full understanding of the design implications that arose. Initially the video for each participant (around 1 hour of video per participant) was reduced to exclude the periods when task interactions were not being performed.

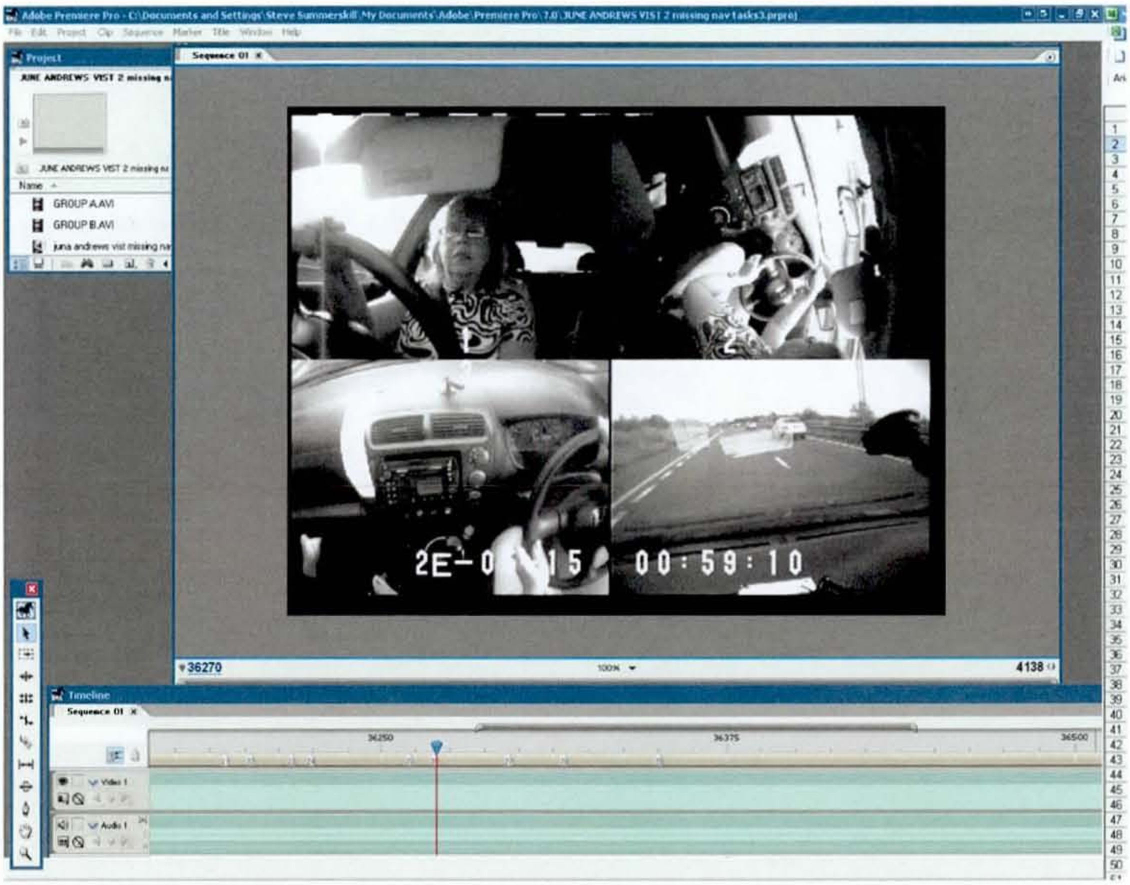


Figure 6.8. The video editing environment in Adobe Premiere Pro Version 7

This was followed by the digitisation of the video footage using a standard Firewire camera connection and Adobe Premiere Pro version 7 software. See Figure 6.8 for an example of the software environment. A technique was then devised for the analysis of the glance durations for each task. The software uses a time line system in which the video sequence is represented as a bar next to a time line scale (see figure 6.9). The software allows markers to be placed on this time line.

Figure 6.9. The timeline interface in Adobe Premiere Pro Version 7. The red circle highlights the marker system that was used to define the start and end of any glance that was performed during a task

The markers were used to highlight the start and end of any glance that was performed during a task. Typically the participant would blink before their eyes left the road, giving a clear indication of the start of the glance; however the video had a suitable level of resolution to allow the movement of the eye ball to be seen. Glance duration was defined as the time period from the eye leaving the view of the road ahead until the eye returned to the road view. The software allows the video sequence to be manipulated on a frame by frame bases (with 24 frames per second) allowing highly accurate measurement of glance durations. Each glance was defined in this way, with the two cameras viewing the system controls being used to determine which glance was associated with which task. The software then allowed the frame number of each glance marker to be exported into Microsoft Excel. The duration of each glance was calculated by subtracting the time code of the starting glance marker from the end glance marker giving a result in frames accurate to $1/24^{th}$ of a second. Figures 6.10 to 6.12 show an example glance for the 'direct airflow' task. Figure 6.10 shows the participant looking at the road ahead whilst performing a non-visual interaction with the airflow direction controls. The participant then made a short glance to the screen to ensure that the correct selections had been made, and returned his gaze to the road ahead. The glance duration shown in figures 6.10 to 6.12 was 0.79 seconds.

The results were subsequently analysed to provide values for median glance duration, summed glance duration and number of glances that were associated with each task. The median glance duration was selected as opposed to the mean glance duration. This was because the use of mean glance duration would inherently assume that the length of glances is distribution normally (following a Gaussian distribution). This assumption was not considered valid due to the type of data collected and the number of participants that performed the study. Median glance duration is not based upon the assumption of the normal distribution. As with the simulator study, the longest glance durations were also collated for each task as it was anticipated that these would identify controls that were more difficult for the participant to identify and operate. The median glance duration allowed an examination of the differences between the glances made to each system. The summed glance duration provided information on the total 'eyes-off-road' time for each task as defined in the objectives of the project described in Chapter 1.

Figure 6.10. The participant is engaged in the airflow direction task whilst looking ahead

Figure 6.11. The participant glances to the screen to determine if the correct option has been selected

Figure 6.12. The user refocuses on the road ahead as the hand touches the steering wheel

6.5 User trial issues

The user trials performed by ESRI had a number of issues that affected the results. As described in 6.3.2 it was intended that 16 subjects should be analysed. At the end of the time allotted it was found that 1 subject had not returned for the second user trial. The data for 3 subjects was of no use due to the tape having run out during the one of the trials so that only half of the tasks had been recorded, making their data incomplete. One subject (a very small lady with a height of 1512mm) had difficulty driving the Honda Civic. This participant had particularly short legs and required that the seat should be almost fully forward, making it difficult for her to reach the ICE pod on the PTI system, this trial run was halted early due to the difficulty the participant had experienced. The final subject count was 11, with three participants being over 55 and eight subject being in the age range 21-30. This subject count was still seen as sufficient when compared to other similar research that has been performed as discussed in the literature review.

In addition, a PhD student was allowed to perform an Occlusion test (see section 2.2.2.3.) on the PTI and baseline systems by ESRI as part of a separate research effort. The researcher who performed the Occlusion test arbitrarily increased the task time for the sound option tasks in the PTI system during the road trials to better suit the needs of this additional study. As discussed in section 5.12.6 the prototype issues required that tasks should only require two detents of movement of the on screen cursor or CD track selection. The researcher changed this stipulation and required full motion of the sound options fade, balance, bass and treble. This greatly increased the time required to adjust the sound options when compared the baseline system. This meant that the sound options tasks were excluded from the analysis.

The results of the user trial issues mentioned above produced some problems, but an analysis of the tasks that were performed on both systems was still possible, for the majority of tasks with a suitable sample size.

6.6 Conclusions

The chapter has described the process that was undertaken to allow a comparison between the PTI and baseline systems. The two systems have been compared to establish which tasks they have in common, and how many control interactions are required to perform those tasks. A full description of the task stages required to perform each task is shown in the following chapter. The chapter also describes the experimental trial methodology that was designed to compare the eyes-off-road time for the two systems as per the best practise described by the literature.

7 Chapter 7: Results from the analysis of the road trials data

7.1 Introduction

The following chapter summarises the results from the road trials that were performed as described in the previous chapter. The chapter initially outlines the methodology for the analysis of results and describes the rationale for the processing of the 'eyes-off-road' time (the addition of all glances made to complete a task) that was observed during the study. The results are then described for each task that was performed using the two systems. A description of the task stages that were required to complete each task on each system is also reported in order to provide a context for the results. The structure of the chapter is as follows:

- The rationale for the processing of the glance data
- The results from the comparison between the PTI and the baseline system
- The conclusion for the results of the 'on the road' study

7.2 The rationale for the processing of the glance data

The duration and frequency of the glances associated with interaction with the PTI or baseline interface can be affected by a number of variables. The layout, location and modality level of the two test interfaces will all have an effect on the length of glances that are exhibited by the study participants. A reduction in glance duration that is found when comparing the two systems could therefore be attributed to a number of variables as listed below;

- The tactile coding built into the PTI
- The subdivision of the PTI into functional groups
- The symbolic layout of the PTI
- The reduction in the number of available functions in the PTI when compared to the baseline system
- The differences in the level of modality between the PTI and the baseline system

During the analysis of the video data it was noted that a number of tasks were performed non-visually by participants when using the PTI. A non-visual interaction was defined as the successful use of a PTI control or controls without the participant looking at the functional arrays. The analysis of the controls that fostered non-visual interactions provides an objective measure that relates directly the use of tactile coding, based upon the user having established a mental model of the arrays that was detailed enough to remove the need to use vision. This does not negate the value of the analysis of glance duration for tasks where no non-visual interactions were performed, but provides a context for the reduction in glance duration where non-visual interactions were found. By examining the controls that fostered non-visual interactions it was possible to identify the most successful control layout designs. The following sections describe the methods used to present the results in this chapter.

7.2.1 Task stages for the PTI and baseline systems

The control interactions that are required to complete each task are described and illustrated. The number of control interactions can then be taken into account when a comparison of the number of glances is made e.g. it would be expected that a task that requires multiple control interactions would require more glances that a task that only required one control interaction.

7.2.2 The analysis of glance duration data

For each task the glance duration data was gathered as described in chapter 6. The median glance duration, number of glances and summed glance duration were calculated for the glances made. This allowed an examination of possible reductions in individual glance length, that would be associated with the layout and labelling of controls, and the overall task time that would be associated with 'eyes-off-road' time. The results are presented using tables. These tables also show the significant differences between the results obtained from the two systems that were tested using a Wilcoxon Signed Rank test as is appropriate for the comparison of median glance duration data (see section 5.6.6). Values that are approaching significance are highlighted with amber table cells. Values that are significant to the 5% level (0.05) are highlighted using a light green cell. Values that are significant to the 1% level (0.01) are highlighted using a dark green cell. Table cells that are grey show no significant difference. An example data table is shown in Table 7.1.

	Median glance duration			No. of glances			Summed glance duration		
	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test
Select Map View	0.92	1.04	0.126	16	28	0.05	14.28	31.2	0.007

Table 7.1. An example data table showing the median glance duration, no. of glances and summed glanced duration and the results from the statistical testing of the these results

7.2.3 Graphs and tables showing the maximum glance duration elicited by each task

The maximum glance duration elicited for each task is shown for all participants. The glance durations are compared to the glance duration thresholds of 1.58 seconds and 1.82 seconds as defined in the literature review. These thresholds have been highlighted with a green line (1.58 seconds) and a red line (1.82 seconds) on the graphs. For the rest of the chapter, the glances that were below the defined thresholds will be considered to be 'safe'. The Wilcoxon Signed Ranked test was also applied to the maximum glance durations to determine if there were significant differences between the systems. The tables use colour coding of the results. Green values are below the 1.58 second threshold. Amber values are between the 1.58 and 1.82 second thresholds, and red values are above the 1.82 second threshold.

7.2.4 Evidence for non-visual use for the baseline and PTI systems

The video recordings for the user trial were analysed to find occasions when the participant operated a control without looking at the PTI or baseline system. It was anticipated that any non-visual interactions performed after only 30 minutes of contact with the interface would illustrate successful control coding. The location of the PTI in the Honda Civic allowed the glances that were made to the screen to be separated from the glances made to the PTI arrays. Therefore any control interactions that were performed whilst either looking out of the vehicle or looking at the screen could be counted as non-visual interactions that utilise the tactile coding built into the design of the PTI. This was done as it was anticipated that the need to use to screen to gain feedback that the correct action had been performed would quickly diminish as the user becomes acclimatised to the interface. The baseline system was in same location as the screen of the PTI, with the baseline screen and controls co-located. It was therefore not possible to separate the glances that were made to the screen or controls for the baseline system. Only control interactions that were performed whilst the user was looking at the road could be considered non-visual for the baseline system.

7.2.5 Task failures

Any occasions where participants failed to perform a task were recorded.

7.3 Results for the navigation array

7.3.1 Task: Select map view

7.3.1.1 Baseline system task stages

Figure 7.1. The control that is used to select a map view in the navigation system of the baseline interface

In order to select the map view of the baseline system the user must select the 'MAP' button on the right hand side of the interface as shown by the green ellipse in Figure 7.1.

7.3.1.2 PTI system task: Select map view

Figure 7.2. The control that is used to select a map view in the navigation system on the PTI

In order to select the map view of the PTI system the user must select the 'MAP' button as shown by the green ellipse in figure 7.2.

7.3.1.3 Results for glance duration

Table 7.2 shows the differences in the summed glance duration, number of glances, and median glance duration and the significance of the differences between these variables. There were significant differences for both the number of glances and the summed glance duration for the select map view task. The PTI produced a 12% reduction (0.12 seconds) in median glance duration, a 42% reduction (12 glances) in number of glances and a 54% reduction (16.92 seconds) in summed glance duration.

	Median glance duration			No. of glances			Summed glance duration		
	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test
Select Map View	0.92	1.04	0.126	16	28	0.056	14.28	31.2	0.007

Table 7.2 The statistical difference between the PTI and baseline systems for the Median Glance duration, No. of glances and summed glance duration

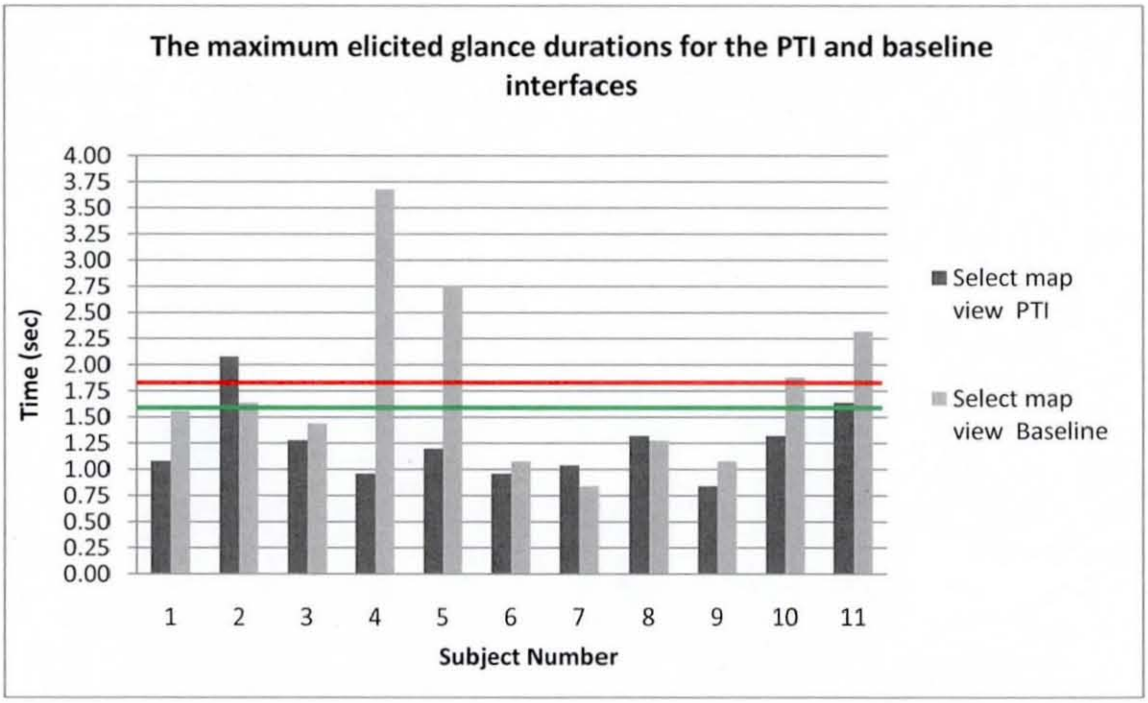


Figure 7.3. The maximum glance duration for each participant when performing the select map view task

Select map view		Subject Number										
		1	2	3	4	5	6	7	8	9	10	11
	PTI	1.08	2.08	1.28	0.96	1.20	0.96	1.04	1.32	0.84	1.32	1.64
	base line	1.56	1.64	1.44	3.68	2.76	1.08	0.84	1.28	1.08	1.88	2.32

Table 7.3. The maximum glance duration for each participant when performing the select map view task

The longest glance durations elicited by the PTI were significantly shorter than those for the baseline system at the 0.05 level using a Wilcoxon Signed Rank test. The PTI system produced one glance that was over the 1.83 second threshold. The baseline system produced four glances that were above this threshold with one recorded glance that was twice the threshold.

7.3.1.4 Evidence of non-visual use

There were no non-visual interactions for the select map view task on either system. For the PTI the glances were separated into those made at the screen and those made at the PTI. Of all the glances made when performing the select map view task 40% were directed to the PTI arrays.

		% of glances
Select map view	*Arrays*	60
	Screen	40

Table 7.4. The percentage of PTI glances directed to the screen or PTI arrays

7.3.1.5 Task failures

There were no task failures for either system when performing the select map view task.

7.3.1.6 Summary for the select map view task

The PTI system achieved significantly lower number of glances (approaching half as many), maximum glance duration and summed glance durations than the baseline system for the select map view task, with a non significant reduction in median glance duration for the PTI. The reduction in the number of glances shows that the participants found this task to be much easier when using the PTI system. This is an interesting result as the level of modality for the select map view task is the same on both systems, and the button used was of a similar size on each system, with the text size of the associated label being slightly smaller on the PTI system. The subdivision of the functional groups and the layout the array is assumed to have affected the results. In terms of the safety of performing the task on each system the PTI could be considered less likely to foster lane exceedances in that the average glance duration was lower and the maximum glance durations were lower when compared to the baseline system. The median glance durations for both systems were below the 1.58 second threshold.

7.3.2 Task: Zoom map

Figure 7.4. The task stages used to change the zoom level of the map view on the baseline interface

7.3.2.1 Baseline system task stages

In order to select different zoom levels for the map view of the baseline system the user must select the 'zoom' screen 'soft key' on the left of system screen (action 1 in figure 7.4). After this the user must push the joystick up and down to select a zoom level (action 2 in Figure 7.4) and finally the user must press the joystick in to select the zoom level (action 3 in Figure 7.4).

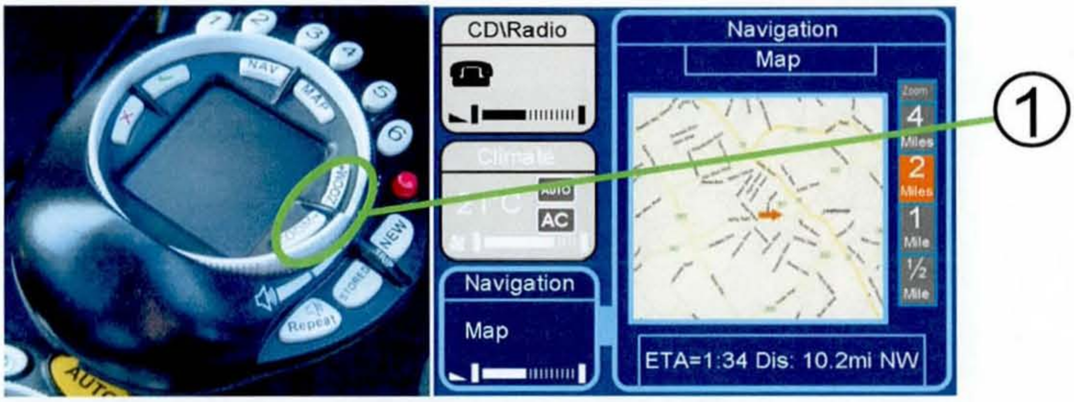


Figure 7.5. The task stages used to change the zoom level of the map view on the PTI system

7.3.2.2 PTI system task stages

In order to select different zoom levels for the map view of the PTI the user must select the 'zoom +/-' buttons on the navigation array. Using these buttons will also automatically switch to the navigation map view. See figure 7.5.

7.3.2.3 Results for the Zoom map task: A comparison between the results for the baseline system and the PTI

There were significant differences for both the number of glances and the summed glance duration for the select map view task. The PTI produced a 22% reduction (0.26 seconds) in median glance duration, a 38% reduction (22) in number of glances and a 47% reduction (34.88 seconds) in summed glance duration when compared to the baseline system.

	Median glance duration			No. of glances			Summed glance duration		
	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test
zoom map	0.9	1.16	**0.139**	36	58	**0.018**	39.2	74.08	**0.007**

Table 7.5. The statistical difference between the PTI and baseline systems for the Median Glance duration, No. of glances and summed glance duration

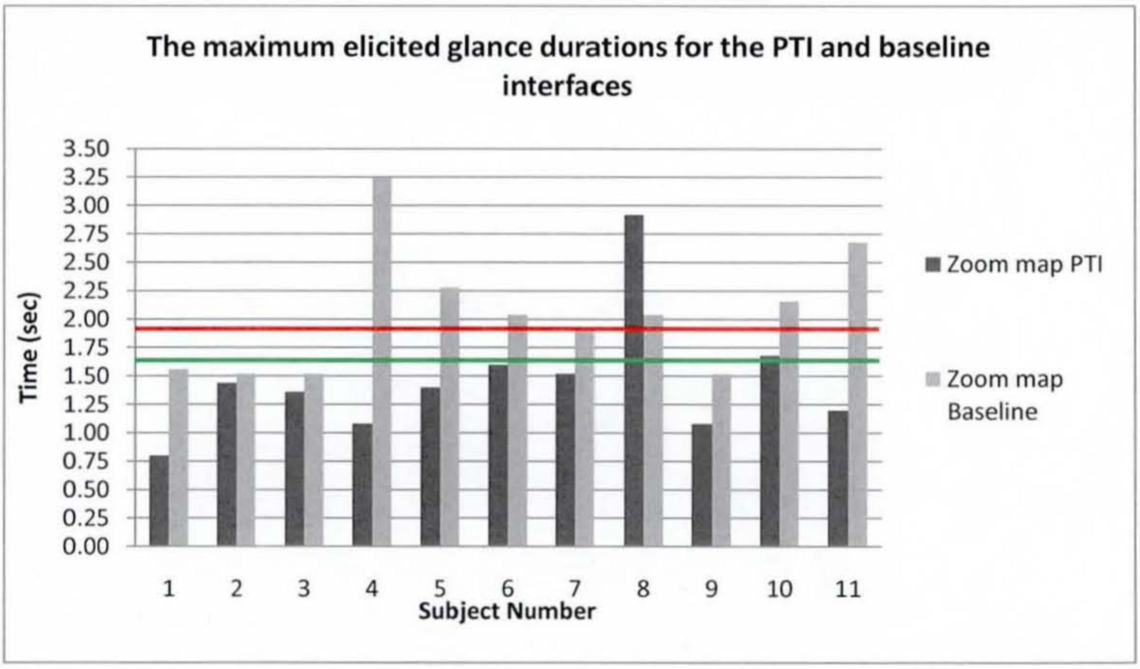


Figure 7.6. The maximum glance duration for each participant when performing the zoom map task

The maximum glance durations for each participant are shown in Figure 7.6 and table 7.6. One participant exceeded the 1.82 second threshold on the PTI compared to seven on the baseline system. The PTI can therefore be considered to be less likely to cause lane exeedances than the baseline system.

		Subject Number										
		1	2	3	4	5	6	7	8	9	10	11
Zoom map	*PTI*	0.80	1.44	1.36	1.08	1.40	1.60	1.52	2.92	1.08	1.68	1.20
	Base-line	1.56	1.52	1.52	3.24	2.28	2.04	1.92	2.04	1.52	2.16	2.68

Table 7.6. The maximum glance duration for each participant when performing the zoom map view task with significance testing

The longest glance durations elicited by the PTI were significantly shorter than those for the baseline system at the 0.029 level using a Wilcoxon Signed Rank test

7.3.2.4 Evidence of non-visual use

Of the eleven participants that performed the zoom map task three subjects (7,9,11) performed the task completely non-visually on the PTI i.e. whilst looking at the road they used the tactile coding to access the correct zoom control and then checked the screen to ensure that they had obtained the correct zoom level. None of the participants performed this task non-visually when using the baseline system. Generally the participants would use the edge of the white bezel that subdivides the array as a reference for finding this control. The majority of glances made to the PTI during the zoom map task were directed to the screen.

		% of glances
Zoom map	*Arrays*	35
	Screen	65

Table 7.7. The percentage of PTI glances directed to the screen or PTI arrays

7.3.2.5 Task failures

Subject number 5 failed to change the map zoom level on the baseline system.

7.3.2.6 Summary for the Zoom map task

The PTI system achieved a significantly lower number of glances, and summed glance durations than the baseline system for the zoom map task. In the results discussion for the select map view task it was noted that a significant difference was found for these variables when the level of modality was the same i.e. the same number of actions were required to perform the task. In the case of zooming the map there was a difference in the number of task elements. The baseline system required the user to select a soft key and then change the zoom by moving the joystick up and down. The PTI required one button push to zoom the map. It should therefore be expected that the number of glances and summed glance duration should be higher for the baseline system as more than one action is required. The PTI also encouraged non-visual use by over a quarter (27%) of the sample. There were no non-visual interactions for the zoom map task on the baseline system. The analysis of the maximum glance durations showed that one unsafe glance was made during PTI use, compared to seven for baseline system use. The PTI controls used to vary map zoom were shown to be less likely to cause a lane exceedance than those of the baseline system. This shows that the simplification of the zoom map task shown in the PTI significantly reduced the 'eyes-off-road' time.

7.3.3 Task: Select stored destination

7.3.3.1 Baseline system task stages

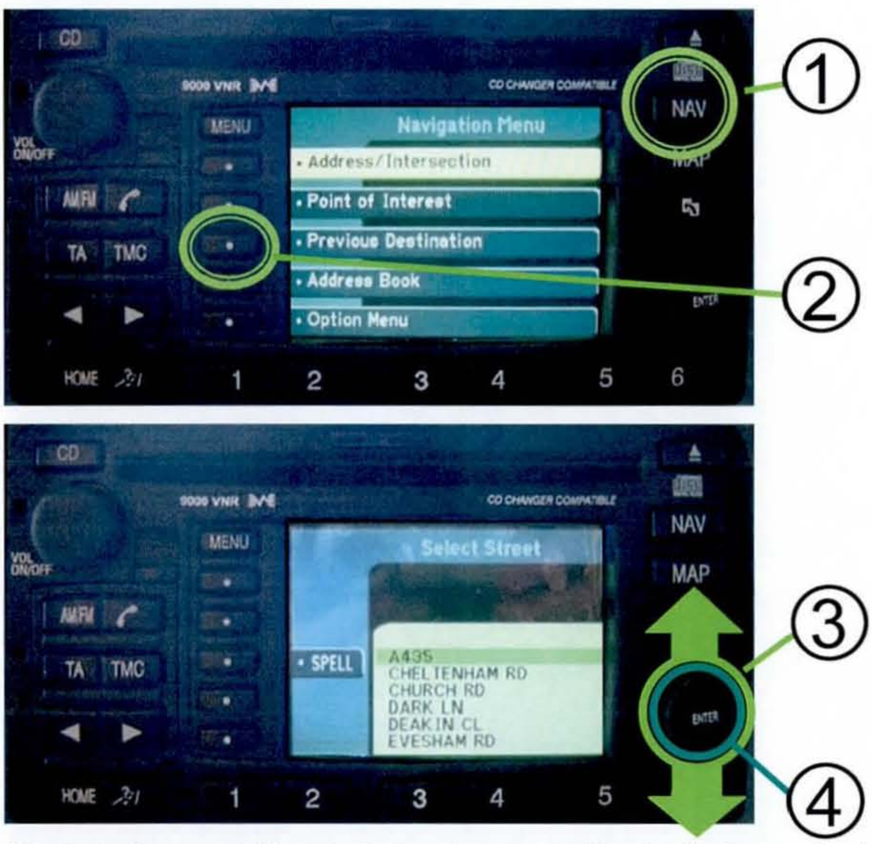


Figure 7.7. The task stages used to select a previous navigation destination on the baseline interface

In order to select a previous destination in the navigation system of the baseline interface the user must perform the following task stages. Select the navigation mode by using the button labelled number 1 in Figure 7.7. Select the 'soft key' next to the screen label 'previous destination' labelled number 2 in Figure 7.7. Move the joystick up and down to browse through the available previous destinations as shown by label number 3 in Figure 7.7. Push the joystick to select the highlighted destination as shown by label 4 in Figure 7.7.

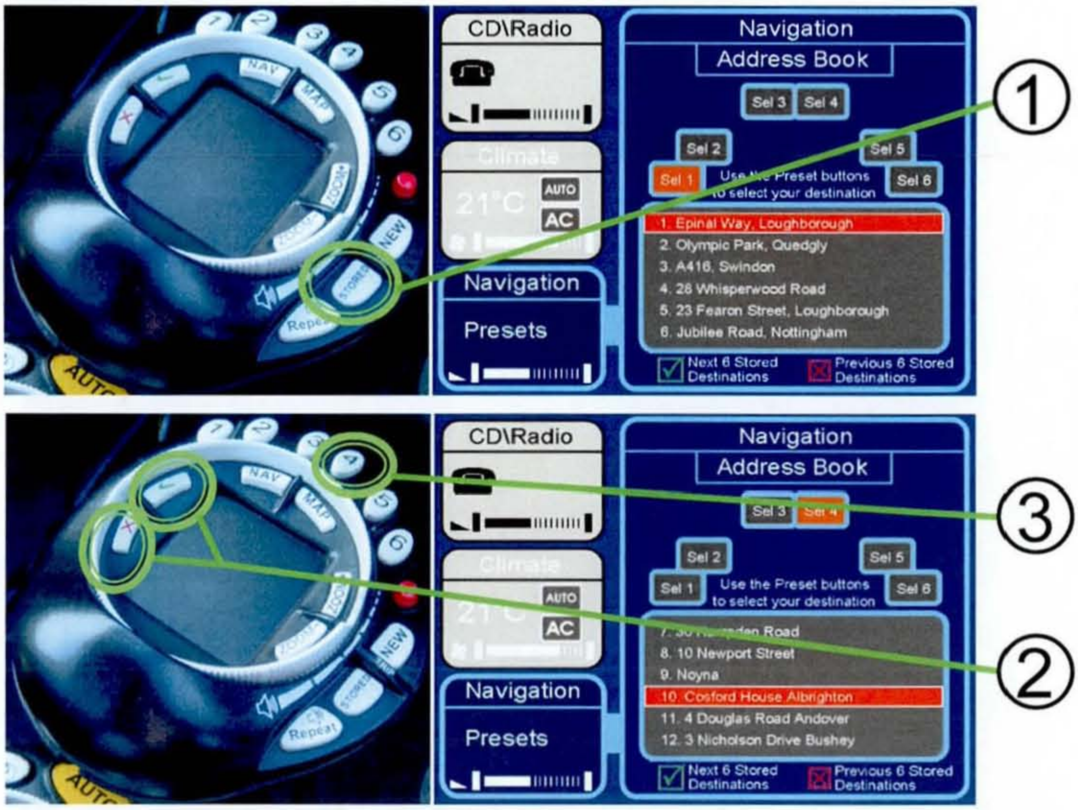


Figure 7.8. The task stages used to select a previous navigation destination on the PTI

7.3.3.2 PTI system Task Stages

In order to select a previous destination in the navigation system of the PTI the user must perform the following task stages. Select the 'stored destination' button as shown by label 1 in Figure 7.8. In order to avoid the issues identified with using scrolling lists the PTI was designed to present only six destinations on the screen at any one time. The user can switch between screens of six previous destinations using the 'tick' and 'cross buttons on the PTI navigation array as shown by label 2 in Figure 7.8. The required destination is then selected using the preset key i.e. the screen destination number four would be selected with the 4th preset key as shown by label 4 in Figure

7.8. In both the baseline and PTI the previous destination to be selected was always beyond the first six destinations requiring the user to scroll through the list or change the page of six destinations on the baseline system and the PTI respectively.

7.3.3.3 Results for the Select previous destination task: A comparison between the results for the baseline system and the PTI

There was a significant reduction in median glance duration and a reduction in the number of glances and the summed glance duration for the select stored destination task. The PTI produced a 16% reduction (0.18) in median glance duration, a 3% reduction (4) in number of glances and a 25% reduction (34.92 seconds) in summed glance duration when compared to the baseline system.

	Median glance duration			No. of glances			Summed glance duration		
	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test
Select Dest	0.96	1.14	**0.036**	119	123	**0.838**	129	163.92	**0.07**

Table 7.8. The statistical difference between the PTI and baseline systems for the Median Glance duration, No. of glances and summed glance duration

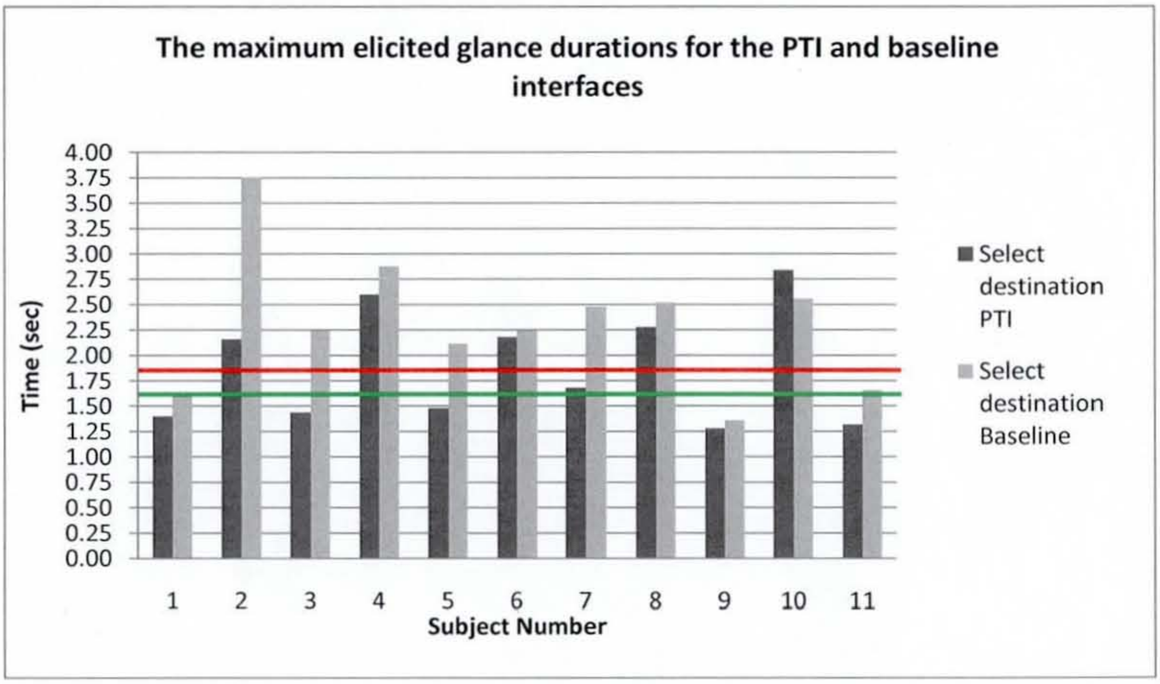


Figure 7.9. The maximum glance duration for each participant when performing the select destination task

The maximum glance durations for each participant are shown in Figure 7.9 and Table 7.9. The longest glance durations for each system were above the 1.82 threshold for five PTI glances and eight baseline glances.

		Subject number										
		1	2	3	4	5	6	7	8	9	10	11
Select destination	*PTI*	1.40	2.16	1.44	2.60	1.48	2.18	1.68	2.28	1.28	2.84	1.32
	Base-line	1.64	3.76	2.24	2.88	2.12	2.24	2.48	2.52	1.36	2.56	1.66

Table 7.9. The maximum glance duration for each participant when performing the select destination task with significance testing

The longest glance durations elicited by the PTI were significantly shorter than those for the baseline system at the 0.014 level using a Wilcoxon Signed Rank test.

7.3.3.4 Evidence of non-visual use

For the PTI there was particular task element that encouraged non-visual use when performing the select a stored destination task. The action of using the tick and cross buttons to select pages of six destinations, followed by selecting a particular preset button was performed non-visually by subjects 2, 6, 7, 10 and 11. There were no non-visual interactions when using the baseline system.

		% of glances
Select destination	*Arrays*	39
	Screen	61

Table 7.10. The percentage of PTI glances directed to the screen or PTI arrays

7.3.3.5 Task failures

There were no task failures for the PTI interface when performing the select previous destination task. The baseline system had one task failure. Subject 5 failed to find the correct menu for finding a stored destination.

7.3.3.6 Summary for the select a stored destination task

The PTI achieved significantly reduced median glance duration when compared to the baseline system. The task of scrolling through previous destinations and selecting the required destination was performed without looking at the PTI for five participants. The task showed good evidence for non-visual use but the maximum glance durations that were exhibited for this task were considerably larger than the defined 1.58/1.83

second thresholds. The longest glance durations for each system were made whilst trying to find a specific location in the previous destinations list. The text size on screen was larger on the PTI when compared to the baseline system. This is illustrated by the longest glance of 2.84 seconds for the PTI and 3.76 seconds for the baseline system. Even though the median glance durations were below the 1.58 second glance threshold (0.96 for the PTI and 1.14 for the baseline system) the longest glance durations for both systems could potentially lead to lane exceedances and therefore the select stored navigation task is recommended for use when the vehicle is stationary only.

7.3.4 Summary for all navigation tasks

The following section shows a summary of the combined results for the navigation array. The glances for all tasks were combined and analysed to show the median glance duration, number of glances and summed glance duration for all of the navigation tasks. As with the separate task analyses a statistical analysis was performed to search for significant dereferences between the PTI and baseline interfaces.

7.3.4.1 Results

When the glances for the three navigation tasks are combined a significant reduction in median glance duration and summed glance duration was found. The PTI produced a 23% reduction (0.25 seconds) in median glance duration, a 15% reduction (37) in number of glances and a 31% reduction (95.6 seconds) in summed glance duration. These reductions are above the 10% decrease that was stated as a project aim.

	Median glance duration			No. of glances			Summed glance duration		
	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test
All Navigation tasks	0.91	1.16	**0.015**	209	246	**0.105**	218.3	313.9	**0.009**

Table 7.11. The statistical difference between the PTI and baseline systems for the Median Glance duration, No. of glances and summed glance duration

7.3.4.2 Evidence of non-visual use and task failures summary table

Table 7.12 summarises the non-visual interactions and task failures associated with the navigation array (the red cells show a failed task or no non-visual interactions. The green cells show successful completion and non-visual interaction). There were no non-visual interactions performed for the baseline system. The PTI encouraged non-visual interaction for the zoom map view task and elements of the select stored destination task. There were no task failures for the PTI system. Participant number 5 failed to complete the zoom map and select destination tasks when using the baseline system.

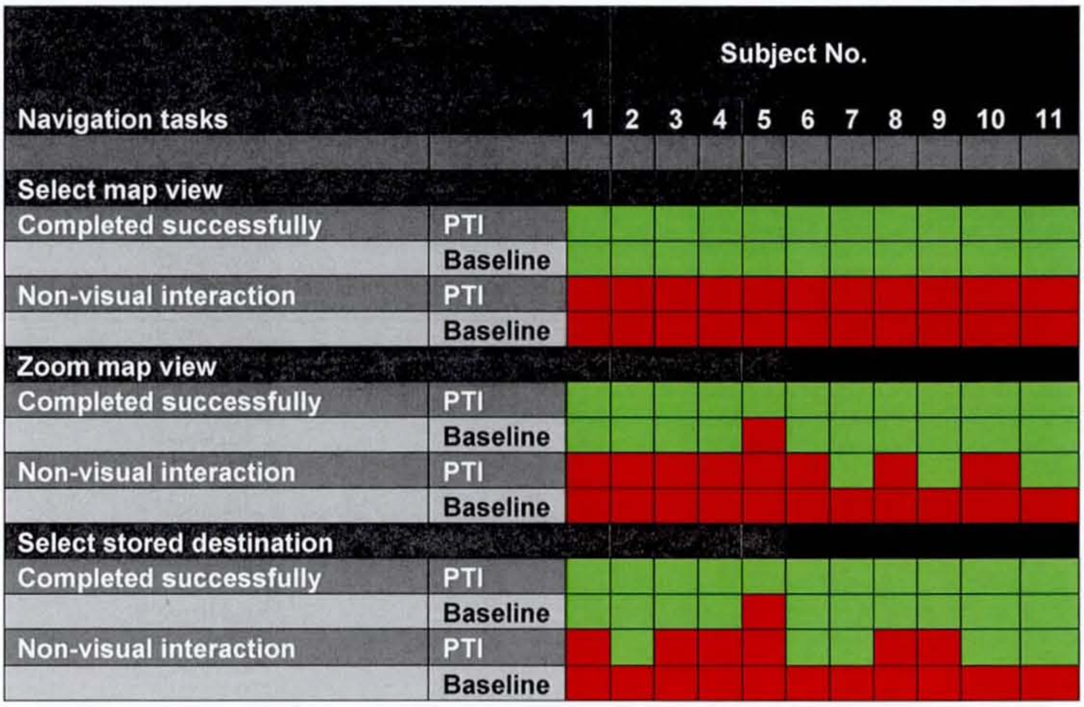


Table 7.12. A summary of the task failures and the successful use of non-visual interaction for both systems

7.3.4.3 Analysis of the longest glances made when performing navigation tasks

The longest glances durations elicited by each system are shown in table 8.12. It should be noted that median glance duration was lower than the 1.58 second threshold for all navigation tasks on both systems.

Subject number		1	2	3	4	5	6	7	8	9	10	11
PTI	Select map view	1.08	2.08	1.28	0.96	1.2	0.96	1.04	1.32	0.84	1.32	1.64
	Zoom map	0.8	1.44	1.36	1.08	1.4	1.6	1.52	2.92	1.08	1.68	1.2
	Select desti-nation	1.4	2.16	1.44	2.6	1.48	2.18	1.68	2.28	1.28	2.84	1.32
Base-line	Select map view	1.56	1.64	1.44	3.68	2.76	1.08	0.84	1.28	1.08	1.88	2.32
	Zoom map	1.56	1.52	1.52	3.24	2.28	2.04	1.92	2.04	1.52	2.16	2.68
	Select desti-nation	1.64	3.76	2.24	2.88	2.12	2.24	2.48	2.52	1.36	2.56	1.66

Table 7.13. The maximum glance durations for all navigation tasks and the significance testing of maximum glance duration between the two systems

All navigation tasks produced significantly shorter 'longest glance' durations for the PTI when compared to the baseline system.

7.3.4.4 Conclusions for the navigation array

The tactile coding and symbolic design of the PTI navigation array have been shown to foster less glances of shorter duration with reduced maximum glance durations than the baseline system. The PTI system is therefore potentially safer than the baseline system. The analysis of the navigation array has shown that the tactile coding was successful for two of the tasks allowing six of the participants to perform non-visual control interactions.

7.4 Results for the HVAC array

7.4.1 Task: Increase fan speed

7.4.1.1 Baseline system task stages

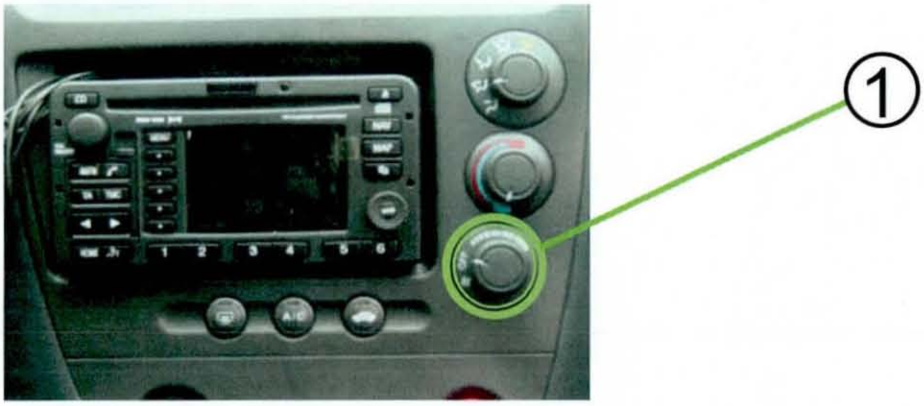


Figure 7.10. The task stages used to increase the fan speed on the baseline interface

In order to change the fan speed in the baseline system the user must rotate the control indicated in Figure 7.10.

7.4.1.2 PTI task stages

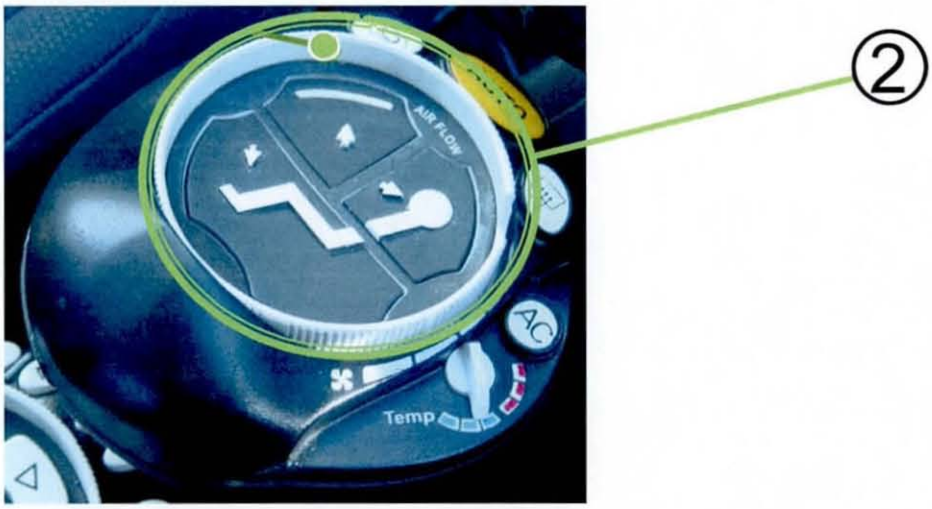


Figure 7.11. The task stages used to increase the fan speed on the PTI

In order to change the fan speed on the PTI system the user must rotate the white bezel that encloses the air flow direction buttons as shown in Figure 7.11.

7.4.1.3 Results for the increase fan speed task

There were significant differences for both the number of glances and the summed glance duration for the fan speed task. The PTI produced a 17% reduction (0.18

seconds) in median glance duration, a 35% reduction (9) in number of glances and a 52%reduction (16.92 seconds) in summed glance duration when compared to the baseline system. See table 7.13.

	Median glance duration			No. of glances			Summed glance duration		
	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test
Increase Fan Speed	0.9	1.08	0.06	17	26	0.096	15.72	32.64	0.047

Table 7.13. The statistical difference between the PTI and baseline systems for the Median Glance duration, No. of glances and summed glance duration

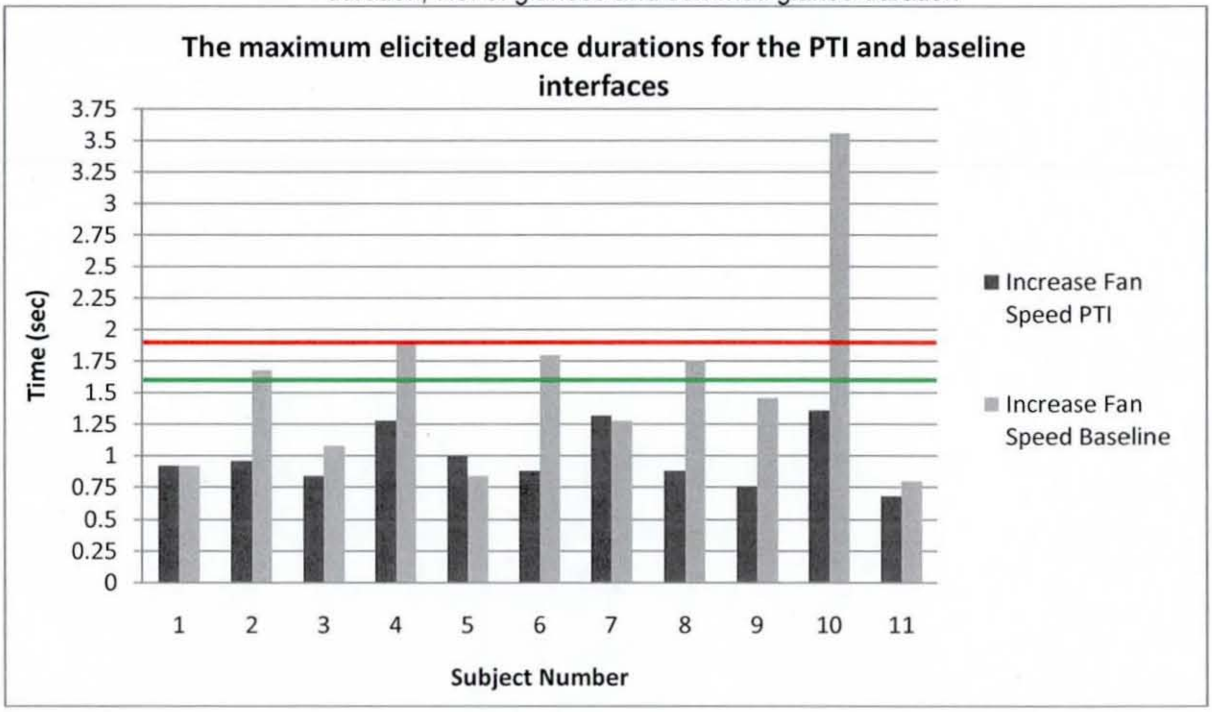


Figure 7.12. The maximum glance duration for each participant when performing the increase fan speed task

The maximum glance durations for each participant are shown in Figure 7.12 and Table 7.14. The table shows that the longest glances for the baseline system were longer than those when using the PTI. No participants exceeded the 1.58 second threshold on the PTI compared to five on the baseline system.

Subject Number		1	2	3	4	5	6	7	8	9	10	11
Increase Fan Speed	*PTI*	0.92	0.96	0.84	1.28	1	0.88	1.32	0.88	0.76	1.36	0.68
	Base -line	0.92	1.68	1.08	1.88	0.84	1.8	1.28	1.76	1.46	3.56	0.8

Table 7.14. The maximum glance duration for each participant when performing the increase fan speed task with significance testing

The longest glance durations elicited by the PTI were significantly shorter than those for the baseline system at the 0.017 level using a Wilcoxon Signed Rank test.

7.4.1.4 Evidence of non visual use

In terms of the PTI interface the task of changing the fan speed was performed non-visually by four subjects (Subjects 2, 7, 9 and 11). There were no non visual interactions for the baseline system. The majority of glances made to the PTI were directed to the screen.

		% of glances
Increase Fan Speed	*Arrays*	41
	Screen	59

Table 7.15. The percentage of PTI glances directed to the screen or PTI arrays

7.4.1.5 Task failures

There were no task failures for either system for the change fan speed task.

7.4.1.6 Summary for the increase fan speed task

The PTI system achieved significantly lower summed glance durations than the baseline system for the increase fan speed task, with a non significant reduction in median glance duration for the PTI. The subdivision of the functional groups and the layout the array is assumed to have affected the results. In terms of the safety of performing the task on each system the PTI could be considered safer in that the median glance duration was lower, the maximum glance duration was lower when compared to the baseline system. The median glance durations for both systems were below the 1.58 second threshold. The maximum glance durations were considered potentially unsafe for the baseline system with two glances in excess of the 1.82 second threshold.

7.4.2 *Task: Change airflow direction*

7.4.2.1 Baseline system task stages

Figure 7.13. The task stages used to change the airflow direction on the baseline interface

In order to change the air flow direction with the base line system the user must operate the rotary dial shown in Figure 7.13. The airflow settings from the bottom to the top of the rotary are face, feet and face, feet, feet and screen and screen.

7.4.2.2 PTI task stages

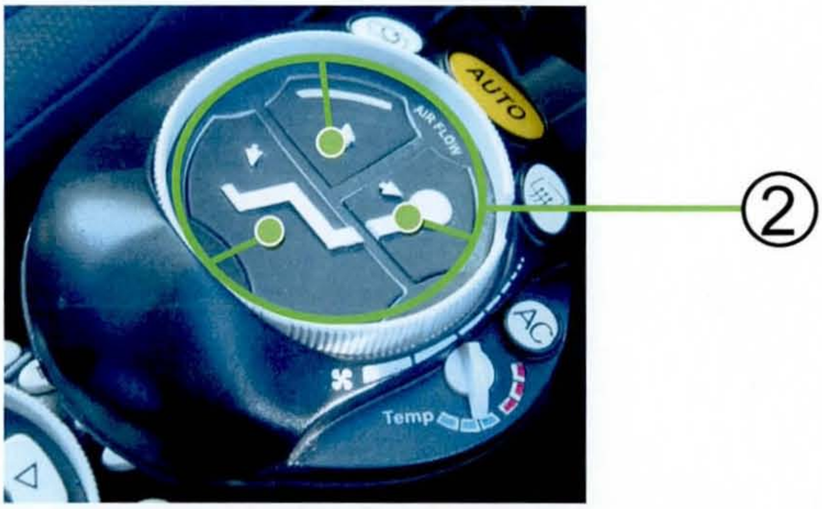


Figure 7.14. The task stages used to change the airflow direction on the PTI

In order to change the air flow direction with the PTI system the user can select any combination of feet, face and screen by selecting the controls highlighted in Figure 7.14.

7.4.2.3 Results for the airflow direction task

There was a significant reduction for the PTI system in regards to the number of glances, the maximum glance duration and the summed glance duration for the change airflow direction task. The PTI produced a 34% reduction (0.43 seconds) in median glance duration, a 16% reduction (4) in number of glances and a 49% reduction (16.36 seconds) in summed glance duration when compared to the baseline system.

	Median glance duration			No. of glances			Summed glance duration		
	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test
Direct airflow	0.84	1.27	**0.028**	21	25	**0.38**	17.12	33.48	**0.037**

Table 7.16. The statistical difference between the PTI and baseline systems for the Median Glance duration, No. of glances and summed glance duration

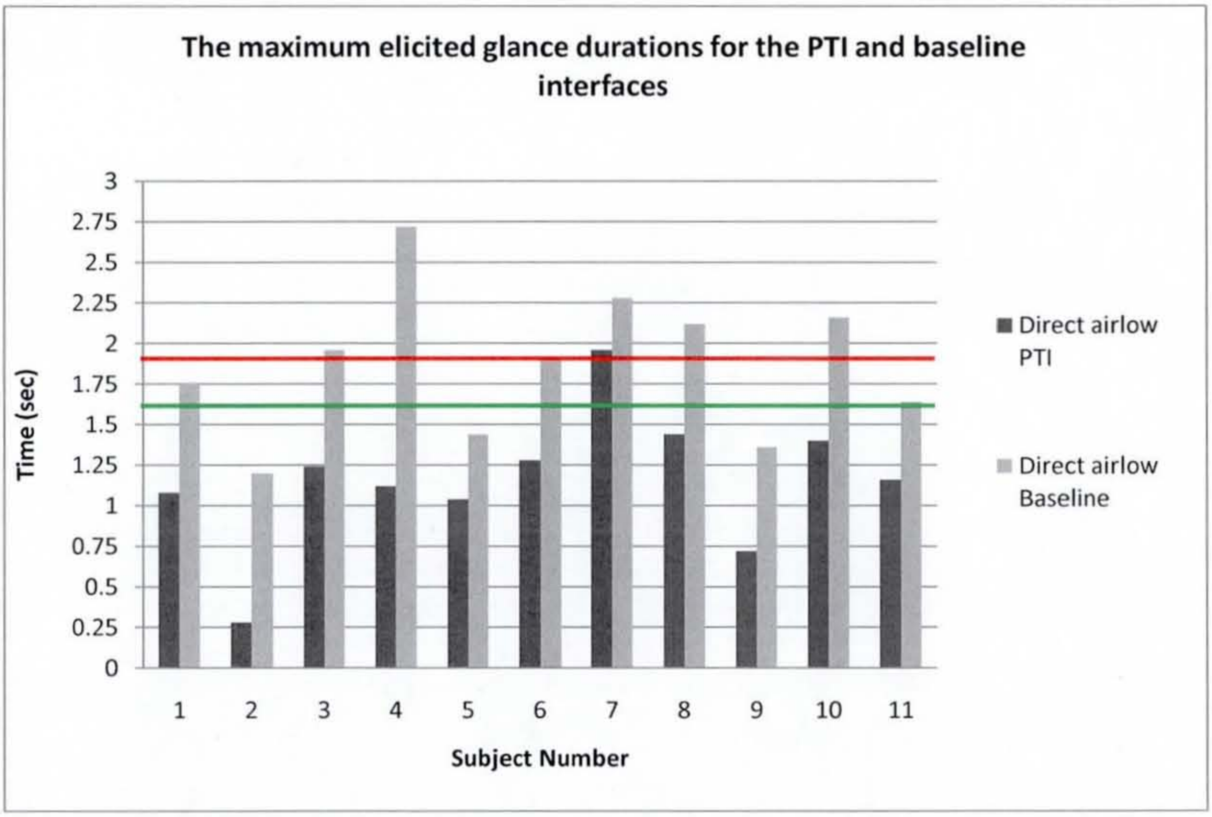


Figure 7.15. The maximum glance duration for each participant when performing the direct airflow task

The maximum glance durations for each participant are shown in Figure 7.15 and Table 7.17. The table shows that the longest glances for the baseline system were longer than those when using the PTI. One participants exceeded the 1.82 second threshold on the PTI compared to six on the baseline system.

HVAC tasks		Subject number 1	2	3	4	5	6	7	8	9	10	11
Direct airflow	*PTI*	1.08	0.28	1.24	1.12	1.04	1.28	1.96	1.44	0.72	1.4	1.16
	Base-line	1.76	1.2	1.96	2.72	1.44	1.92	2.28	2.12	1.36	2.16	1.64

Table 7.17. The maximum glance duration for each participant when performing the direct airflow task with significance testing

The longest glance durations elicited by the PTI were significantly shorter than those for the baseline system at the 0.013 level using a Wilcoxon Signed Rank test.

7.4.2.4 Evidence of non-visual use

Changing the airflow direction was the most successful example of non-visual control interaction for the PTI system. Seven members of the sample performed this task non-visually (subjects 1, 2, 3, 5, 9, 10, 11). There were no non-visual interactions with the baseline system.

		% of glances
Direct airflow	*Arrays*	41
	Screen	59

Table 7.18. The percentage of PTI glances directed to the screen or PTI interface

7.4.2.5 Task failures

Subject number 8 failed to select the correct airflow direction when using the baseline system.

7.4.2.6 Summary for the change airflow direction task

The PTI achieved significantly reduced summed glance duration and median glance duration when compared to the baseline system. The PTI also achieved a non significant reduction in the number of glances. The ordering of the airflow options on the baseline system forced the user to look at the control whereas the simplified version in the PTI allowed the same airflow combinations to be achieved whilst fostering the strongest non-visual performance of all of the tasks performed during the user trials. The median glance durations for both systems were below the 1.58 second threshold. The maximum glance durations were considered potentially unsafe for the baseline system with more than half the sample performing glances in excess of the 1.82 second threshold.

7.4.3 Task: Turn off air conditioning

7.4.3.1 Baseline system task stages

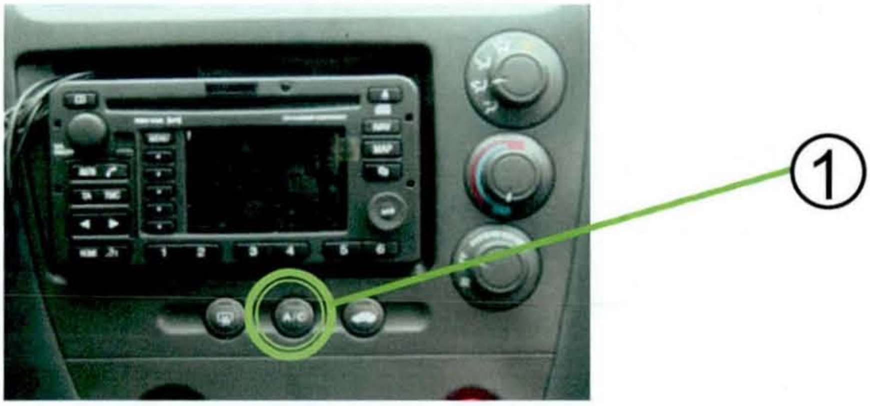


Figure 7.16. The task stages used to turn on the air conditioning on the baseline interface

In order to turn on the air conditioning the user must push the button indicated in Figure 7.16.

7.4.3.2 PTI system task stages

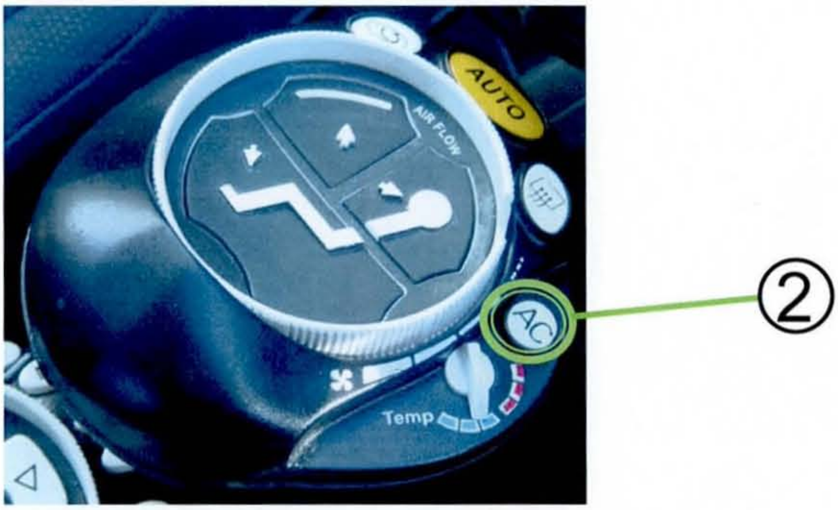


Figure 7.17. The task stages used to turn on the air conditioning on the PTI

In order to turn on the air conditioning the user must push the button indicated in Figure 7.17.

7.4.3.3 Results

There were no significant differences between the two systems for this task. See table 7.19. The PTI produced an 18% increase (0.2 seconds) in median glance duration, the same number of glances and a 3.4% increase (0.96 seconds) in summed glance duration when compared to the baseline system.

	Median glance duration			No. of glances			Summed glance duration		
	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test
Turn off the AC	1.13	0.93	0.515	26	26	1	28.76	27.8	0.891

Table 7.19. The statistical difference between the PTI and baseline systems for the Median Glance duration, No. of glances and summed glance duration

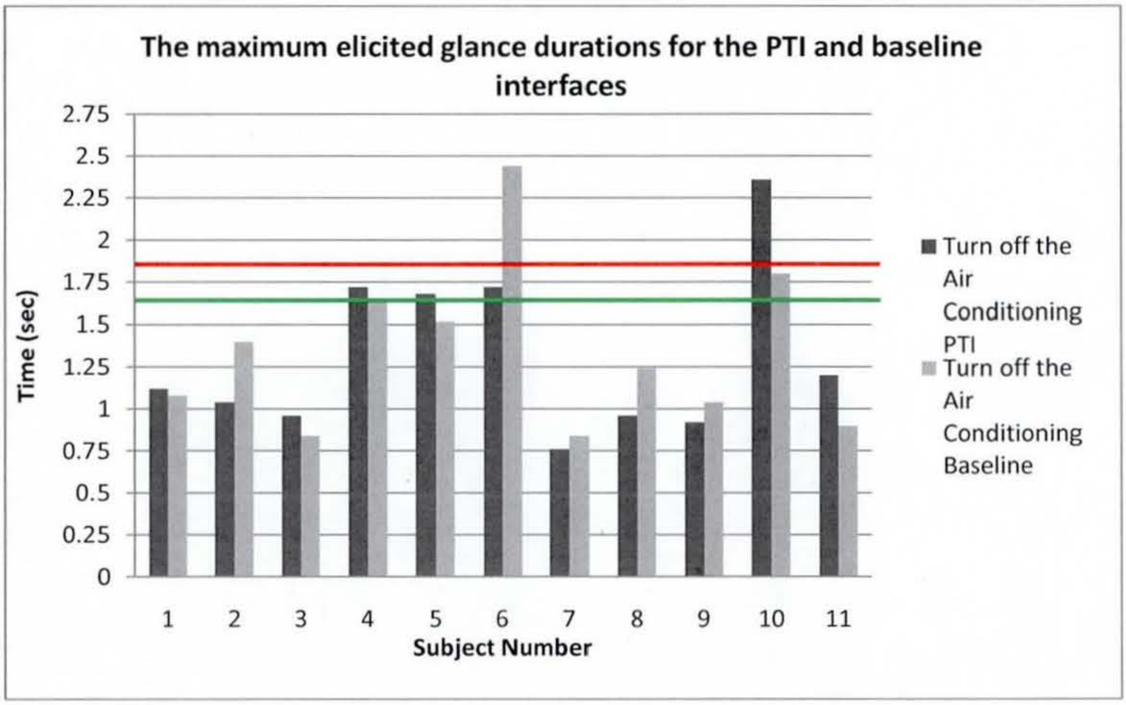


Figure 7.18. The maximum glance duration for each participant when performing the direct airflow task

The maximum glance durations for each participant are shown in Figure 7.18 and table 7.20. The table shows that the longest glances for the baseline system were of the same order as those for the PTI with both systems producing one glance that was longer than the 1.82 second threshold.

HVAC tasks		1	2	3	4	5	6	7	8	9	10	11
Turn off the Air Conditi-oning	*PTI*	1.12	1.04	0.96	1.71	1.68	1.72	0.76	0.96	0.92	2.3	1.04
	Base-line	1.08	1.4	0.84	1.64	1.52	2.44	0.84	1.24	1.04	1.08	1.4

Table 7.20 The maximum glance duration for each participant when performing the direct airflow task with significance testing

There was no significant difference between the longest glance durations for each system for this task.

7.4.3.4 Evidence of non-visual use

There were no non-visual interactions for either system when turning on the air conditioning. The majority of glances made to the PTI were directed to the screen.

		% of glances
Turn off the Air Conditioning	*Arrays*	42
	Screen	58

Table 7.21. The percentage of PTI glances directed to the screen or PTI interface

Of all of the glances made to the PTI system 42% were made to the PTI and 58% were made to the screen.

7.4.3.5 Task failures

There were no task failures for either system when turning off the air conditioning.

7.4.3.6 Summary for the turn on air conditioning task

There were no significant differences between the two systems in terms of the task of turning off the air conditioning, with the baseline system achieving a slight reduction in median glance duration.

7.4.4 All tasks associated with the HVAC array

When the glances for the three HVAC tasks are combined a significant reduction in median glance duration and summed glance duration was found. The PTI produced a 15% reduction (0.16 seconds) in median glance duration, and a 20% reduction (24.65 seconds) in summed glance duration. These reductions are above the 10% decrease that was stated as a project aim.

	Median glance duration			No. of glances			Summed glance duration		
	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test
All HVAC tasks	0.88	1.04	0.12	104	102	0.878	97.85	122.5	0.075

Table 7.22. The statistical difference between the PTI and baseline systems for the Median Glance duration, No. of glances and summed glance duration

7.4.4.1 Evidence of non-visual use and task failures summary table

The table below summarises the non-visual interactions and task failures associated with the HVAC. There were no non-visual interactions performed for the baseline system. The PTI encouraged non-visual interaction for the increase fan speed task and elements for the change airflow direction task. There were no task failures for the PTI system. Participant number 8 failed to complete the change airflow direction task when using the baseline system.

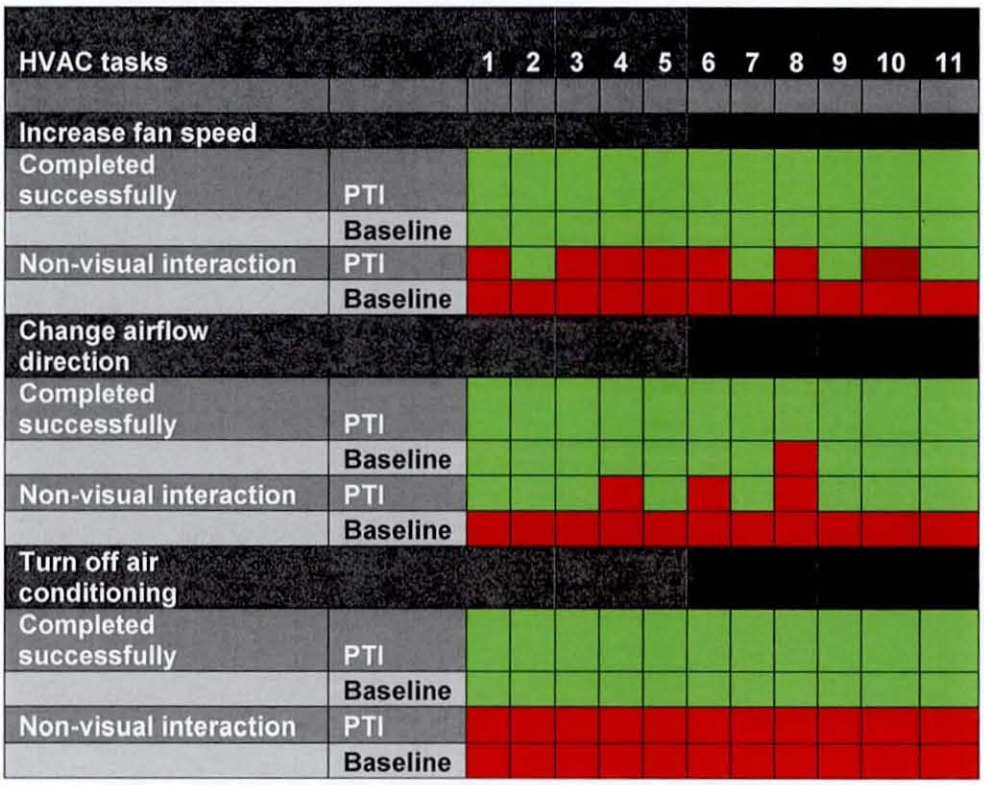


Table 7.23. A summary of the task failures and the successful use of non-visual interaction for both systems

7.4.4.2 Analysis of the longest glances made when performing navigation tasks

The longest glances durations elicited by each system are shown in table 7.24. It should be noted that median glance duration was lower than the 1.58 second threshold for all HVAC tasks on both systems.

		Subject number										
		1	2	3	4	5	6	7	8	9	10	11
PTI	Increase Fan Speed	0.92	0.96	0.84	1.28	1	0.88	1.32	0.88	0.76	1.36	0.68
	Direct airflow	1.08	0.28	1.24	1.12	1.04	1.28	1.96	1.44	0.72	1.4	1.16
	Turn off the Air Condit-ioning	1.12	1.04	0.96	1.71	1.68	1.72	0.76	0.96	0.92	1.12	1.04
Base-line	Increase Fan Speed	0.92	1.68	1.08	1.88	0.84	1.8	1.28	1.76	1.46	3.56	0.8
	Direct airflow	1.76	1.2	1.96	2.72	1.44	1.92	2.28	2.12	1.36	2.16	1.64
	Turn off the Air Condit-ioning	1.08	1.4	0.84	1.64	1.52	2.44	0.84	1.24	1.04	1.08	1.4

Table 7.24. The maximum glance durations for all HVAC tasks

The results indicate that the change airflow direction task produced potentially unsafe glance durations for more than half of the participants when using the baseline system. This task would be considered potentially unsafe for use whilst driving on the baseline system.

7.4.4.3 Conclusions for the HVAC array

The tactile coding and symbolic design of the PTI HVAC array have been shown to foster glances of a shorter duration with reduced maximum glance durations and is therefore potentially safer to use than the baseline system. The analysis of the HVAC array has shown that the tactile coding was successful for two of the tasks allowing eight (72%) of the participants to perform non-visual control interactions. The PTI controls associated with changing airflow direction were the most successful at fostering non-visual use of all the PTI controls.

7.5 Results for the ICE array

7.5.1 *Task: Turn on CD player*

7.5.1.1 PTI task stages

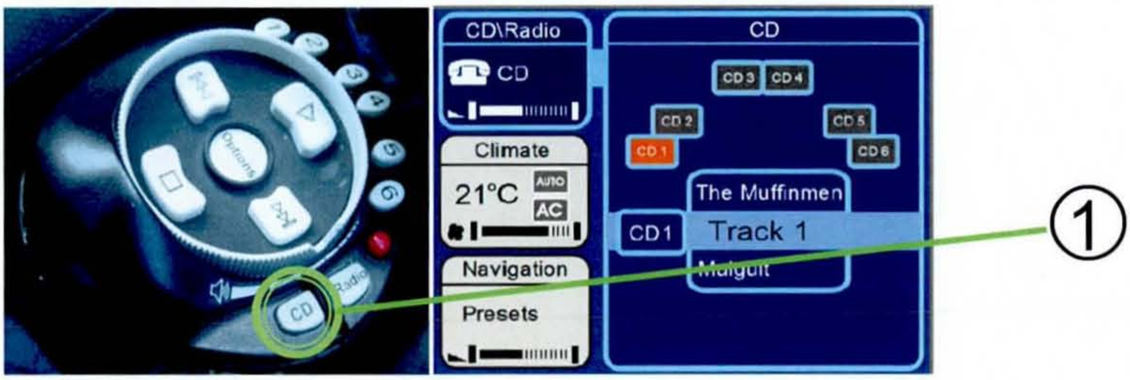


Figure 7.19. The task stages used to select CD mode on the PTI

In order to turn on the CD player the user must push the button indicated in Figure 7.19.

7.5.1.2 Baseline system task stages

Figure 7.20. The task stages used to select CD mode on the baseline interface

In order to turn on the CD player the user must push the button indicated in Figure 7.20.

7.5.1.3 Results

There was a significant reduction in the number of glances made for the PTI. The PTI produced a 14% increase (0.12 seconds) in median glance duration, a 44% reduction (14) in number of glances and a 31% reduction (10.64 seconds) in summed glance duration when compared to the baseline system. See table 7.25.

	Median glance duration			No. of glances			Summed glance duration		
	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test
Turn on the CD player	0.96	0.84	0.333	18	32	0.023	23.92	34.56	0.241

Table 7.25. The statistical difference between the PTI and baseline systems for the Median Glance duration, No. of glances and summed glance duration

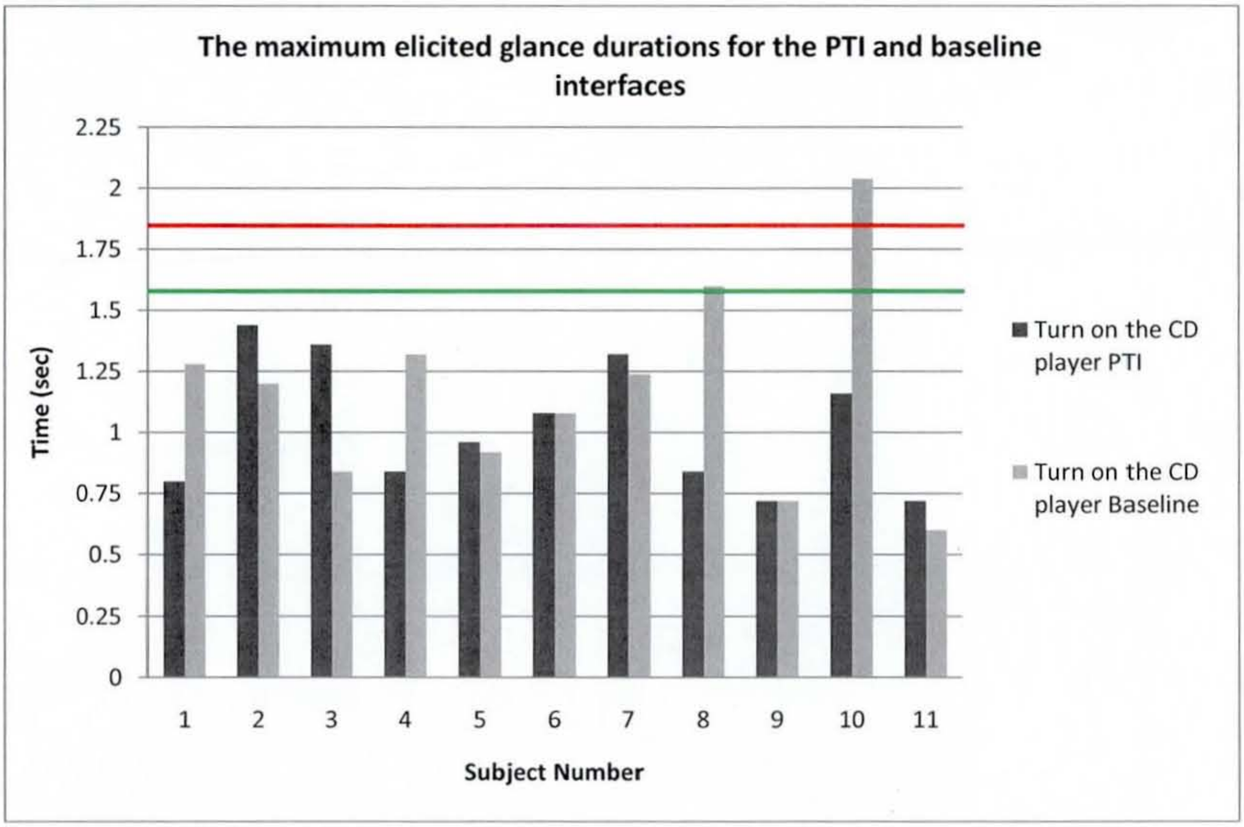


Figure 7.21. The maximum glance duration for each participant when performing the turn on CD player task

The maximum glance durations for each participant are shown in Figure 7.21 and Table 7.26. No participants exceeded the 1.82 second threshold on the PTI compared to one on the baseline system.

ICE tasks		Subject number 1	2	3	4	5	6	7	8	9	10	11
Turn on the CD player	PTI	0.8	1.44	1.36	0.84	0.96	1.08	1.32	0.84	0.72	1.16	0.72
	Base-line	1.28	1.2	0.84	1.32	0.92	1.08	1.24	1.6	0.72	2.04	0.6

Table 7.26. The maximum glance duration for each participant when performing the turn on CD player task with significance testing

There was no significant difference between the longest glance durations for each system for this task.

7.5.1.4 Evidence of non-visual use

There were no non-visual interactions for either system for the turn on CD player task.

		% of glances
Turn on the CD player	*Arrays*	62
	Screen	38

Table 7.27. The percentage of PTI glances directed to the screen or PTI interface

7.5.1.5 Task failures

There were no non task failures for either system for the turn on CD player task

7.5.1.6 Summary for the select CD mode task

There were no significant differences between the two systems for the select CD mode task. The PTI required less glances than the baseline system but these glances were slightly longer. This resulted in reduced summed glance duration for the PTI system.

7.5.2 Task: Select CD track 7

7.5.2.1 PTI task stages

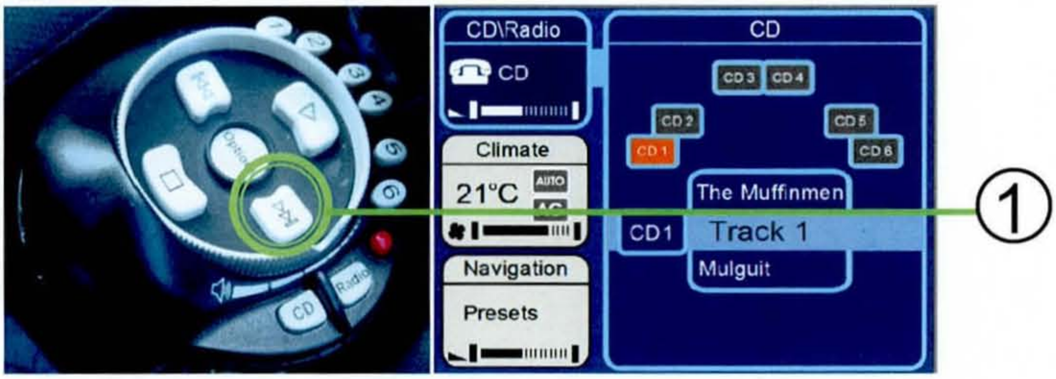


Figure 7.22. The task stages used to change the CD track on the PTI

In order to change the CD track the user must push the button indicated in Figure 7.22.

7.5.2.2 Baseline system task stages

Figure 7.23. The task stages used to change the CD track on the baseline system

In order to change the CD track the user must push the button indicated in Figure 7.23.

7.5.2.3 Results

The PTI produced a 16% increase (0.16 seconds) in median glance duration, a 22% increase (7) in number of glances and a 14% increase (4.96 seconds) in summed glance duration when compared to the baseline system. See Table 7.28.

	Median glance duration			No. of glances			Summed glance duration		
	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test
Select track 7	1	0.84	0.138	39	32	0.254	39.52	34.56	0.646

Table 7.28. The statistical difference between the PTI and baseline systems for the Median Glance duration, No. of glances and summed glance duration

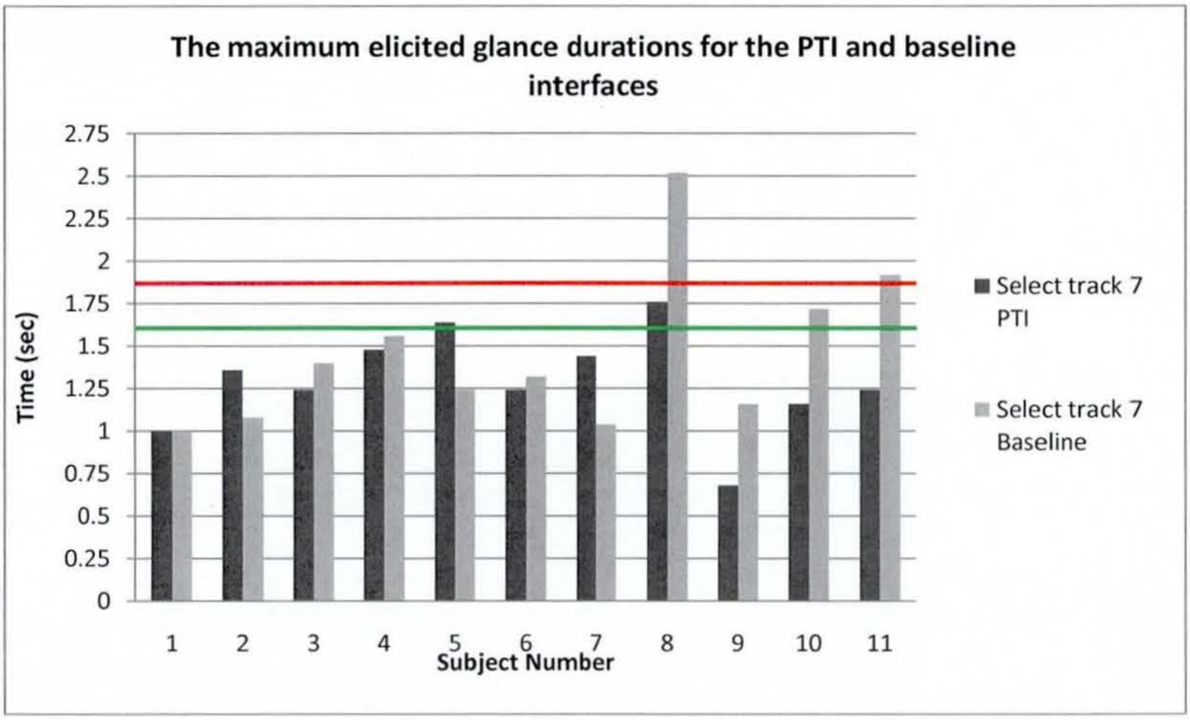


Figure 7.24. The maximum glance duration for each participant when performing the select CD track 7 task

The maximum glance durations for each participant are shown in Figure 7.24 and Table 7.29. No participants exceeded the 1.82 second threshold on the PTI compared to two on the baseline system.

ICE tasks		Subject number										
		1	2	3	4	5	6	7	8	9	10	11
Select track 7	*PTI*	1	1.36	1.24	1.48	1.64	1.24	1.44	1.76	0.68	1.16	1.24
	Base-line	1	1.08	1.4	1.56	1.24	1.32	1.04	2.52	1.16	1.72	1.92

Table 7.29. The maximum glance duration for each participant when performing the select CD track 7 task

There was no significant difference between the longest glance durations for each system for this task.

7.5.2.4 Evidence of non-visual use

Participants 7, 9, and 11 performed the task of changing the CD track non-visually when using the PTI system. There were no non-visual task executions for the baseline system.

		% of glances
Select track 7	*PTI*	30
	Screen	70

Table 7.30. The percentage of PTI glances directed to the screen or PTI interface

Seventy percent of the glances made during PTI use were directed at the screen.

7.5.2.5 Task failures

There were no task failures for the change CD track task with either system

7.5.2.6 Summary for the select track 7 task

The task of selecting CD track 7 on the PTI system was hampered by the software lag in the ALTIA software discussed in Chapter 6 (i.e. the prototype software did not always recognise multiple button depressions in quick succession) . This lead to an increased number of glances to the screen in order to check if the correct track had been selected, as opposed to simply pushing the track button six times to select track 7. Three participants reached to and found the skip track button without looking at the PTI ICE array.

7.5.3 Task: Select Radio Mode

7.5.3.1 PTI task stages

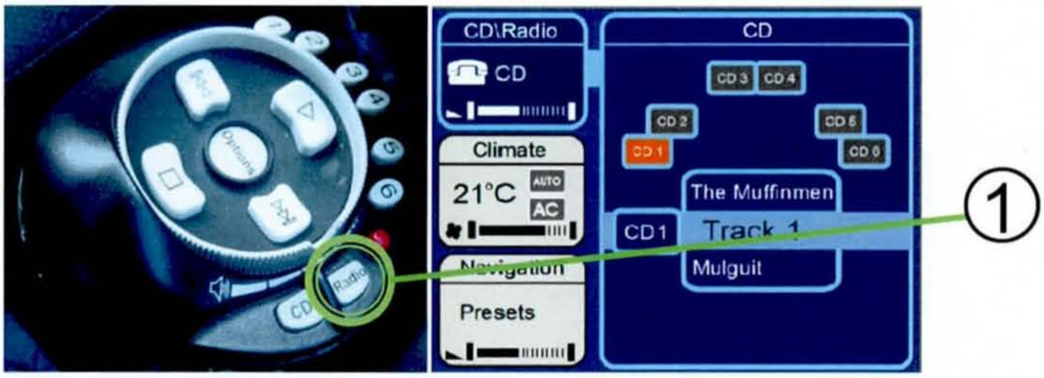


Figure 7.25. The task stages used to select radio mode on the PTI interface

In order to select radio mode the user must push the button indicated in Figure 7.25.

7.5.3.2 Baseline system task stages

Figure 7.26. The task stages used to select radio mode on the baseline interface

In order to select radio mode the user must push the button indicated in figure 7.26.

7.5.3.3 Results

There was a significant reduction in median glance duration, the number of glances and the summed glance duration for the PTI turn on radio. The PTI produced a 27% reduction (0.30 seconds) in median glance duration, a 28% reduction (9) in number of glances and a 53% reduction (22.24) in summed glance duration when compared to the baseline system. See table 7.31.

	Median glance duration			No. of glances			Summed glance duration		
	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test
Turn on radio	0.82	1.12	0.033	23	32	0.041	19.48	41.72	0.021

Table 7.31. The statistical difference between the PTI and baseline systems for the Median Glance duration, No. of glances and summed glance duration

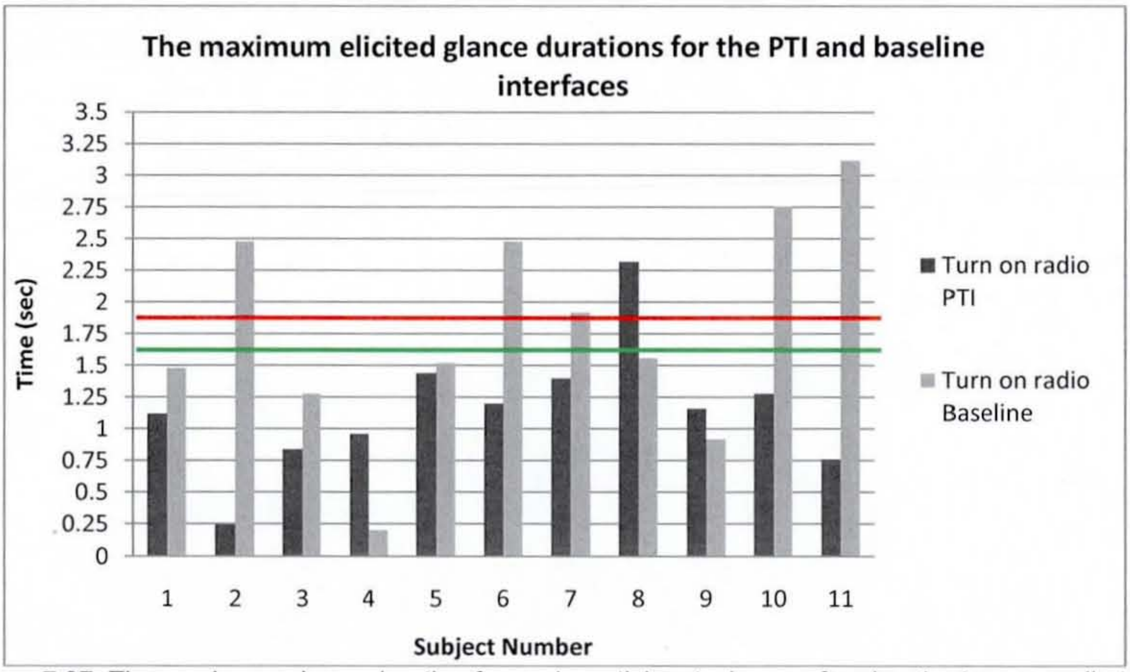


Figure 7.27. The maximum glance duration for each participant when performing the turn on radio task

The maximum glance durations for each participant are shown in Figure 7.27 and Table 7.32 . One participant exceeded the 1.82 second threshold on the PTI compared to 5 on the baseline system.

		Subject number										
		1	2	3	4	5	6	7	8	9	10	11
Turn on radio	*PTI*	1.12	0.24	0.84	0.96	1.44	1.2	1.4	2.32	1.16	1.28	0.76
	Base-line	1.48	2.48	1.28	0.2	1.52	2.48	1.92	1.56	0.92	2.76	3.12

Table 7.32. The maximum glance duration for each participant when performing the turn on radio task

There was no significant difference between the longest glance durations for each system for this task.

7.5.3.4 Evidence of non-visual use

None of the participants performed this task non-visually.

		% of glances
Turn on radio	*Arrays*	42
	Screen	58

Table 7.33. The percentage of PTI glances directed to the screen or PTI interface

Fifty eight percent of the glances made during PTI use were directed at the screen.

7.5.3.5 Task failures

There were no task failures for the select radio mode task.

7.5.3.6 Summary for the select radio mode task

The PTI system achieved a significant reduction in all measures apart from maximum glance duration. Again, the baseline system elicited glances that were in excess of the 1.82 second threshold, making this task potentially dangerous when driving a vehicle and using the baseline system.

7.5.4 *Task: Select Classic FM preset*

7.5.4.1 PTI task stages

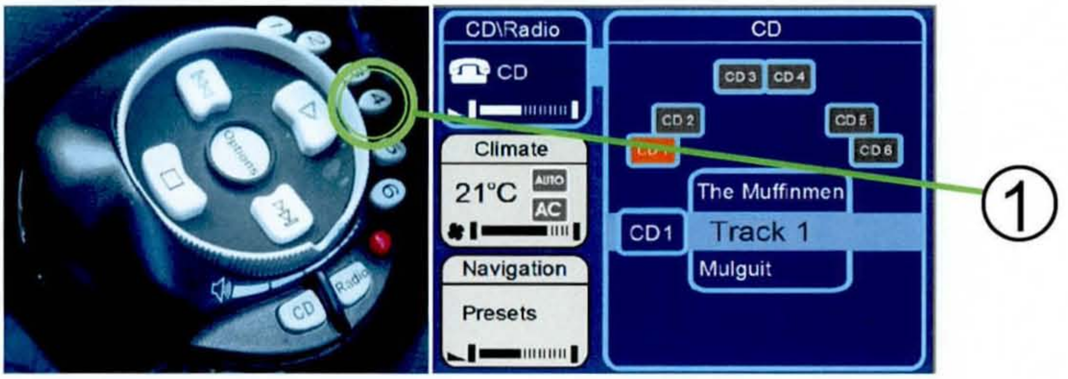


Figure 7.28. The task stages used to select a radio preset on the PTI

In order to select the Classic FM radio preset the user must push the button indicated in Figure 7.28.

7.5.4.2 Baseline system task stages

Figure 7.29. The task stages used to select a preset radio station on the baseline interface

In order to select the Classic FM radio preset the user must push the button indicated in Figure 7.29.

7.5.4.3 Results

There was a significant reduction in median glance duration, an increase in the number of glances and a reduction in the summed glance duration for the PTI select Classic FM radio preset task. The PTI produced a 39% reduction (0.54 seconds) in median glance duration, a 25% increase (9) in the number of glances and a 13%

reduction (6.36) in summed glance duration when compared to the baseline system. See Table 7.34.

	Median glance duration			No. of glances			Summed glance duration		
	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test
Select Classic FM preset	0.84	1.38	0.007	44	35	0.304	41.6	47.96	0.508

Table 7.34. The statistical difference between the PTI and baseline systems for the Median Glance duration, No. of glances and summed glance duration

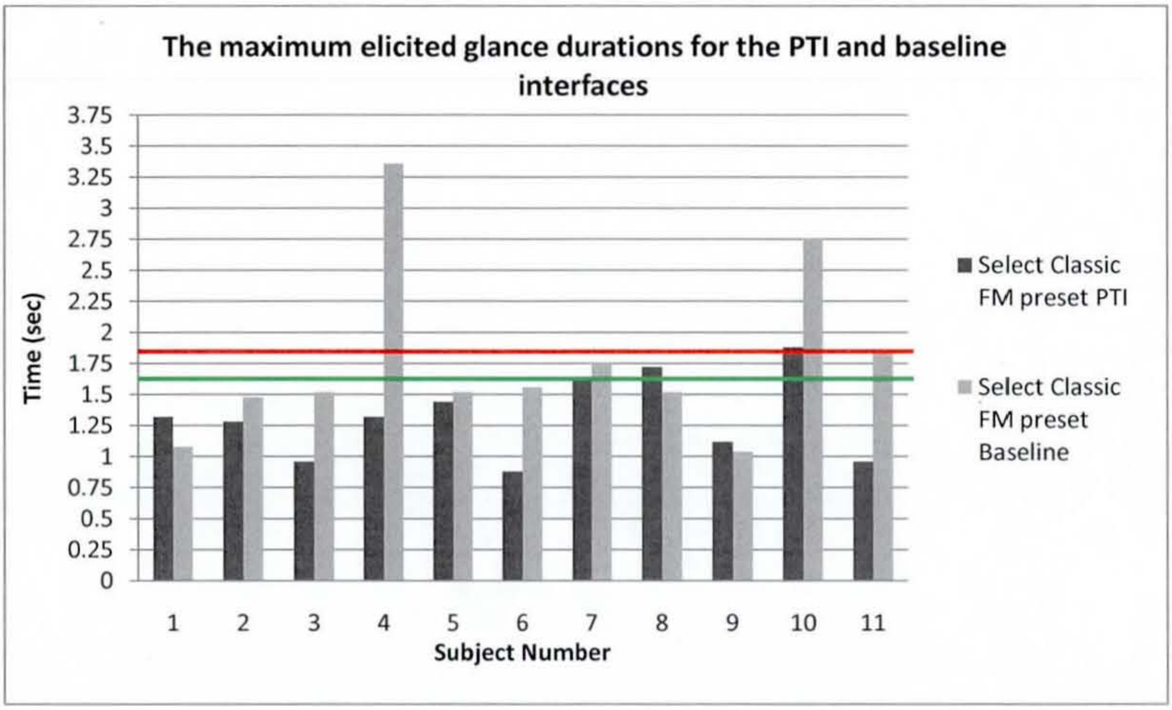


Figure 7.30. The maximum glance duration for each participant when performing the select radio preset task

The maximum glance durations for each participant are shown in Figure 7.30 and Table 7.35. One participant exceeded the 1.82 second threshold on the PTI compared to three on the baseline system.

ICE tasks		Subject number 1	2	3	4	5	6	7	8	9	10	11
Select Classic FM preset	PTI	1.32	1.28	0.96	1.32	1.44	0.88	1.64	1.72	1.12	1.88	0.96
	Baseline	1.08	1.48	1.52	3.36	1.52	1.56	1.76	1.52	1.04	2.76	1.84

Table 7.35. The maximum glance duration for each participant when performing the select radio preset task

There was no significant difference between the longest glance durations for each system for this task.

7.5.4.4 Evidence of non-visual use

For the PTI system subjects 6, 8, 9, and 10 performed the tasks of selecting the classic FM radio station non-visually. None of the participants performed this task non-visually for the baseline system.

		% of glances
Select Classic FM preset	*PTI*	29
	Screen	71

Table 7.36. The percentage of PTI glances directed to the screen or PTI interface

The non-visual use of the preset buttons is illustrated by the percentage of glances directed at the controls which in this case was 29%. Over two thirds of the glances were made to the screen.

7.5.4.5 Task failures

Subject 5 failed to select the classic FM preset on both systems. Subject 9 failed to select the classic FM preset on the baseline system.

7.5.4.6 Summary for the select radio preset task

The PTI system fostered more glances of a shorter duration when compared to the baseline system. The difference in glance duration was significant. This resulted in reduced summed glance duration for the PTI. The careful design process for the preset buttons was successful in fostering non-visual use by four of the participants, with the majority of the glances made during the completion of the PTI task being directed to the screen.

7.5.5 *Task: Increase Volume*

7.5.5.1 PTI task stages

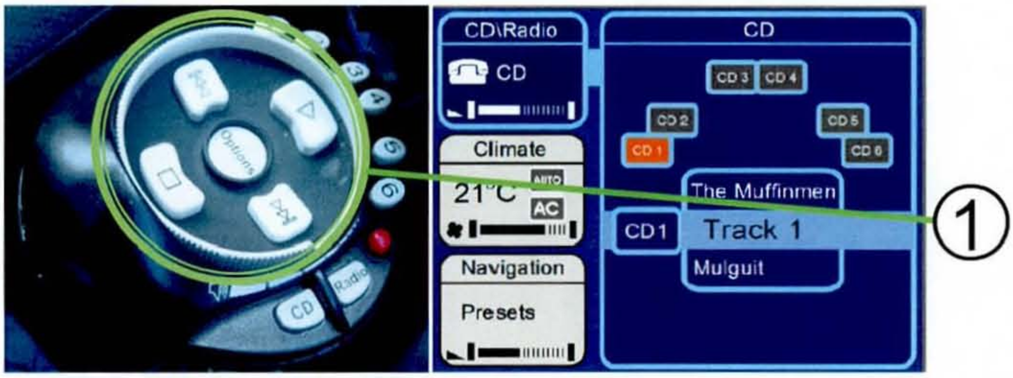


Figure 7.31. The task stages used to increase the volume on the PTI

In order to change the volume of the music on the PTI system the white bezel shown in Figure 7.31 must be rotated.

7.5.5.2 Baseline system task stages

Figure 7.32. The task stages used to increase the volume on the baseline interface

In order to change the volume of the music on the baseline system the knob shown in Figure 7.32 must be rotated.

7.5.5.3 Results

The PTI produced a 4% reduction (0.03 seconds) in median glance duration, a 17% increase (3) in the number of glances and a 32% increase(4.72) in summed glance duration when compared to the baseline system. See Table 7.37.

	Median glance duration			No. of glances			Summed glance duration (secs)		
	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Paired Sample T-test	BIONIC system	Baseline System	Paired Sample T-test
Increase volume	0.82	0.85	0.4	20	17	0.558	19.2	14.48	0.327

Table 7.37. The statistical difference between the PTI and baseline systems for the Median Glance duration, No. of glances and summed glance duration

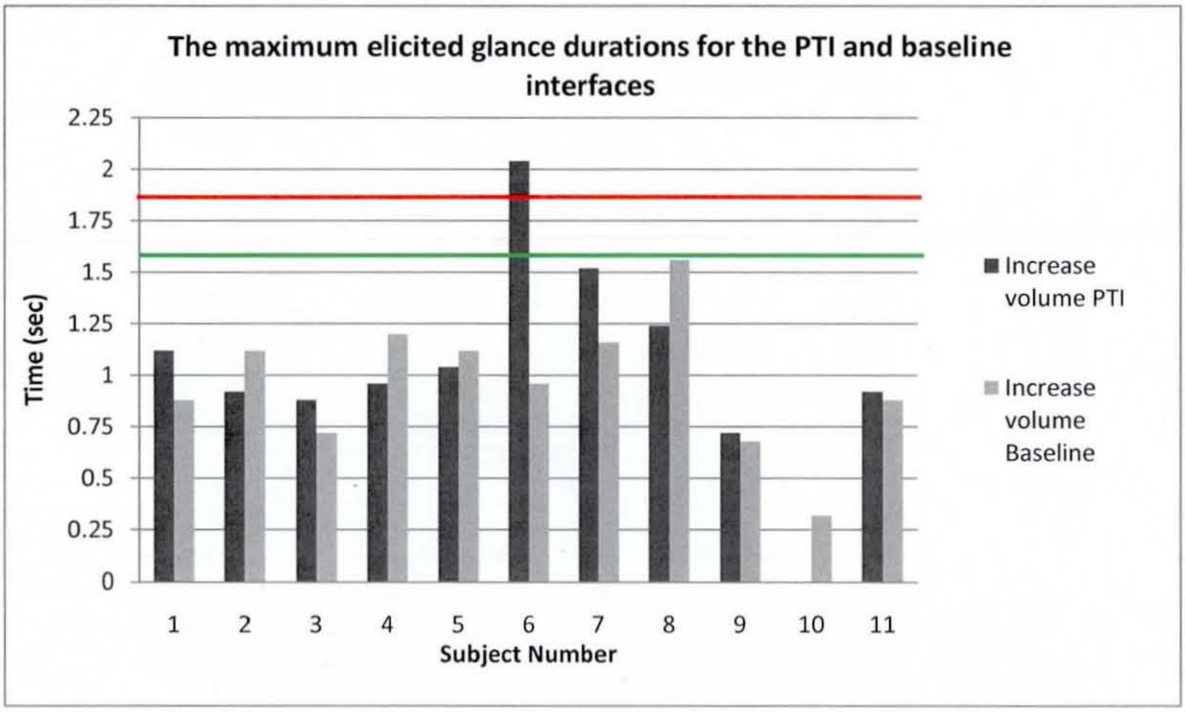


Figure 7.33. The maximum glance duration for each participant when performing the increase volume task

The maximum glance durations for each participant are shown in Figure 7.33 and Table 7.38. One participant exceeded the 1.82 second threshold on the PTI compared to none on the baseline system. The maximum glance durations were significantly shorter for the PTI.

		Subject number										
		1	2	3	4	5	6	7	8	9	10	11
Increase volume	*Arrays*	1.12	0.92	0.88	0.96	1.04	2.04	1.52	1.24	0.72	0	0.92
	Base-line	0.88	1.12	0.72	1.2	1.12	0.96	1.16	1.56	0.68	0.32	0.88

Table 7.38. The maximum glance duration for each participant when performing the increase volume task

There was no significant difference between the longest glance durations for each system for this task.

7.5.5.4 Evidence of non-visual use

Subject 1, 4, 8, and 10 performed the task of increasing the volume non-visually when using the PTI system. There were no non-visual interactions for the baseline system when increasing the volume.

		% of glances
Increase volume	*Arrays*	42
	Screen	58

Table 7.39. The percentage of PTI glances directed to the screen or PTI interface

7.5.5.5 Task failures

There were no task failures for the increase volume task.

7.5.5.6 Summary for the volume task

The results for the increase volume task may at first seem contradictory. There was good evidence for non-visual use with four participants, and yet no significant differences in glance duration, summed glance duration and number of glances. The comments made by the participants during the user trial indicate that the position of the ICE array may have been too far rearwards in the car to allow a good view if required. Therefore the high level of non-visual use by some participants is in contrast to the length of glances that were made by other participants.

7.5.6 All tasks associated with the ICE array

7.5.6.1 Results

When the glances for the five ICE tasks are combined it was found that there were no significant reductions in any of the measures.

	Median glance duration			No. of glances			Summed glance duration		
	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test	BIONIC system	Baseline System	Wilcoxon signed rank test
All ICE tasks	0.95	0.95	1	236	206	0.137	226	223.2	0.887

Table 7.40. The statistical difference between the PTI and baseline systems for the Median Glance duration, No. of glances and summed glance duration

7.5.6.2 Evidence of non-visual use and task failures summary table

The table below summarises the non-visual interactions and task failures associated with the ICE array. There were no non-visual interactions performed for the baseline system. The PTI encouraged non-visual interaction for the select CD track 7 task and the select a radio preset task.

ICE tasks		1	2	3	4	5	6	7	8	9	10	11
Select CD mode												
Completed successfully	PTI											
	Baseline											
Non-visual interaction	PTI											
	Baseline											
Select CD track 7												
Completed successfully	PTI											
	Baseline											
Non-visual interaction	PTI											
	Baseline											
Select radio mode												
Completed successfully	PTI											
	Baseline											
Non-visual interaction	PTI											
	Baseline											
Select Classic FM preset												
Completed successfully	PTI											
	Baseline											
Non-visual interaction	PTI											
	Baseline											
Increase volume												
Completed successfully	PTI											
	Baseline											
Non-visual interaction	PTI											
	Baseline											

Table 7.41. A summary of the task failures and the successful use of non-visual interaction for both systems

7.5.6.3 Analysis of the longest glances made when performing ICE tasks

The longest glance durations elicited by each system are shown in table 7.42. It should be noted that median glance duration was lower than the 1.58 second threshold for all navigation tasks on both systems.

		Subject number										
		1	2	3	4	5	6	7	8	9	10	11
PTI	Turn on the CD player	0.8	1.44	1.36	0.84	0.96	1.08	1.32	0.84	0.72	1.16	0.72
	Select track 7	1	1.36	1.24	1.48	1.64	1.24	1.44	1.76	0.68	1.16	1.24
	Turn on radio	1.12	0.24	0.84	0.96	1.44	1.2	1.4	2.32	1.16	1.28	0.76
	Select Classic FM preset	1.32	1.28	0.96	1.32	1.44	0.88	1.64	1.72	1.12	1.88	0.96
	Increase volume	1.12	0.92	0.88	0.96	1.04	2.04	1.52	1.24	0.72	0	0.92
Base-line	Turn on the CD player	1.28	1.2	0.84	1.32	0.92	1.08	1.24	1.6	0.72	2.04	0.6
	Select track 7	1	1.08	1.4	1.56	1.24	1.32	1.04	2.52	1.16	1.72	1.92
	Turn on radio	1.48	2.48	1.28	0.2	1.52	2.48	1.92	1.56	0.92	2.76	3.12
	Select Classic FM preset	1.08	1.48	1.52	3.36	1.52	1.56	1.76	1.52	1.04	2.76	1.84
	Increase volume	0.88	1.12	0.72	1.2	1.12	0.96	1.16	1.56	0.68	0.32	0.88

Table 7.42. The maximum glance duration for each participant when performing all ICE tasks

There were significantly greater longest glance durations for the baseline system with nine unsafe glances made to the baseline system compared to the two unsafe glances made when using the PTI.

7.5.6.4 Conclusions for the ICE array

The difference in maximum glance durations and the comments from the participants indicate that the ICE array was too far rearwards in the car and more difficult to view than the other two arrays. The participants stated that were happy with the locations of the navigation and HVAC arrays, which could be seen much more easily. This is discussed in more detail in section 8.2.2. The relatively poor performance of the ICE array was unexpected as the ICE array contained commonly used tasks in a form that was strongly stereotypical of entertainment controls. The results have shown that participants prefer to be able to easily see the controls that they are interacting with.

7.6 Chapter summary

The aim of this thesis was to determine if the tactile sense can be used to reduce the amount of time that the user spends with their eyes off the road when interacting with secondary in car functionality. Non-visual interactions were performed by all participants at least once when performing seven of the eleven tasks on the PTI system. There were no non-visual interactions for the baseline system.

Non-visual interactions for the PTI	Subject No. 1	2	3	4	5	6	7	8	9	10	11	No. of non-visual interactions	% that performed non-visual interaction
Change airflow												8	73
Select stored destination												5	45
Increase fan speed												5	45
Select Classic FM preset												4	36
Increase volume												4	36
Select CD track 7												3	27
Zoom map view												3	27
Turn off air conditioning												0	0
Select CD mode												0	0
Select radio mode												0	0
Select map view												0	0

Table 7.43. Evidence for non-visual use of the PTI with the tasks ranked in the order of non-visual interactions

The project aim also included the benchmark of a 10% reduction in glance duration for the PTI when compared to the baseline system. This was achieved for all three of the navigation tasks, two of the three HVAC tasks, and two of the five ICE tasks.

The ranking of the number of non-visual interactions shown in table 7.34 shows the most successful tactile features in the PTI design. The following chapter discusses these results in further detail and shows a list of recommendations for tactile interface design that have been collated from the three studies and the literature.

8 Chapter 8: Discussion

8.1 Introduction

The following chapter discusses the design process that has been used to produce the PTI, followed by an analysis of the device to determine which features were successful and which features were unsuccessful. This is followed by sections which discuss the answers that have been generated to the research questions that were defined at the end of chapter 2. These discussions result in a set of design recommendations, and recommendations for further studies. These recommendations have been collated and combined with other lessons learnt from the PTI design process. The result is a set of generic guidelines for the design of interfaces that aim to reduce visual load on the user.

8.2 The methodology used to design and assess the PTI

The BIONIC project aimed to produce a working prototype of an interface that allowed the operation of a range of secondary in-car tasks, (from activating the air conditioning to entering a navigation destination) utilising tactile coding as a method to reduce visual load on the driver. This approach had advantages and disadvantages in terms of the recommendations that can be inferred from the resultant design. The PTI interface is a specific example of a design that exploits a combination of location coding, button shape, and mounting structure shape. The reason for the success or failure of a particular design feature is therefore difficult to ascertain, due to the number of design features that are contributing to that success. However, by examining the successful and unsuccessful design features in terms of non-visual interaction it has been shown that design recommendations can be generated as discussed in section 8.2.2. The design of the PTI has been based upon a variety of inputs, from small fitting trial exercises, to recommendations from the literature.

The follow section discusses the approach that has been taken in the design of the PTI, by describing the key stages of the design process and potential alternatives for these process steps.

8.2.1 The key stages of the PTI design process

8.2.1.1 Literature review

The literature review highlighted previous work that explored the concept of using the tactile sense to reduce visual load in safety critical situations. The tactile coding built into the control knobs of the machinery shown in Figure 8.1 was specifically designed to allow non-visual use. Other examples of design for the tactile sense were found that related to products to be used by visually impaired people (see section 2.4.3). There were no mainstream examples of design for the tactile sense and no literature that specifically describes the variables that must be considered when undertaking a design exercise as described in this thesis.

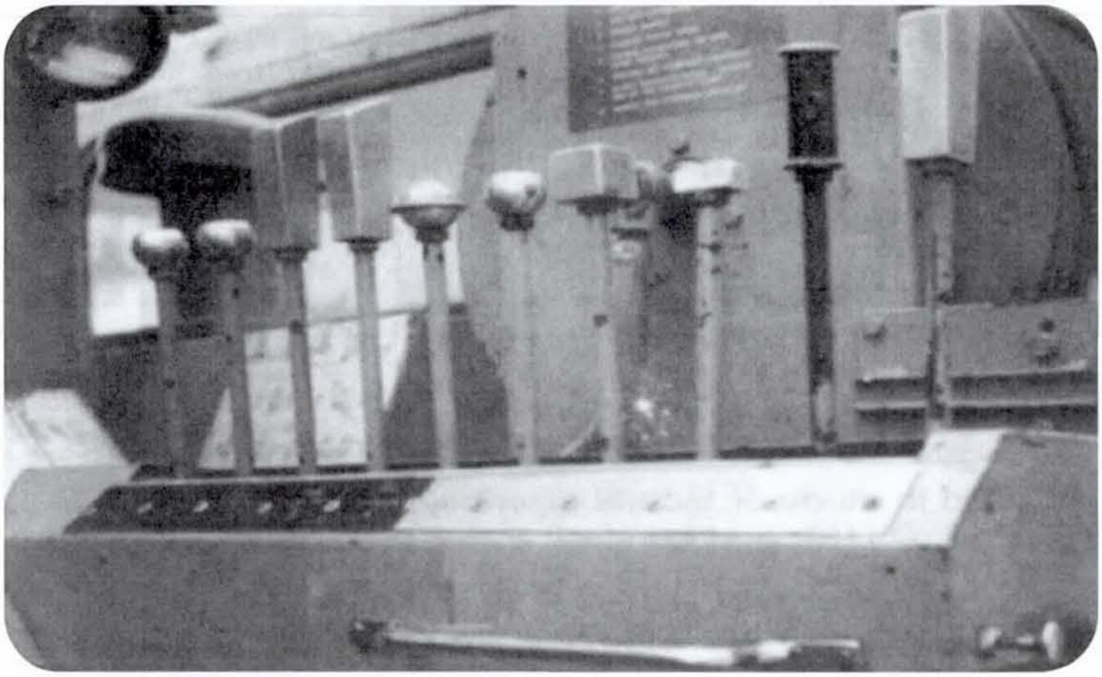


Figure 8.1. A previous use of tactile coding to allow control identification

The exploration of the literature that describes the limitations of the tactile sense was more successful and a number of key concepts were defined (see section 2.4.2). These were,

- The use of the finger tips as the area designed to receive tactile input
- The definition of two kinds of tactile interaction, active and passive
- The inherent link between the visual and tactile processing by the brain
- The need to design within the processing capabilities of nerve afferents

These concepts supported the production of the protocol for the assessment of products for use by visually impaired people in the study described in the next section.

8.2.1.2 The study examining the use of tactile coding by visually impaired people

The literature provided baseline information that allowed an understanding of the opportunities and limitations of the tactile sense, but it did not reveal information on the behaviours that are associated with the use of the tactile sense to interact with objects. It was anticipated that observing visually impaired people as they interact with familiar and unfamiliar products would highlight good and bad examples of tactile coding. The study was designed and performed in the first year of the project and proved to be highly illustrative (see section 3.3). The key findings of the study were as follows;

- The use of stereotypical control layout and modes of operation are crucial to allow the non-visual use of controls
- Subdivision of control panels using tactile features aids recognition
- The use of HCRP (Hand Control Reference Points) allowed visually impaired people to 'navigate' the control panels that were built into products that they owned
- The device should be visible to the user to aid conceptualisation
- Low levels of modality should be employed in a design process that aims to foster non-visual use

The information gained from the study combined with the literature review findings to create the design specification for the first PTI prototypes. The interaction with the visually impaired participants was a valuable process. However, the results from the study required careful consideration. The behaviours exhibited by the visually impaired participants varied according to the level of impairment. The initial exploration of the unfamiliar electronic equipment showed that people with no vision performed an evaluation of the overall size of the device, and then worked their way in to explore the finer detail of the control panel design and the mode of operation of the individual controls. The participants with some visual capability would spend much longer performing the initial product inspection, using the level of vision they had to explore the shape of the controls and the general layout. It was assumed that the general population would exhibit behaviour similar to those participants that had some form of visual capability, i.e. would attempt to look at the controls that were being interacted with. With hind sight, it would have been useful to perform the same study with people that have no visual impairments. If the same portable music player had been presented to none disabled blind-folded participants, the use of stereotypical control interaction and the methods used to determine the overall layout, could have been compared to the those used by visually impaired people, and the recommendations from the study could have been validated. However, the extent to which the participants in the simulator study and the final 'on the road' study engaged with the tactile coding and stereotypical use of controls validated the recommendations derived from the study with visually impaired participants. (See section 9.2.2.).

8.2.1.3 The exploration of active tactile feedback

The next stage in the design process involved the exploration of the active and passive models of tactile interaction. The active feedback methodology considered was a pin matrix symbol presentation mechanism. This was explored for a short period of time as it was quickly recognised that users would be unable to use a system that relied entirely upon the use of active tactile symbol usage to interact with all of the potential functions that the PTI would contain. As the development time and costs were considered prohibitive for the production of a suitable pin matrix display prototype, it was decided to focus on the use of the passive mode of tactile interaction. This was a key point in the PTI design process. The use of passive tactile feedback such as the use of conventional controls combined with tactile coding of the surrounding structures was seen as a more appropriate and achievable goal. There was other supporting evidence for this approach. At the time, the use of active tactile feedback was seen as a highly modal approach, with different tactile feedback potentially informing the user of the current mode, and state of that mode. The study examining the capabilities of visually impaired people highlighted multifunction controls, with modal feedback provided through the use of visual displays, as a cause of difficulty for participants with little or no vision. The non-modal approach taken in the design of the PTI was therefore seen as appropriate. However, an examination of the use of active tactile feedback for use in the automotive environment still has potential in specific circumstances where there is a stereotypical model to follow. When the design of tactile symbols was considered, it was noted that the coding that would be most readily accepted by users would be that relating to navigation information. The potential to provide direction of turn information through an active pin matrix display is discussed in greater detail in section 9.2.4.

8.2.1.4 Design process: Passive tactile concepts

With a passive tactile structure defined for the design of the PTI, the process of function selection was carried out in parallel with a number of concept generation exercises (see section 5.2). Functional arrays were defined and prototype designs were tested to determine the appropriate size for each control array and the integrated hand rest. The SAMMIE human modelling system was used to define suitable control locations, and a prototype design was generated for testing. This stage of the process was driven by the constraints of the Honda Civic interior, as supplied as the test vehicle by Honda R&D.

As discussed in Chapter 5, and shown in Figure 8.2, the Honda Civic interior proved to be a challenging environment for the addition of secondary controls. The gear stick is mounted in a higher position than conventionally designed cars, with the design intent of providing an open feeling to the cabin of the vehicle. The design deliberately included the void below the gear stick to give a feeling of space.

Figure 8.2. The interior of the 2001 Honda Civic, showing the unusual gear stick location that occupies the 'hot zone' for reach in the vehicle.

The analysis of the Honda Civic interior in SAMMIE showed that the position of the gear stick had been very well designed, with a full range of users (5^{th}%ile Japanese female - 99^{th}%ile US male) being able to comfortably reach and operate the gear stick.

The SAMMIE analysis also emphasised the limited space that was available in the vehicle for adding control panels that can be easily reached and viewed. The location of the ICE array, at the rear of the identified available space, was found to be too far rearwards and potentially difficult to view. This was highlighted by the fact that the ICE array showed no significant differences in maximum glance duration when compared to the baseline system, whereas the SATNAV and HVAC arrays (which were further forward in the vehicle and easier to view) produced longest glance durations that were significantly shorter than the baseline system.

It is likely that these difficulties would not have arisen if a more standard vehicle layout had been used in the design of the PTI. Figure 8.3 shows two possible configurations for the PTI arrays mounted on a standard dash configuration with the gear stick mounted in the usual location. These locations would have allowed a more direct comparison between the PTI and Baseline interface, with the screen and PTI arrays effectively being collocated for both systems. Conversely, the Baseline interface could have been lowered in the car to provide a more direct comparison to the PTI system. However, this would increased glance durations to the screen and controls (with larger movements of the head and eyes being required) and would not reflect current in car layouts, which was the aim of using a baseline system. Ideally, the design process for the PTI would have involved the production of a fully flexible dash board and gear stick position that could support a variety of suitable locations, for ease of viewing and reaching the PTI arrays. However, this would have required financial and time commitments that were not possible within the constraints of the project brief.

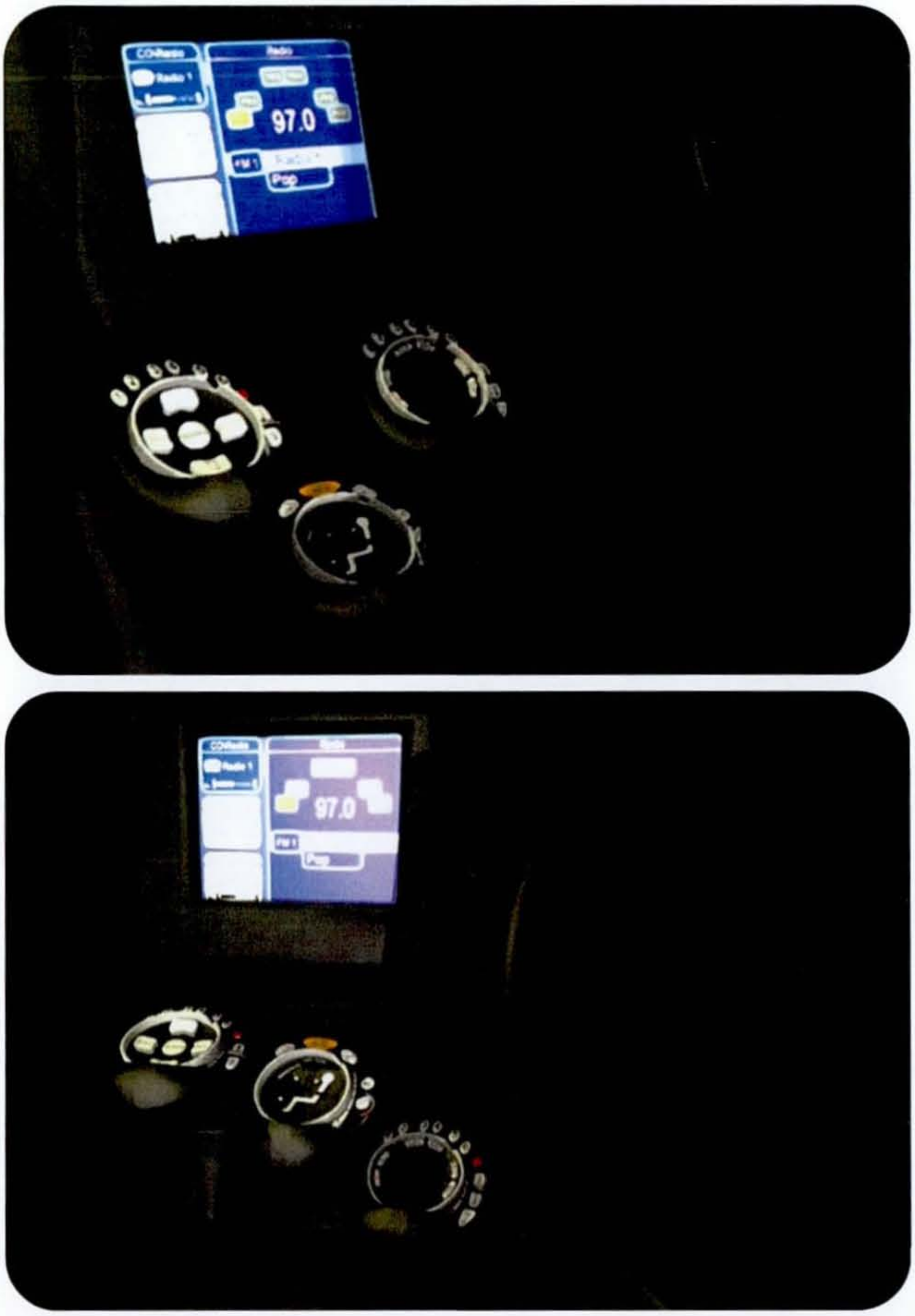


Figure 8.3 A possible configuration of the PTI arrays in a car with a standard dash layout

It is highly likely that the designs shown above would allow a full range of user sizes to be able to reach and view the control arrays comfortably. It should be emphasised that the form of the arrays is specific to the Honda Civic interior, and would have taken a different form if a car with a standard dash layout had been provided by Honda R&D. The form of the PTI design is discussed further in 9.2.2.

8.2.1.5 Simulator study

The testing of the first full prototype with a driving simulator was an extremely valuable process (see section 5.6). The study highlighted the tactile features that were readily accessed by the participants, and also showed that some tactile features did not allow enough discrimination. The trial run in which the user's vision of the controls was blocked highlighted that the tactile coding could allow non-visual access to the controls with the correct control being selected by touch alone in more than 90% of the control selection tasks. As discussed in the previous chapter and in section 8.2.2, the ICE array was identified as being too far rearwards in the car during the user trials. It was the successful non-visual use of the ICE array in the simulator trials that seemed to validate the decision to place the ICE array. This has been shown to be incorrect due to the need of users to be able to see the arrays to allow conceptualisation. Apart from this the simulator study was highly appropriate. The testing established that users were able to correctly identify functions without promoting, as demonstrated by the results of the 'guess-ability' phase (see section 5.7) and that they also engaged with tactile coding to allow non-visual of controls. This was a key finding from the study that was also found in the final 'on the road' study.

8.2.1.6 Design Process: Building a working prototype

The creation of the high fidelity prototype was an extremely challenging process. The design changes that were suggested by the simulator study were combined and a completely new CAD model of the product was generated in the parametric CAD modelling program, Pro Engineer. This process alone took four months. This final CAD model included all of the switch gear, mechanical components and printed circuit boards that were required to allow the full operation of the functional arrays. These CAD parts were then produced using rapid prototyping technology, and integrated with printed circuit boards that were produced by the author. The only aspect of the design that was not built by the author was the software. The structure for the software was designed and passed to Visteon, who then paid for a working version of the software to be produced using a software development tool called ALTIA. This software linked with the electronic connections of the PTI through a data logger, providing on screen feedback of the control interactions. Development of the design from the post simulator study specification to a fully working prototype took a full year. The whole process replied upon the industrial design and ergonomics skill sets held by the author. It should be noted that the process of designing, building and testing a prototype tactile interface took approximately four man years to complete and required a multi disciplinary approach. However, by producing a high fidelity prototype it was possible to perform a direct comparison with a baseline system, which has provided evidence for the use of tactile coding to reduce visual load. A lower fidelity prototype such as the one used in the simulator study would not have been appropriate for a comparison with a baseline system due to the differing level of system feedback between the prototype and baseline systems.

8.2.1.7 Final testing of the PTI

The final testing of the PTI was performed by the Ergonomics and Safety Research Institute (ESRI) as prescribed by the EPSRC project brief. Although some of the data was lost, the final testing of the PTI has highlighted the benefits of adding tactile coding to arrays of controls, and provided evidence for the production of generic design recommendations that can be applied to the design of other products.

Three methods are used to assess in car technology according to the literature. The occlusion method was designed to reduce the cost and time that are associated with 'on the road' user trials, and is still considered controversial in terms of how accurately it represents the task of driving and using controls as the vehicle is always stationary. The second method, the use of driving simulators, is considered superior to the occlusion method as the task of driving is more accurately represented during testing, however, differences in driving style and visual accommodation have been shown when compared to driving on public roads in the literature. The 'gold standard' is still considered to the third method, 'on the road' trials. On the road user trials most accurately represent normal driving. The decision to perform testing of the PTI on public roads has provided the most realistic test of the new interface of the methods that are described in the literature.

8.2.1.8 Data analysis and results

The analysis of the video based data collected during the user trials was an extremely time consuming activity, taking 4 months to complete. The accurate measurement of glance durations and correctly associating each glance with the task being performed required a rigorous approach. Careful interpretation of the results was required. The use of glance duration data on real road conditions was recommended by the literature as being the most realistic and appropriate technique to use. From the perspective of the time and effort that is involved in this process it is clear why the occlusion method discussed in section 2.2.3.3 has become popular. The only other method that is currently available that has the potential reduce the analysis time of a study of this size would be the use of eye tracking hardware and software. Eye tracking systems have the potential to hasten video analysis to determine glance durations, and allow the experiment designer to see exactly where each participant is looking at any one moment. Two forms of eye tracking hardware exist (see section 2.2.3.2.). Those mounted into helmets that monitor the position of the eye ball, and those that use an external camera that monitors the combined head and eye location, producing estimates of gaze direction. Both systems produce video clips and telemetry data, with the helmet mounted system having the benefit of showing the direction of view from the helmet mounted camera, with a superimposed red dot indicating the centre of gaze, allowing the user to determine the current viewing target. It was anticipated that this capability would allow the analysis of the visual search method performed by each participant when looking for individual controls. This could have been highly informative in the analysis of the controls that were easily located, and those which were difficult to find. There have however been some issues identified after testing of an eye tracking system. Current eye tracking systems have to be carefully calibrated for each user, and the viewing distance for the visual target is set during this calibration. Some tests that were performed with a helmet mounted eye tracking system demonstrated that the accuracy of the eye tracking system was variable for vision targets that were close to the user in the Honda Civic equipped with the PTI. Effectively, the eye tracking system was not capable of accurately capturing eye movement for the range of positions required by the testing of the PTI. This would have added unacceptable error to the data produced. The experimental method used to test the PTI, and the subsequent analysis of the data was therefore performed as per the best practice described by the literature. This is discussed further in Section 9.2.2.

8.2.1.9 Summary of the PTI design process

The design process that has been used to create the PTI has been highly user centred and iterative. The design process has created an interface that has fulfilled the brief, and provided good evidence for the ability of users to engage with tactile coding. The design process could certainly have included further design iterations and studies that could have improved the results obtained if time and resources had allowed. The following sections discuss the successful and unsuccessful tactile features in terms of the fostering of non-visual interaction with the controls. Recommendations for further studies are inferred from these discussions.

8.2.2 The successful and unsuccessful design features

There are a number of PTI design variables that are assumed to have affected the differences between the glance duration data found in the PTI/Baseline comparison. These variables were;

- The functional grouping of the controls
- The layout of each functional group to aid conceptualisation
- The tactile coding built into the design

It is assumed that these variables were associated with the reduced glance durations that were fostered by the PTI, when compared to the baseline interface.
The process of unpacking the results has relied upon the fact the PTI fostered non-visual interactions with some controls, and not others. The non-visual use of controls is proposed as a strong indicator for the potential to reduce eyes-off-road time. With hind sight, other approaches could have been taken. If time and resources had allowed, it would have been beneficial to include further iterations of user interaction with tactile structures earlier in the project. For example, a number of controls in the PTI interface did not foster non-visual interaction during the 'on the road' study. This was potentially because there was not sufficient tactile coding to allow discrimination between all controls. Figure 8.4 highlights the mode switching buttons that were included in the ICE and SATNAV arrays. None of these four controls were used non-visually, presumably because the only coding technique that allows control differentiation is the label when identifying function.

Figure 8.4. Two sets of controls that were not used non-visually

Could this situation have been improved by using tactile coding with a finer level of detail? It is possible that by providing further tactile coding such as shape coding of the buttons shown in Figure 8.5, or by adding to the surface of the buttons, that improved tactile differentiation between the buttons could have been achieved. In the case of the ICE array buttons, tactile symbols could have been derived and tested that represent the CD and Radio modes. Example tactile structures for these functions are illustrated in Figure 8.5, with the left hand image showing the radio tacton (tactile icon), represented by a waveform, and the right hand image showing the CD tacton, represented by circle a with hole in the middle. The buttons shapes could directly replace those found in the PTI.

Radio tacton: Waveform CD tacton: Torus

Figure 8.5. Tactile icons that have the potential to aid discrimination between controls

By adding this iterative loop to the design process the design could have been improved. This point led to the definition of a research study as described in section 9.3. It is acknowledged that the tactile coding used in the design of the PTI is not sufficient to allow all controls to be differentiated non-visually in the relatively short time that the users were exposed to the PTI interface. The non-visual use of some controls relies upon the user building a mental model of the array structures and remembering the function that is associated with a particular location, shape and protrusion level of each control. The relatively short duration of the 'on the road' trial brings into question whether users would have assimilated the extra tactile coding that is being proposed above. Based upon the literature, one would expect the effects of age (reduced cognitive abilities, reduction in tactile sensitivity) to increase the time that it takes to build a mental model of the control layout that fosters higher levels of tactile interaction. This leads to the recommendation of a further study that examines the use of a the PTI over a prolonged period of time as discussed in section 9.3. By increasing the exposure period to the PTI device, do non-visual interactions increase and is this affected by the age of participants?

The HVAC and SATNAV functional arrays produced the most successful results during user testing in terms of reducing glance duration, the number of glances used and the maximum glance durations with significant differences being identified when compared to the baseline system. The ICE array raised some concerns amongst the participants in terms of its location. The location of the ICE array was specified in the SAMMIE system on the premise that the layout of the ICE controls would be most easily recognised of the three array designs, and therefore would not require as many glances to be operated. The analysis of head and eye rotation to allow vision of the arrays indicated that the ICE array location would be suitable. Also, Figure 8.6 shows the use of the peripheral vision contour to establish the rear most useable location in the Honda Civic interior. The assumption for the location of the ICE array was that the simplicity of the layout would require little visual interaction. This assumption seemed to be validated by the results found in the simulator study, discussed in Chapter 6 section 2. The results from the simulator study showed that when allowed to look at the controls, the participants correctly selected 96% of the controls. When the participant's vision of the arrays was blocked, they still completed 92% of the tasks successfully. This indicated that the tactile coding was working successfully, and that direct vision was not required after only a short period of time. However, during the on road study, the ICE array performed relatively poorly when compared to the HVAC and SATNAV arrays, with comments made by the participants indicating that they would prefer to be able to easily view all of the controls. This was illustrated by the lack of difference between the baseline system and the PTI in terms of maximum glance duration for the ICE functions. The HVAC and SATNAV arrays produced a significant difference in maximum glance duration. The mismatch of results between the simulator study and the 'on the road' study is interesting. There have been a large number of studies examining the level of fidelity offered by different driving simulators when compared to driving on real roads.

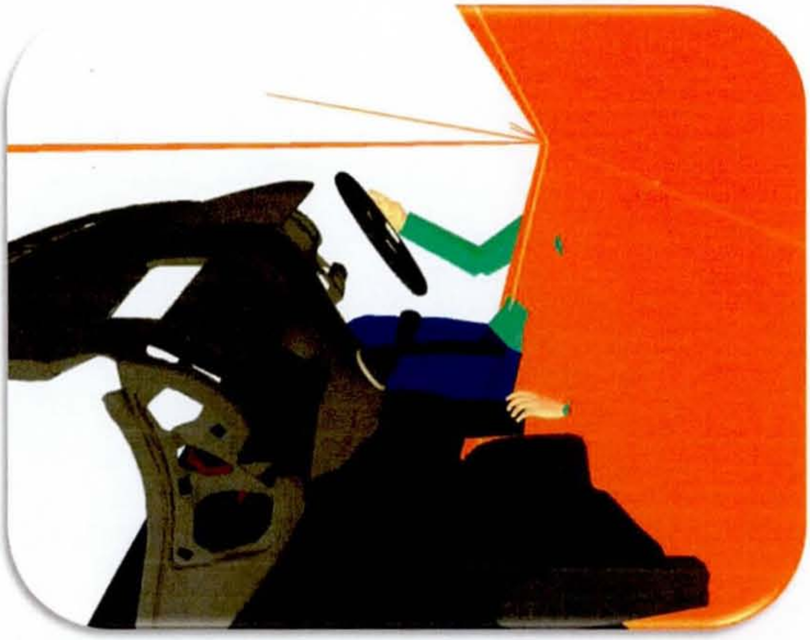


Figure 8.6. The hand, in the location required to access the ICE array, is shown to be in front of the contour that represents the limit of peripheral vision

There have been significant differences noted in speed, speed variation and lane keeping (Harms et al, (1996), Blauww (1982) among others) between real and simulated conditions. In terms of the position of the ICE array this may indicate that users were less concerned about the ICE array location in a simulator study, where there no real risk produced by looking into the car. However, the main difference between the driving simulator and 'on the road' studies was that the last run in the simulator study forced users to perform non-visual interactions by use of the screen that stopped users looking at the arrays.

The study that examined the use of electronic equipment by visually impaired people described in Chapter 3 indicated that the compulsion to use even very limited visual capabilities was strong in participants. The evidence from the 'on the road' study indicates that this is true for people without visual impairment also. This, combined with the literature forming the link between the visual and tactile senses, hinted that all controls should be easily seen by all users. The design process assumption that users would interact with the tactile coding of the ICE array, as the previous participants had in the simulator study, was incorrect.

This indicates that there is a threshold head and eye movement used to allow controls to be seen, beyond which the length of glances required to view a location are increased beyond the 1.82 second threshold used in the assessment of the PTI. This creates a tension in a design process that aims to produce a product that is to be interacted with by vision and touch. The control surfaces must be within comfortable reach, to enable prolonged tactile interactions without causing discomfort, and must also be viewable by the participant, at least during acclimatisation to the interface design, so that a visual model of the layout can be developed. This finding indicates that a further study could be performed that would examine various possible control locations in an automotive environment in terms of view-ability and reach-ability as discussed in section 9.3. It is presumed that there is a combined head and eye angle threshold, as the user looks away from the road, beyond which users feel uncomfortable.

The elements of the PTI design that were most successful in terms of fostering non-visual interaction are discussed in section 8.2.3.1. This section shows how the four tasks that fostered the most non-visual interactions amongst the participants, also showed significant reductions in glance duration and no. of glances. These tasks have been used as the basis for the design recommendations discussed in section 9.2.3.1, combined with other recommendations derived from the literature and the interaction with visually impaired participants.

8.2.3 Research question 1: Can the tactile sense reduce the visual load on the driver with a suitably designed interface?

The literature indicated that a period of time is required to acclimatise to a tactile interface, with successful non-visual interaction relying on the user conceptualising the structure and functionality of the design (see section 2.4.2). The length of the total user interaction with the PTI interface during the 'on the road' study was approximately one hour. However, it was anticipated that there would be little evidence of non-visual use of controls based upon tactile interaction. It was anticipated that the functional grouping and layout of the controls would lead to reduced glance durations when compared to the baseline system. The user trials demonstrated that non-visual use of controls was performed by all participants with at least one control type, combined with reductions in glance duration for a number of tasks. The following sections discuss the controls that were successfully used non-visually.

8.2.3.1 The controls that were used non-visually

The definition of a non-visual interaction used in this thesis is described as any PTI control interaction that is performed without the user looking at the arrays. This included glances that were made to the screen of the PTI that were made during control interactions, as these were associated with the user obtaining feedback such as the correct track number in the 'select CD track 7' task. The definition of a non-visual interaction was specified in this way as it was considered important to examine control interactions that used only the tactile coding of the PTI arrays for control selection, as these were considered to be an indication of good tactile design. This definition of non-visual interactions cannot be applied to the baseline interface as glances made to the baseline system could not be separated from those that are related to finding the correct control, and those related to obtaining feedback from the screen. However, there were no tasks performed on the baseline system without direct vision of the interface. The PTI controls that were successfully used non-visually during the 'on the road' user trials were the air flow direction, use of presets for both the navigation and ICE arrays, the use of the rotary bezel for both the HVAC and ICE arrays, and the zoom map view controls as shown in Figure 8.7. The figure also shows that all but two of the tasks associated with these controls showed a significant difference in glance data between the PTI and baseline conditions. The glance duration data can be seen as a measure of how successfully control panel designs allow the user to find the correct control. The summed glance duration and number of glances should be seen as a measure of how long it takes to perform the task. The following sections describe the features shown in Figure 8.7 and the design recommendations that have been derived.

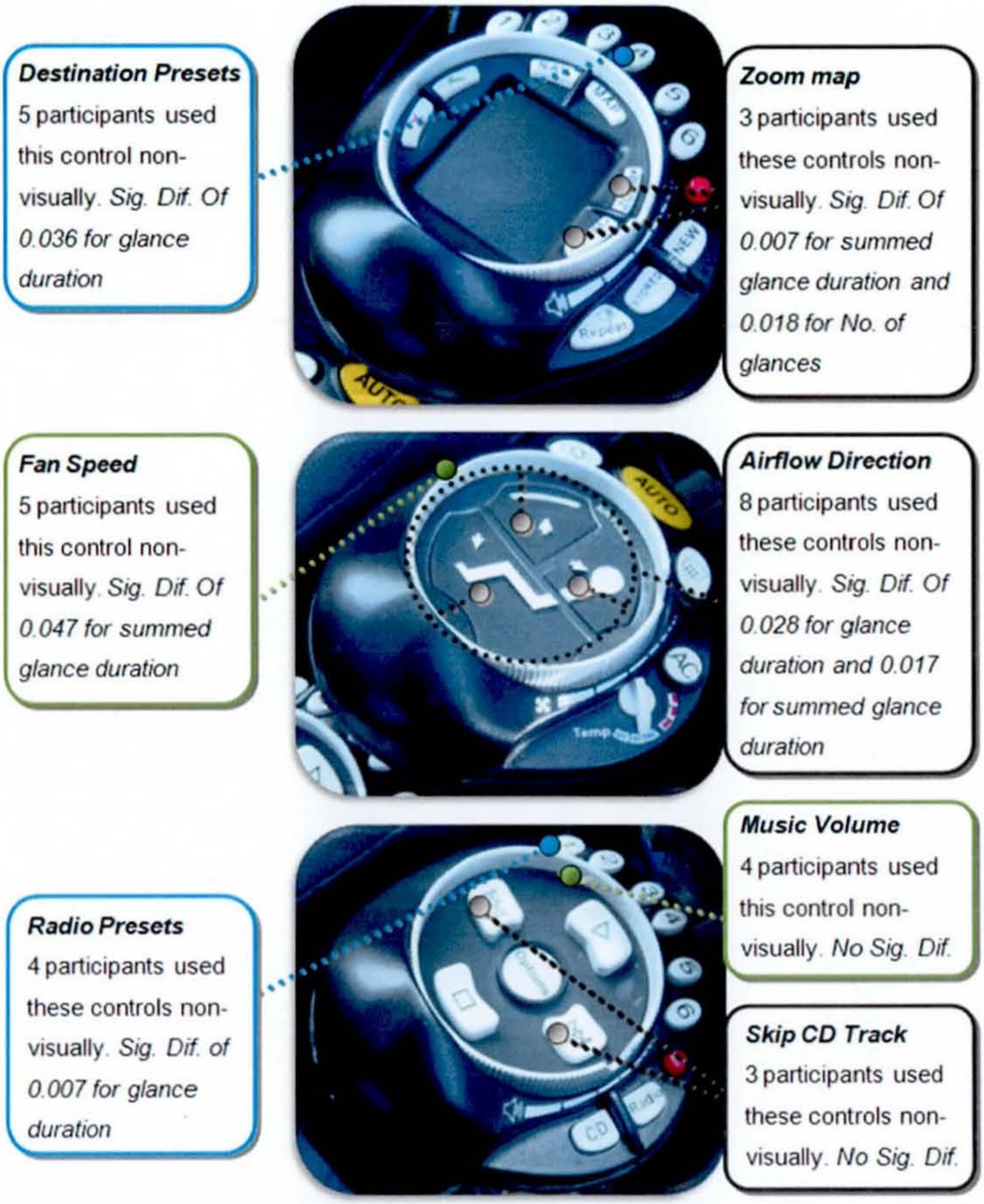


Figure 8.7. The controls that were used non-visually in the on road trial

The non-visual use of the airflow controls

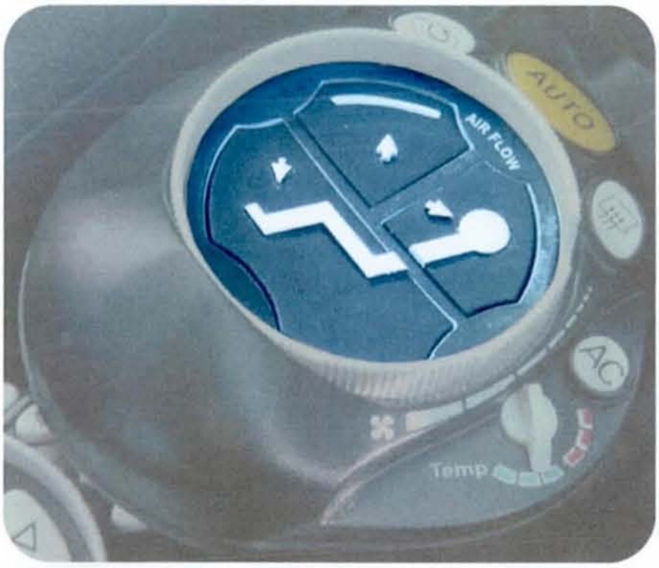


Figure 8.8. The airflow direction controls

The most successful control design was the airflow direction array, allowing the airflow to be directed to the windscreen, face and feet in any combination of the three options. Eight of the eleven participants used these controls non-visually during the completion of tasks that require the selection of specific airflow settings, including multiple interactions. The symbol used to represent the different airflow directions is standard in many car interiors, and was presumed to be easily recognised by users, as demonstrated by the correct identification of function on all occasions in the 'guess-ability' phase of the study. This, and the size of the symbol, combined with the easily viewable location are assumed to have contributed to the high levels of non-visual use. The airflow direction controls also provide a link between the tactile and visual coding, with the three buttons being surrounded by the inner wall of the fan speed control. The relatively large airflow buttons, located in the quadrants of the circular panel were easily identified and used by the participants. This leads to the first two design recommendations that can derived from the controls that fostered non-visual use.

> ***Design Recommendation 1**: An interface that uses tactile coding with the aim of reducing visual load should allow the users to conceptualise the layout by being able to easily view all controls*

This design recommendation is derived from the high levels of non-visual use demonstrated for the airflow direction controls, and the relatively poor performance of the ICE array during the 'on the road' trial, as demonstrated by the participant comments regarding its position. The recommendation to allow users to view the controls with ease is inherently linked to the second recommendation regarding a link between the visual and tactile coding of controls.

Design Recommendation 2: *The tactile and visual model of the controls should be linked.*

The premise of an inherent link between the tactile and visual senses discussed in the literature review (see section 2.4.2.1) has been supported by the results of the PTI testing, as demonstrated by the strong non-visual performance of the largest single control array, directing the airflow. Other examples below also support these design recommendations.

The non-visual use of the fan speed and volume controls

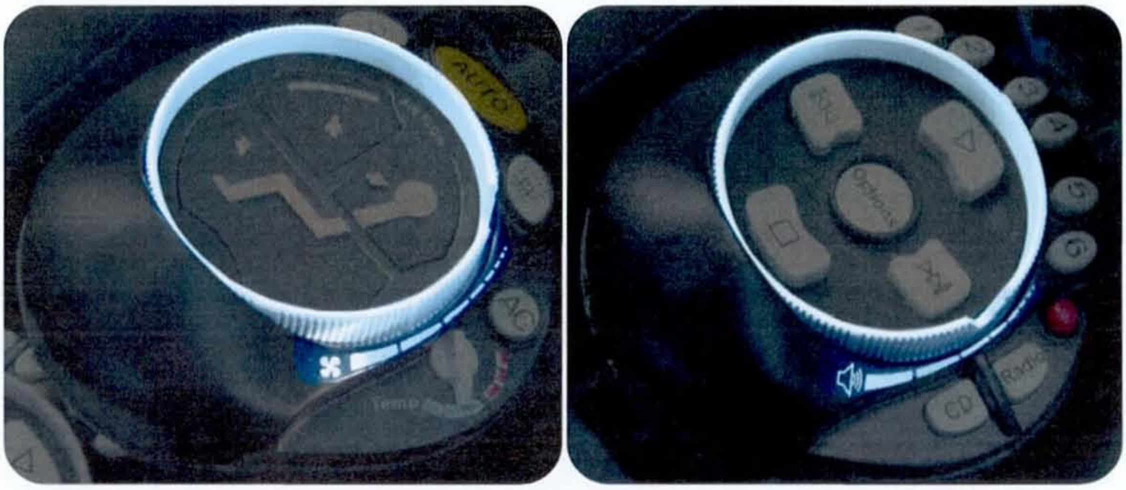


Figure 8.9. The rotary bezels that control the fans speed and the ICE volume level

The fan speed and music volume (the same control type on two separate functional arrays) fostered non-visual interaction by 5 and 4 participants respectively out of the 11 tested. As with the airflow array, the white bezel used to control the volume and fan speed variables was a strong visual and tactile feature, subdividing the control panel. This supports the first and second design recommendations, and illustrates a third. The design cue taken from the summary of tactile design issues by Perera, S. (2002) recommended protrusion levels of 5mm between two surfaces that are to be differentiated. This recommendation was based upon work examining the differences in thresholds of tactile discrimination between younger and older people. The 5mm limit was used wherever possible in the design of the tactile features of the PTI. An example of this is that the top of the bezel used to control the fan speed and the volume is 5mm above the panel on the inside of the circle.

***Design Recommendation 3**: An interface that uses tactile coding with the aim of reducing visual load should be subdivided into appropriate functional groups.*

***Design recommendation 4**: Where ever possible, the step height between two surfaces that are to be differentiated should be 5mm.*

The non-visual use of the preset buttons in the SATNAV and ICE arrays

Figure 8.10. The preset keys used to select radio stations and navigation destinations

Figure 8.11. The 5mm high dividers used to separate groups of two preset buttons

The radio presets and destination presets (the same control type on two different arrays) fostered non-visual interactions by 5 and 4 participants respectively of the 11 tested. Participants were observed using the tactile coding that divided the 6 preset radio station preset buttons into clusters of two (see Figure 8.11). Participants also used the edge of the rotary bezels that control the navigation voice volume, as a guide when selecting specific navigation destinations using the preset keys on the SATNAV array. This was an unforeseen use of the tactile coding, and illustrates the differences in preset location between the two functional array locations. This has led to a further design recommendation.

> ***Design Recommendation 5**: When a number of controls are associated with each other they should be subdivided using tactile coding and spacing to provide distinct interaction points. Any included ordering of the controls e.g. the radio preset buttons in the ICE array, should be demonstrated through tactile and visual coding*

The non-visual use of the skip track buttons

Figure 8.12. The skip track buttons

The skip track buttons were used non-visually by 3 of the 11 participants. This was done without looking at the array, during the select CD track 7 task (see section 7.5.2.4). The use of these controls non-visually is in line with the use of the airflow direction controls. The participants used the edge of the volume bezel to located the skip forward and skip back buttons. The layout of the controls was seen as highly stereotypical when compared to other entertainment systems.

8.2.3.2 Summary for the controls that fostered non-visual interaction

The fact that these controls were used without vision indicates that the tactile and visual coding that was incorporated into the PTI design were successful in terms of Research Question 1. i.e. it is assumed that non-visual interactions allow the user to view the road ahead. These results demonstrate that controls can be designed to allow non-visual interactions and therefore can reduce eyes off the road time. This is a key finding of the thesis.

8.2.3.3 The tasks that showed reduced summed glance durations when compared to the baseline system

The results in the previous chapter showed that users with a range of age and gender engaged with suitably designed tactile structures to allow a reduction in summed glance duration. The summed glanced duration (the addition of all glances for each task) relates directly to the 'eyes-off-road' time. Table 8.1 shows the significant differences between the two systems for all tasks.

	Median glance duration			No. of glances			Summed glance duration		
	PTI	Base-line	Wilcoxon signed rank test	PTI	Base-line	Wilcoxon signed rank test	PTI	Base-line	Wilcoxon signed rank test
Select Map View	0.92	1.04	0.126	16	28	0.05	14.28	31.2	0.007
zoom map	0.9	1.16	0.139	36	58	0.018	39.2	74.08	0.007
Select Dest	0.96	1.14	0.036	119	123	0.838	129	163.92	0.07
Increase Fan Speed	0.9	1.08	0.06	17	26	0.096	15.72	32.64	0.047
Direct airflow	0.84	1.27	0.028	21	25	0.38	17.12	33.48	0.037
Turn off the AC	1.13	0.93	0.515	26	26	1	28.76	27.8	0.891
Turn on the CD player	0.96	0.84	0.333	18	32	0.023	23.92	34.56	0.241
Turn on radio	0.82	1.12	0.033	23	32	0.041	19.48	41.72	0.021
Select Classic FM preset	0.84	1.38	0.007	44	35	0.304	41.6	47.96	0.508
Increase volume	0.82	0.85	0.4	20	17	0.558	19.2	14.48	0.327

Table 8.1. The significant differences for median glance duration, number of glance and summed glance duration for each task

Six of the ten tasks produced a significant reduction in summed glance duration. Only two tasks produced an increase in summed glance duration for the PTI when compared to the baseline system. These tasks were 'turn on CD player' and 'turn off AC'. In both cases the buttons that operated these functions in the baseline system were separate from the rest of the controls and therefore easier to identify when compared to other baseline controls. Four of the 10 tasks produced a significant reduction in median glance duration with another approaching significance. Five of the tasks produced a significant reduction in 'number of glances'. Table 8.2 shows the percentage reduction or increase in Median glance duration, number of glances and summed glance duration for each task (Green cells indicate a reduction for the PTI when compared to the baseline system, grey cells indicate no change and red cells indicate an increase). These results show that the PTI surpassed the 10% reduction in 'eyes-off-road' time for seven of the ten tasks that were performed during the user trials. It should be noted that a reduction in summed glance duration, and therefore 'eyes-off-road' time greater than 50% was achieved for the 'select map view task', the 'increase fan speed' task, and the 'turn on radio task'. There were small increases in median glance duration for the 'turn off AC task' and the 'turn on CD player' task. The number of glances increased by 25% and 17% for the 'select classic FM preset' task and the 'increase volume' task respectively. There was a small increase in summed glance duration for the 'turn off AC' task, and a 32% increase in summed glance duration for the increase volume task. As discussed, the ICE array has been shown to be potentially too far rearwards in the car. Three of the four tasks that showed an increase for the PTI when compared to the baseline system were associated with the ICE array. The other increases were associated with the design of the air conditioning button, which, as discussed, had a prominent and separate location when compared to other baseline controls. The PTI air conditioning button was mounted in a prominent location, but was surrounded by more control clutter.

	Value and % reduction in Median glance duration	Value and % reduction in number of glances	Value and % reduction in summed glance duration
Select Map View	(0.12) 12%	(12) 42%	(16.92) 54%
zoom map	(0.26) 22%	(22) 38%	(34.88) 47%
Select Dest	(0.18) 16%	(4) 3%	(34.92) 25%
Increase Fan Speed	(0.18) 17%	(9) 35%	(16.92) 52%
Direct airflow	(0.43) 34%	(4) 16%	(16.36) 49%
Turn off the AC	(0.2) 17%	(0) 0	(0.96) 3.4%
Turn on the CD player	(0.12) 14%	(14) 44%	(10.64) 31%
Turn on radio	(0.3) 27%	(9) 28%	(22.24) 53%
Select Classic FM preset	(0.54) 39%	(9) 25%	(6.36) 13%
Increase volume	(0.03) 4%	(3) 17%	(4.72) 32%

Table 8.2. The percentage reduction in Median glance duration, number of glances and summed glance duration for each task (Green cells indicate a reduction for the PTI when compared to the baseline system, grey cells indicate no change and red cells indicate an increase)

8.2.3.4 Summary for research question 1

Research question 1 has been addressed by the PTI design, with a positive result. It is indeed possible to reduce the eyes-off-road time by using suitably designed tactile structures. The 'on the road' study has highlighted that improvements could be made to the design of the PTI in terms of the location of the ICE array, but has also demonstrated that it is possible to reduce the 'eyes-off-road' time by over half by using functional grouping, symbolic layout and tactile coding.

It should also be noted that the prevalence of portable SATNAV systems such as the TOMTOM and Garmin models that are currently available, could potentially lead to glance durations that exceed those fostered by either the PTI or baseline system due to the inherently small touch screen interface. There has been no experimentation performed examining the glance durations for common SATNAV tasks when using portable touch screen navigation systems. A further study examining this issue is recommended. The PTI design has demonstrated that tactile interaction can be used to reduce visual load, and a number of design recommendations have been derived. The following section describes the response to the second research question that was defined after the literature review.

8.2.4 Research question 2: What mode of tactile interaction is most applicable for the design of in car interfaces, active or passive?

In the literature review, the two options for modes of tactile interaction were defined as 'active' (moving the fingers over a static surface that provides shape and location coding) and passive (an active tactile display that changes its structure with the finger in one location). See Figure 8.13.

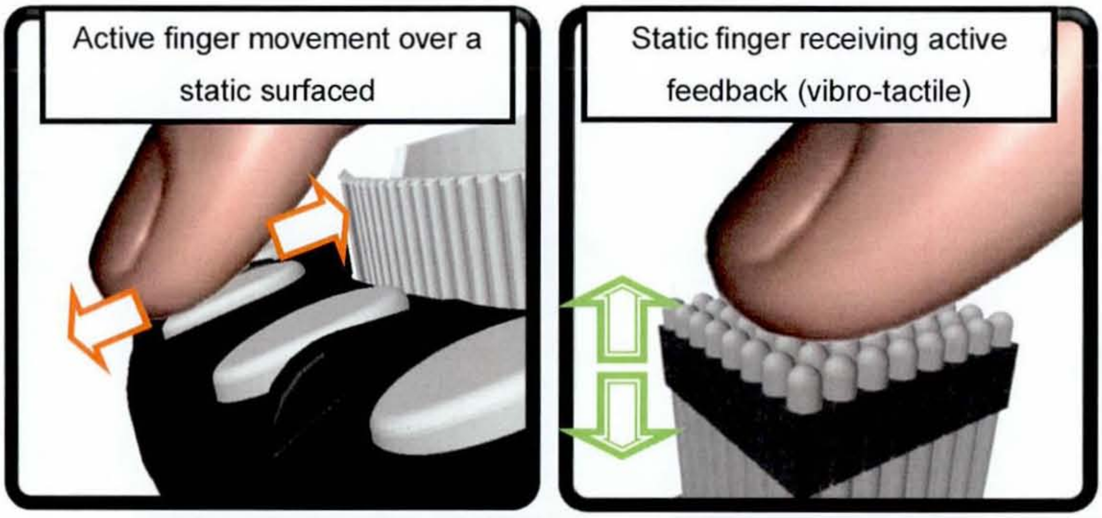


Figure 8.13. The two types of tactile interaction defined in the literature

In the context of the automotive environment it was decided early in the project that it was inappropriate to design a system that relies entirely on an active tactile display that would require the user to learn different tactile symbols. This was based upon a series of scenarios that were generated in brain storming sessions, including the 'hire car at the airport' scenario as discussed in Section 4.51. The PTI was therefore designed to encourage the user to actively scan the control surfaces with the finger tips to allow control location and function to be determined. Further reflection on this issue has highlighted the potential benefits of combining the active and passive modes of interaction as discussed in section 9.3 and shown in Figure 8.14.

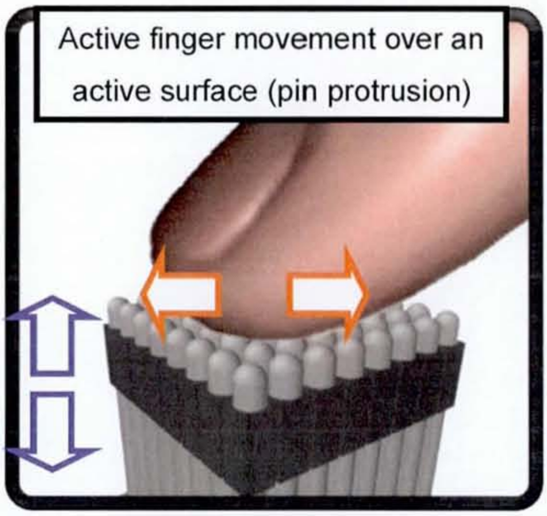


Figure 8.14. An example of active tactile feedback that could be used non-visually in an automotive environment.

8.2.4.1 Summary for research question 2

There is potential for both active and passive modes of tactile interaction, and active and passive tactile feedback, to combine. The evidence from the design of the PTI and the literature would indicate that passive interaction alone (with an active tactile display or vibro-tactile display) would be unsuitable for the level of feedback that is required by the user, and the training time required to familiarise with the tactile icon designs. Active tactile exploration of a static tactile surface as demonstrated by the PTI design has been shown to be successful in reducing glance duration and fostering non-visual interaction. In hind sight the research question should have been ' How can the active and passive tactile exploration methodologies combine with active and static modes of tactile information presentation?'.

In answer to Research question 2, both active and passive modes of tactile interaction are possibly appropriate for the automotive environment. If one had to be chosen, active exploration of static tactile surfaces, combined with a strong visual image for the control layout, has been demonstrated as a viable option.

8.2.5 Research question 3: Can the experiences of visually impaired people help with design of the tactile device for use by people without visual impairment?

The experience of visually impaired people influenced the project in a number of ways. The conclusions that were drawn from the study described in Chapter 4 influenced the design of the PTI in the following ways:

- The methodologies used for initial product interaction
- Adaptations to existing controls to reduce the number of functions
- Exemplar of active tactile interaction demonstrated by users tracing the shapes built into the device
- The use of HCRPs in the navigation of control panels

These issues were at the core of the design process that the produced the PTI in that the PTI was subdivided to allow the exploration of each functional group with one hand, which is stabilised using a consistent hand rest (HCRP). The number of functions were kept to the minimum number possible whilst the vehicle is in motion. The controls and their mounting structures produced distinct tactile experiences that helped to allow control identification. In answer to the question, the experience of visually impaired people informed the design process to produce a reduction in 'eyes-off-road' time and to foster non-visual interactions by people without visual impairment.

8.2.6 Was the baseline system an appropriate comparison to the PTI and to current in car technology?

The 'on the road' user trials were performed in 2005/2006, with the baseline and PTI systems. At the time of writing (Summer 2009) the use of in car technology has expanded considerably since the start of the BIONIC project (2001).

This raises the question of the validity of the baseline as a comparison to current in car technology. Automotive manufacturers still produce OEM navigation systems that combine with the HVAC and ICE functions. There are still numerous examples of OEM navigation systems that use a combination of screen based controls and physical buttons for specific functions in the same way as used in the control of the baseline system (see Figure 8.15). Screen sizes have increased, allowing better readability of text of graphics, but in many respects the design of current in car technology incorporates the same modes of interaction that are required to operate the baseline system. i.e. the use of physical buttons combined with functions presented using an LCD screen. The baseline system is therefore considered to be a valid comparison reflecting current interaction methodologies.

Figure 8.15. The baseline system (top image) and a current design (2009 Nissan Altima)

A trend that was not foreseen at the start of the BIONIC project was the advent of small, portable, aftermarket navigation systems such as the units shown in Figure 8.16 which are now ubiquitous in the driving environment.

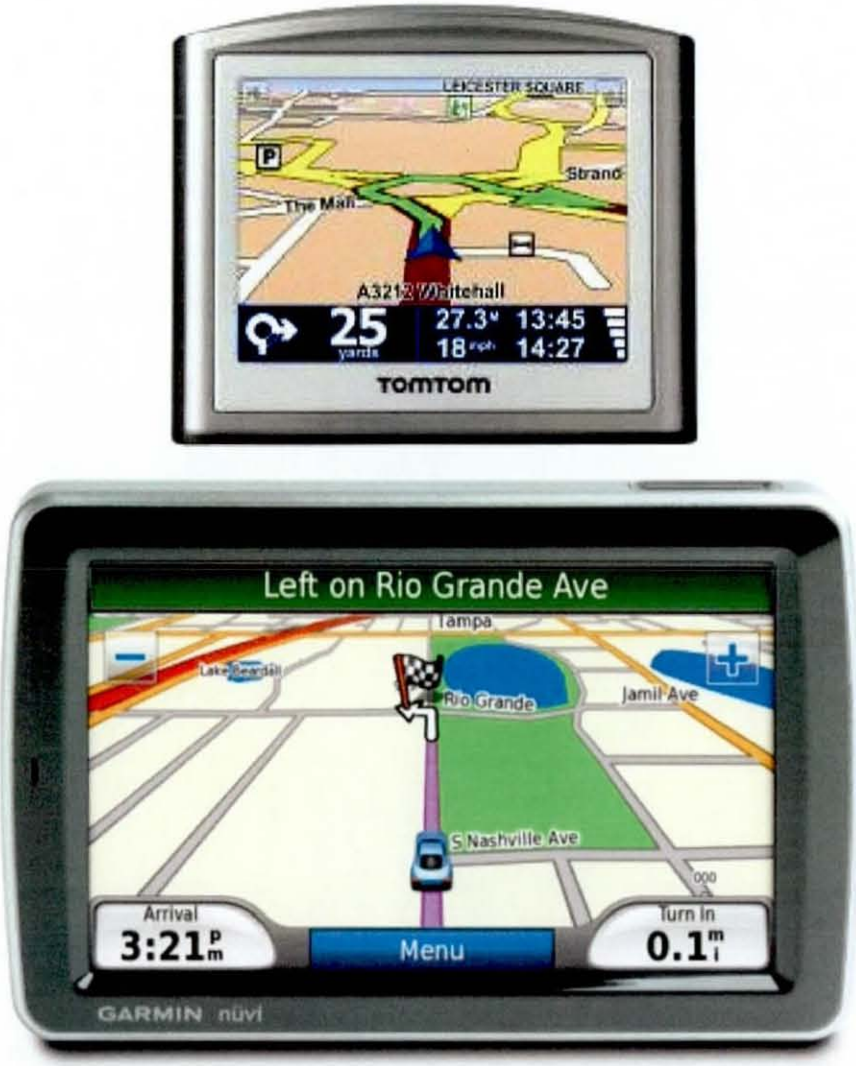


Figure 8.16. Budget (top image), and high end (bottom image) portable navigation system with a 3 inch and 4.2 inch screen respectively

Figure 8.17 shows an example navigation system (Tomtom V6, running on a Windows based smart phone with a 3.5 inch screen) with a touch screen interface. The requirement to attach the device to the windscreen produces viewing distances equivalent to those of the binnacle instruments, but with smaller text sizes available on the navigation system screen. This raises the comparison between the PTI navigation system and the aftermarket touch screen navigation systems that are prevalent today. The range of screen sizes currently available for portable navigation systems ranges from 3 inches to 5.2 inches, making it potentially difficult to read information on the screen whilst driving.

Figure 8.17. An example of the on screen keyboard used in current portable navigation system (example shown Tomtom v6 running a Windows based smartphone with 3.5 inch screen)

Also, all of the functions of portable navigation systems are accessed through the touch screen. This removes any of the location coding that may be used to find controls without using vision. Indeed, all tasks require the user to look at the screen. With this in mind, it is highly likely that the PTI would have been superior to portable navigation systems due to the use of tactile coding that was evident in the behaviour of participants during the final 'on the road' trials.

8.2.7 User trial issues

As discussed in Chapter 5 the 'on the road' study was designed and performed in conjunction with ESRI at Loughborough University. This was part of the BIONIC project work plan and organisation. An analysis of the data gathered that was subsequently performed by the author highlighted a number of experimental errors that were made during the assessment. These involved video tapes running out before the completion of the final user trial run. Some of the tasks that were designed with ESRI were also arbitrarily changed by a junior researcher during the user trials, with the effect of increasing task times and user frustration considerably. The effect of these errors was to reduce the usable sample size from 16, to 11 subjects. A sample size of eleven subjects still provided enough data to provide a valid comparison between the two conditions in a statistical sense. This is based upon the literature review performed by Blana, E. (1995) that examined the number of subjects that are commonly used in 'on the road' and driving simulator studies. The lowest number of participants was found to be 7, with a mean value of 20. Also, the results found in the 'on the road' study match well with the results found in other studies in terms of median glance duration and longest glance duration data. This would indicate that the sample size was sufficient. The errors that were found in the users trials have been carefully balanced in the analysis. Where video data for the last trial run was absent for any participant, this participant was removed from the analysis. Generally the tape problems occurred during the last run on the A50 road. It could have been said that the first practice run data could have been used. But with the limited exposure time to the two interfaces this was considered inappropriate. Where tasks were to be removed due to experimental error, such as the fade/balance task, these tasks were completely removed from the analysis.

One negative effect of the user trial errors was the reduction in the number of older drivers that had complete data sets. It would have been useful to compare the effects of age on the ability of drivers to engage with tactile coding by comparing the glance durations of two samples of 8 as originally planned. This led to the recommendation of a further study looking at long term exposure to the PTI as mentioned above.

8.2.8 Alternative approaches to the methodology used in the design of the PTI

A different approach for the BIONIC project could have been the execution of a series of smaller studies, examining the shapes and textures that provide the best differentiation between a range of functions. This series of studies could have provided more baseline information for the production of design recommendations, such as the most recognisable shapes, or textures for use in the design of tactile interfaces. However, the holistic approach taken in the design of the PTI allowed a comparison to be made with a baseline system, and promoted the exploration of design variables that are associated with creating a complete system, such as the design of the screen based content and definition of functions that should be included.

8.3 Design recommendations for the generic replication of the PTI design process

The previous section contained discrete design recommendations derived from the features that were successful in the PTI testing in the 'on the road' study. The following section adds to these recommendations, providing a structure for the generic application of the PTI design process.

8.3.1 Proposed design recommendations for the replication of the PTI design process

The following design stages are recommended for the production of control interfaces that use tactile coding to provide non-visual feedback to the user. These recommendations presume that the functions that are to be integrated into the design are to be used whilst vision is required for other tasks, and that a number of discrete functions are required for the operation of the device.

1. A list of possible functions for inclusion in the interface should be created. The generation of the function list should be supported by interaction with relevant stake holders (potential operators of the device)
2. Where possible the number of functions should be kept to a minimum. The design process should therefore aim to reduce the number of functions present in a product that is to be redesigned, or resist 'functional creep' in the development of a new product

3. Where possible functional groups should be assigned to allow subdivision of the function list
4. The level of modality should be kept low for an interface that relies upon tactile coding to reduce visual load due to the difficulty of communicating the current mode
5. The visual and tactile coding should be combined and used to reinforce each other. Where a symbolic arrangement of control layout is being designed, the tactile features should provide subdivision of the control array that matches the visual subdivision
6. Any stereotypical visual associations with the control functions, such as existing symbols, should be noted for inclusion in the control layout. Where appropriate, the use of existing symbols as a strong visual cue for the identification of functional groups has been shown to be successful
7. New symbols that are designed to represent functions should be tested on potential users with a suitable methodology, such as *ISO/IEC 11581: Icon symbols and functions*
8. The environment within which the controls are to be placed should be analysed to determine the area or volume that can be easily viewed and reached by the user
9. Where a sufficient number of functions are to be included, separate functional groups should be defined, allowing separate physical locations of these functional arrays
10. The size and shape of the functional arrays should be designed to best fit the shape of the volume of space within which controls can be viewed and touched comfortably
11. Each functional array should be designed to be as iconic, with the shape and orientation of the separate controls providing a strong visual image
12. Where possible distinct controls should be individually identifiable through the use of shape coding to represent function, and surface finish to aid discrimination between controls
13. Prototype functional arrays should be produced to allow exploration by potential users in structured user trials. The aims and operation of each functional group

should be shown to the user, and scenarios for use should be used reinforce the methodology for interaction

14. Any associated software and screen based content should be linked to the design and layout of the functional arrays, and should only relate to the functions that used during the high visual load situation that drives the need for tactile coding
15. A number of prototypes should be generated that increase the level of fidelity of the product use simulation. Early user trials should be used to examine issues such as appropriate controls shapes and textures, with later user trials focusing on the integration of these features
16. The final prototype system should be tested in the actual environment within which a final product will be used
17. There should be an opportunity to redesign certain aspects of the design following the high fidelity simulation, with further testing of the modified design

8.4 Chapter Summary

The chapter contains an analysis of the data collected during the 'on the road trials' to demonstrate that the main benefit of the PTI design process is the reduction in the number of glances made, and therefore a reduction in eyes-off-road time. This process has highlighted further studies that could be performed to add to these design recommendations. The chapter has highlighted the successful elements of the design process and those elements that did not perform as expected. This process has been used to derive design recommendations that could be applied to the design of tactile interfaces that include conventional controls. The following chapter concludes the thesis.

9 Chapter 9: Conclusions and future work

The following chapter concludes the thesis by revisiting the aims and objectives. The chapter then contains a presentation of the limitations of the thesis and the directions for future research.

9.1 Conclusions

The aim of the thesis was to examine the potential of the tactile sense to reduce the visual load on the driver of a road vehicle. The conclusions for the thesis are described below by referring the aims and objectives defined in section 1.2.

Research objective 1: To explore the methodologies used by visually impaired people when interacting with electronic products in order to examine the use of the tactile sense

The study with 10 visually impaired people that was conducted highlighted a number of conclusions for the thesis.

When designing an interface that exploits tactile coding to reduce visual load it is important to exploit the stereotypes that are held by users in terms of controls shape, control type and control motion. This was emphasised by the behaviours exhibited by the visually impaired participants when interacting with rotary controls for volume, and the difficulty found by the participants in using the non-standard control layouts.

The study highlighted that an interface design should use a low level of modality, as illustrated by the problems encountered by the participants when accidentally entering a mode as indicated by visual feedback alone.

In addition, it is important to design tactile coding that subdivides the available functions. This was highlighted by the use of tactile features within the products that were owned by the participants to allow the location of specific controls.

The use of visually impaired participants to provide design recommendations for the design in-car controls was a valuable mechanism for the identification of tactile design issues.

Research objective 2: To generate design recommendations based upon the results of this exploration and a review of the literature

The literature highlighted that the potential methods for reducing visual load such as voice recognition are not yet mature enough to allow the control of all secondary functions. This validated the exploration of the use of the tactile sense.

The design recommendations that were produced on the basis of the literature and the study with visually impaired participants defined a distinct design direction. This involved the use of conventional controls, the need to minimise the number of functions that are incorporated, and the potential of linking the visual and tactile experience of interface interaction.

The lack of literature describing design recommendations and design processes that consider the use of the tactile sense in mainstream product design highlighted the originality of the design process describes in this thesis.

Research objective 3: To build a working, high fidelity prototype tactile interface that allows the user to control secondary automotive functions

It was crucial that the final version of the PTI demonstrated a level of fidelity that was equivalent the baseline system. This was demonstrated during the user trials by the number of occasions that users sought feedback from both the PTI and baseline systems in terms of correct control selection.

The production of a working prototype version of the PTI was the result of four years of research effort supported by the design and ergonomics skill sets of the author and substantial financial support, and technical support in terms of software production. Any replication of this design process would benefit from a multi-disciplinary team approach combining design, ergonomics, engineering and software programming skill sets. Such a team would have the potential to reduce the time period required in order to produce a high fidelity prototype.

Research objective 4: To test the prototype tactile interface in both simulator and 'on the road' study formats

The simulator study that was performed with the first PTI with a lower level of fidelity than the final PTI demonstrated that the reasoning behind the design process was sound. This was a crucial stage in the design process that demonstrated that users were able to engage with the visual and tactile coding of the PTI to foster non-visual interactions.

The comparison between the results of the simulator study and the 'on the road' study highlighted that care should be taken when analysing the results from simulator studies. There is the potential for users' behaviour to change between the two experimental conditions. This was highlighted by the difference in the results for the use of the ICE array in both studies, with the location of the ICE array causing no difficulties in the simulator study, but causing concern for participants when using the interface in real driving conditions.

The level of non-visual interactions that were demonstrated in the 'on the road' study exceeded expectations based upon the literature (see section 2.4.2.1). The examination of the tasks and the associated controls that fostered non-visual interactions has been a useful tool for identifying successful control layouts and tactile coding combinations. These act as exemplars of good design for the reduction of 'eyes-off-road' time. The main results from the 'on the road' trial are listed below;

- The PTI surpassed the 10% reduction in 'eyes-off-road' time benchmark for seven of the ten tasks

- A greater than 50% reduction in 'eyes-off-road time' was achieved for three of the 10 tasks (e.g. the 'select map view' task produced summed glance durations of 14.28 for the PTI and 31.2 for the baseline system. A reduction of 53.4%)

    - Six of the ten tasks produced a significant reduction in summed glance duration for the PTI

- Four of the ten tasks produced a significant reduction in median glance duration (e.g. the 'select classic FM task produced median glance durations of 0.84 seconds for the PTI and 1.38 seconds for the baseline system)

- Five of the ten tasks produced a significant reduction in 'number of glances (e.g. the 'zoom map' task produced 36 glances for the PTI and 58 glances for the baseline system)

- There were small increases in median glance duration for the 'turn off AC task' and the 'turn on CD player' task

- The number of glances increased by 25% and 17% for the 'select classic FM preset' task and the 'increase volume' task respectively

- There was a small increase in summed glance duration for the turn off AC task, and a 32% increase in summed glance duration for the increase volume task

- The ICE array has been shown to be potentially too far rearwards in the car

- Three of the four tasks that showed an increase for the PTI when compared to the baseline system were associated with the ICE array

- Only two tasks produced an increase in summed glance duration for the PTI when compared to the baseline system

The results from the 'on the road' user trials have successfully demonstrated that the consideration of the combined visual and tactile models of interaction can reduce the 'eyes off road' time fostered by the interaction with secondary automotive controls.

Research objective 5: To build generic design recommendations for the production of controls and control arrays that employ tactile coding

Generic design recommendations have been derived for the replication of the PTI design process. They provide a frame work for the production of a PTI that can be applied to any situation where the visual resources of the user are limited. Envisaged applications range from the design of interfaces for use in military applications to improve situation awareness in low light levels, to the design of switches that control heavy machinery. These recommendations are also appropriate for use in the design of equipment to be used by visually impaired people.

9.2 Directions for future research and the limitations of the thesis

This thesis has successfully demonstrated the potential of the tactile sense to improve control interactions and generic design recommendations have been derived. The focus on passive tactile interaction has provided a basis for the definition of these design recommendations. The successful non-visual interactions that were demonstrated by the user trials with the final version of the PTI were based upon a limited period of exposure to the control designs. A limitation of the thesis is the lack of a longitudinal examination of tactile interaction provided by the PTI. The literature suggested that the kinaesthetic sense or 'muscle memory' would take over from the tactile sense for control interactions after a period of acclimatisation with the interface. The 'on the road' study demonstrated that non-visual interactions were performed by all participants; however, it is presumed that the prevalence of non-visual interactions would increase for longer durations of exposure to the device. Hence study recommendation number 1 was derived.

> <u>*Study recommendation 1: A longitudinal study examining the potential increase in the use of tactile coding*</u>
>
> *A longitudinal study is recommended that examines how the use of tactile coding develops with time. The PTI interface equipped car could be given to the participant for a period of 6 months. At predetermined stages in that six month period the same filming equipment used in the 'on the road' study could be used to record control interactions. At the end of the process these video sequences could be analysed to determine the levels of non-visual interaction for each control. This process would be performed with samples of older and*

younger users, with a comparison of non-visual interaction rates between the two groups.

The focus of the PTI design process was the use of the passive tactile coding to provide information to the user. The exclusion of active feedback early in the design process was based upon the preconceived modality of an active tactile display when that display is providing information that relates to the full function list that was defined for the design of the PTI. However, there is potential for the combination of the passive and active modes of tactile interaction. For example, an active tactile display could be used to present information that uses coding with which the user is familiar, for example, direction of turn information in a navigation context. Figure 9.1 shows a concept that could be used as part of a SATNAV system. The proposition is that an active pin matrix display could be incorporated into the SATNAV system potentially integrating into the steering wheel of a car, or into a portable navigation device. In the example shown in Figure 9.1 the size of the array would be approximately 25mm square, allowing the finger tip to perform both 'active' and 'passive' modes of interaction to gain direction of turn and distance to turn information.

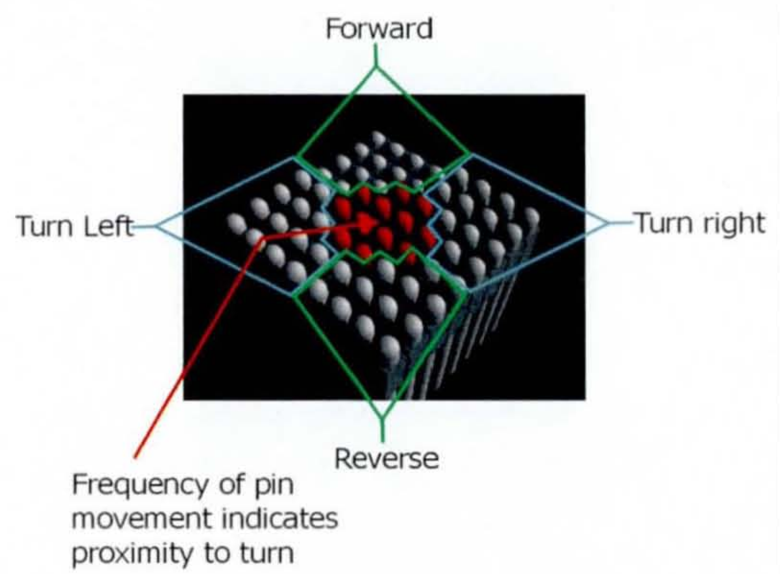


Figure 9.1. An example of active tactile feedback that could be used non-visually in an automotive environment. The pins in the 'forward' position are lower to indicate the required direction of motion

The user would also be able to receive information on the distance to the next turn using the frequency of oscillation of the central pins that are red in colour, and complex information such as which exit of a roundabout that should be taken could be displayed diagrammatically. This leads to the recommendation of a series of further research studies, the first of which examines the design of tactile icons and their ability to convey information to users. The presumption that a range of tactile icons would be difficult to derive for a number of in-car functions should be tested.

> *Study recommendation 2: Baseline analysis of the use of tactile symbols to convey meaning.*
> *An empirical study is recommended that would examine the benefits of designing tactile symbols to represent different functions. It is suggested that a number of alternative tactile icons (tactons) could be generated for that represent a defined list of functions, with user testing establishing which icon best represents the function. The basis of the this study would be the production a prototype pin matrix display design as demonstrated in Figure 9.1.*

This study would be followed by a study that would examine the potential for an active tactile display to provide navigation based information.

> *Study recommendation 3: Testing of the potential to use pin matrix display technology to provide navigation based information with the aim of reducing 'eyes-off-road' time*
> *A prototype pin matrix display could be used to present direction of turn information and distance to turn information using the varying levels of pin protrusion possible with a suitably sized pin matrix display. The experimental variables to be considered are the size of the pin matrix display, the level of protrusion that can be detected, the design of the direction of turn indicators and the frequency of distance to turn oscillations. A suitably designed device could be tested in an 'on the road' study*

A further limitation of the thesis was the differing levels of success that were achieved for each of the functional groups of the PTI. The locations of the HVAC and SATNAV arrays were well received by participants, but the ICE array location was seen as inappropriate. The proximity of the ICE array to the HVAC array (The centre of the ICE array is 39mm lower and 105mm rearwards of the HVAC array) demonstrates that there is a distinct volume of space within which controls should be placed to allow comfortable vision and reach, and that this volume has distinct boundaries. It is presumed that this volume will change depending upon the posture from which the reach and vision is being performed. A further study is therefore recommended that examines the locations within a car interior that are considered to be comfortable for reach and vision. This study should use a number of vehicles that span the range of possible driving postures i.e. from a low two seat sports car (reclined posture) to a large 4 x 4 vehicle (upright posture).

> *Study recommendation 4: Determining the locations within a car interior that users are comfortable viewing and touching*
>
> *Control arrays can be located within a range of locations within the reach and vision of participants, with an increasing level of head and eye movement required to allow the controls to be viewed. This study could be performed using a driving simulator with a complex route design, requiring constant interaction from the driver to keep the vehicle within the current lane. A subjective questionnaire, combined with lane excursion data from the simulator would combine to identify a threshold of head, neck and eye movement beyond which users feel uncomfortable, and/or make driving mistakes.*

The trend to use a GUI to control in car functions and to increase the number of available functions is prevalent in the design of automotive interiors today. The design of the PTI goes against this general design direction by reducing the number of available functions for use whilst the vehicle is in motion, and focusing on an interaction methodology that is unfamiliar to drivers of current car designs. The 'technology push' design ideology found in the design of mobile phones has been mirrored by the design of secondary automotive controls and displays. Anecdotal evidence from automotive design team members indicates that consumers perceive that cars with long specification lists are superior. In this context it is unclear how well the general public would accept an interface design such as the PTI. However, recent legislation in the UK that bans the use of mobile phones whilst driving has the potential to highlight the dangers of distracting technology in the automotive environment. There is therefore potential to improve the acceptance of the design strategies shown in the PTI through the message of improved safety. Further research is recommended that examines the acceptability of the PTI design by the general public using focus groups, questionnaires and demonstrations of the PTI.

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Appendix 1: Vibro-tactile feedback conventions employed in the I-Drive Device

Automotive controls can be programmed with a wide variety of tactile sensations. These are just some of the sensations that can be programmed with Immersion TouchSense™ technology. By combining effects, many more sensations are possible to match specific interface controls. The result is a more intuitive driving experience.

Barrier

Sensation of hitting hard stop. Indicates the end of a list or menu.

Damper

Resistance force dependent on velocity. Creates the sensation of drag.

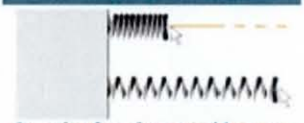
Texture

Sensation of roughness. Communicates the feel of a path or surface.

Waves

Vibration expressing sine, square or sawtooth wave shapes. Indicates intensity and velocity.

Spring

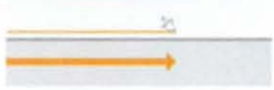


Opposing force increases/decreases with controller position. Communicates stiffness or rate level.

Hill

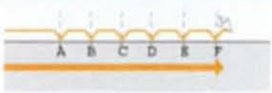
Increasing to decreasing force. Indicates transition to a new menu or list.

Vector



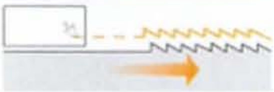
Directional force. Communicates preferred path.

Detent



Notches associated with selection position. Indicates position in a menu or list.

Friction



Force that resists relative motion. Provides the sensation of resistance.

Grid

Framework that attracts or repels. Indicates position in a two dimensional space.

Shapes

Shapes that attract, repel, or slide. Communicates a two dimensional contour or form.

Compound

Combination of several basic effects. Detents can be combined with barriers or hills to construct lists with mid-points and end stops.

Appendix 2: Data sheets from the study visually impaired people

Task Sheet- Using a piece of HIFI equipment

Subject No._L1

Gender = Female

Name: S B_A17_OP_10

Visual Impairment _Not known

OPCS Vision score__ 10

Assumptions

The participant will turn the device on, take a CD and insert it into the player. They will select a track using both the controls on the main device and on the remote control. They will find the volume controls, and lower the volume. They will find the tuning knob and locate a radio station. They will eject the cassette player holder. They will insert a cassette and forward wind it for a short period. They will play the cassette.

Task elements (products)

Portable Hifi

Initial examination performed *Yes* / **No**

This participant was allowed to perform an initial examination of the device before the experiment proper started. This was done on the premise that some people perform a mapping exercise before they try to use a new device. The device was turned off during the initial examination, therefore providing no feedback in the form of lights or noises.

Assumed task stages

If assistance required = Verbal Physical

Turn the HIFI on

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = latching push button Found the power switch by the fact that it protrudes from the surface higher than the surrounding buttons, and the fact that it moved in when depressed.

Find the CD open button, and open the CD player

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Sliding latch (left to unlock) The participant initially pressed the textured surface of the microphone grill thinking that it was a button. She then found the CD eject switch saying it was the bumps on the surface that allowed her to find it, in combination with the location next to the CD player lid.

Switch the machine to CD function

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Slider control with multiple options The mode select button was found after the user played with the radio band selector. She noticed the flashing LEDS but could not determine what was being displayed. She assumed that this meant that the CD had been selected

Play the third track of the CD

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Skip rotary dial The participant spent some time using the circular array, and needed some direction to look elsewhere on the device after two minutes. She could not read the LED display telling her the track number, so she was unable to locate track 3

Adjust the volume lower

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Rotary dial (clockwise to increase) This was done quickly as the volume control had been found earlier by accident.

Select the radio function

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Slider control with multiple options Initially the band selector was used, and then the participant found the correct control, she identified that she was in radio mode by use of the static from the speakers. The radio was tuned to no station

Tune in a radio station

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Rotary dial The tuning control was found straight away as it was assumed that it would a rotary knob, and the other knob of that type had already been identified as the volume

Select the Tape function

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Slider control with multiple options Commented that nothing let you know that you are in the tape mode. But assumed she was as she had already accessed two of the three options.

Eject the tape holder

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Second cassette button from right

She remembered the standard layout and counted keys to find the required function.

Insert a tape and close

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Find the slot and insert ("lets you know when you have it the wrong way") Had initial problems with the orientation of the cassette, managed after a few seconds

Fast forward the tape for a short period and play the tape

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = 3rd button from the right of the cassette controls and second button from the left. Counted the buttons from left to right and found the correct button straight away

General methodolgy notes

The participant tried to use what vision she had and spent some time with her head within 50mm of the device trying to read the button labels, but was unable to do so.

The controls that the participant cited as being easy to use where on her HIFI equipment.

The participant had a mini HIFI similar in dimensions to the one used in the experimentation. However, the main control panel had a well laid out set of buttons that were in the shape of the standard play symbols etc. The buttons protruded from the surface enough to be able to trace a finger tip around the shape. The participant stated that this was the reason that she purchased that particular model.

Task Sheet- Using a piece of HIFI equipment

Subject No._L2

Name: PH_A19_OP12

Visual Impairment _Not known

OPCS Vision score__12

Assumptions

The participant will turn the device on, take a CD and insert it into the player. They will select a track using both the controls on the main device and on the remote control. They will find the volume controls, and lower the volume. They will find the tuning knob and locate a radio station. They will eject the cassette player holder. They will insert a cassette and forward wind it for a short period. They will play the cassette.

Task elements (products)

Portable Hifi

Initial examination performed *Yes* / **No**

Assumed task stages

If assistance required = Verbal Physical

Turn the HIFI on

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = "push button with a click" The participant was selected to perform an initial exam of the device before experimentation started. He performed a very methodical exam of the device using both hands. Initially he established the dimensions of the device, exploring from the back to the front. He then started mapping where the control centres of the device were, again using both hands. He noted that the power switch was the only one that moved inwards, and therefore assumed that it was the power switch. During experimentation, he found the power switch straight away

Find the CD open button, and open the CD player

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Push button next to CD tray During the initial exam he had noted the two textured areas next to the CD lid. He pushed the microphone grill first as he said that he assumed the location made more sense than that of the actual CD lid open button. He then identified the correct control and opened the cd lid.

Switch the machine to CD function

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Slider control with multiple options During the initial exam, he had identified the two mirrored sets of controls with a large rotary knob, next to a slide selector. He therefore played with both sets of slide selector, and identified the fact that he was in CD mode by the CD spinning noise.

Play the third track of the CD

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Skip push button He played with the circular array for some time and was surprised when the left and right portions of the circle did not skip the track. He had noted the two buttons below the power switch and therefore went to these buttons next. He said that he found it difficult to find the split between the buttons, and therefore pushed the skip back button by accident first. He then could not find the third track.

Adjust the volume lower

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Slider He played with both of the large rotary knobs before finding the one required. He said that he assumed that one of the large knobs would be the volume control.

Select the radio function

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Slider control with multiple options Slid the control straight from CD to Radio using white noise as the feedback for completion.

Tune in a radio station

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Rotary dial As he had already used the volume control, he went straight to the tuning knob and found a radio station

Select the Tape function

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Slider control with multiple options As the user had no vision, and there was no audible feedback from the device, he played the cassette that was in the machine in order to verify that the correct mode was selected. He did this unprompted

Eject the tape holder

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Push button at top left of cassette tray opening. He knew the layout of the cassette controls in this configuration and therefore found the correct button straight away, using the counting keys method,

Insert a tape and close

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Find the slot and insert ("It stops you putting it in the wrong way")

Had some trouble finding the orientation required for the cassette

Fast forward the tape for a short period and play the tape

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Push buttons next to the cassette tray (on surface to left or right if a dual deck system)

The button was found quickly due to the participant knowing the cassette button order

Discussion about control designs in general, and the participants methodology.

The participant had vision at all, and yet he performed the tasks much faster than most of the other participants. He methodology for mapping the device was very methodical in approach.

His own HIFI equipment was a very expensive Kenwood device. He liked this because his is a music lover and appreciated the sound quality. However the device had many buttons of the same design, which he said made it difficult to use. He used strategies such as counting along rows of buttons to find the required function, and said it had taken a long time for him to learn how to use the device.

Task Sheet- Using a piece of HIFI equipment

Subject No._L3

Name: DC_A21_OP9

Visual Impairment _He described the condition as having wobbly vision.

OPCS Vision score__ 9

Assumptions

The participant will turn the device on, take a CD and insert it into the player. They will select a track using both the controls on the main device and on the remote control. They will find the volume controls, and lower the volume. They will find the tuning knob and locate a radio station. They will eject the cassette player holder. They will insert a cassette and forward wind it for a short period. They will play the cassette.

Task elements (products)

Portable Hifi

Initial examination performed *Yes* / **No**

Assumed task stages

If assistance required = Verbal Physical

Turn the HIFI on

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Added to rotary volume control, first "click" is on He found the power switch almost straight away, and passed his finger from the power switch to the CD skip track buttons noting the difference in height. When he switched the device on he Said "BINGO" when he heard the CD spin.

Find the CD open button, and open the CD player

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Push button next to CD tray He took some time find the CD open button. The cd eject button on his own HIFI equipment was away from the CD lid itself. He therefore took time to find this location and the button. He identified a button from the dimpled surface

Switch the machine to CD function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Rotary dial with multiple options
The machine was already in CD mode, so he was asked to find the control that would take it out of CD mode and to switch to radio mode and then back to the CD mode. Initially he played with the Radio band selector, and then found the mode slider as it next to the volume control. He switched to radio mode and identified success as he heard a radio station. He then switched back, saying that he assumed that the middle selection between the radio and CD functions was the cassette function

Play the third track of the CD

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Skip push button
The participant played with the circular array of controls for around thirty seconds, and then moved on the rest of the device. He remembered that there were controls under the power switch and tried these successfully

Adjust the volume lower

Notes on coping stratergies/ Differences to assumptions above / safety implications

He Expected control or controls = Rotary dial
had played with the volume control when in the radio mode earlier, and said that he distinguished it by use of the blip on the volume knob when compared to the radio frequency knob.

Select the radio function

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Slider control with multiple options
As this was done previously he selected the correct function straight away

Tune in a radio station

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Rotary dial
The previously identified radio tuning knob was found and used straight away

Select the Tape function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options
As he had identified the tape select function earlier he found this function straight away, and played cassette that was in the machine to determine if he was correct

Eject the tape holder

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls =Push button at top right of cassette tray opening
He remembered the tape control layout and therefore found the eject button. He did ask if the same button also stopped the tape. He was asked to try it and did so successfully

Insert a tape and close

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Find the slot and insert
He used the correct tape orientation straight away

Fast forward the tape for a short period and play the tape

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = 5th button from the left of the cassette controls and second button from the left
Counted from the right to left, and found both keys with no problems

The participant showed how he used his own equipment. He stated that he rests his hand on the device in the same way each time, placing his thumb in a crease in the speaker view. This allowed him to reach all of the main control using the fingers on the resting hand. The crease also helped by dividing the panel in two. He was location coding the controls by use of there position above or below the crease.

Task Sheet- Using a piece of HIFI equipment

Subject No._L4

Name: CB_A42_OP8

Visual Impairment _Not known

OPCS Vision score__8

Assumptions

The participant will turn the device on, take a CD and insert it into the player. They will select a track using both the controls on the main device and on the remote control. They will find the volume controls, and lower the volume. They will find the tuning knob and locate a radio station. They will eject the cassette player holder. They will insert a cassette and forward wind it for a short period. They will play the cassette.

Task elements (products)

Portable Hifi

Initial examination performed *Yes* / **No**

This participant was allowed to perform an initial examination of the device before the experiment proper started. This was done on the premise that some people perform a mapping exercise before they try to use a new device. The device was turned off during the initial examination, therefore providing no feedback in the form of lights or noises.

Assumed task stages

If assistance required = Verbal Physical

Turn the HIFI on

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = latching push button The participant found the switch straight away due to the initial examination that was performed. He said that the different protrusion level of the switch allowed him to find it.

Find the CD open button, and open the CD player

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Push button next to CD tray The participant initially pressed the textured surface of the microphone grill thinking that it was a button. He then found the CD eject switch saying it was the bumps on the surface that allowed him to find it.

Switch the machine to CD function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options The mode select button was found after the user played with the radio band selector

Play the third track of the CD

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Skip push button. The participant spent some time playing with the circular array. Verbal assistance was required after around 2mins. It was suggested that he looked elsewhere on the device for the required control.

Adjust the volume lower

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Rotary control This was done quickly as the volume control had been found earlier by accident.

Select the radio function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options Again the participant played with the radio band selector before going to the opposite side and using the mode selector

Tune in a radio station

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Rotary dial The tuning control was found straight away as it was assumed that it would a rotary knob, and the other knob of that type had already been identified as the volume

Select the Tape function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options Was confused by the fact that nothing let you know that the tape function had been selected. He played the tape in order to make sure that the required function was selected

Eject the tape holder

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Push button at top left of cassette tray opening 2nd

Some confusion with texture of the microphone grille.

Insert a tape and close

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Find the slot and insert

Had initial problems with the orientation of the cassette, managed after a few seconds

Fast forward the tape for a short period and play the tape

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = 5th button from the left of the cassette controls and second button from the left

Counted from the left to right, and wasn't expecting there to a record button next to the play button. He therefore hit the wrong key initially and corrected when he worked out that the record key was there.

General methodolgy notes

The participant tried to use his vision with most of the tasks that were performed. He was unable to read any of the labels on the device, as said that he could just make out light grey areas where the buttons were located.

The controls that the participant cited as being easy to use where on his HIFI equipment.

The volume control was very large an easy to find, being approximately 50mm in diameter with 30mm of protrusion from the surface into which it is mounted. Two sets of cassette controls were located next to the relative cassette draw. A large jog dial of the same proportions as the volume control was used to skip and scan CD tracks. The participant found this particularly easy to use.

Task Sheet- Using a piece of HIFI equipment

Subject No._L5

Name: GA_A23_OP8

Visual Impairement _Not known

OPCS Vision score__ 8

Assumptions

The participant will turn the device on, take a CD and insert it into the player. They will select a track using both the controls on the main device and on the remote control. They will find the volume controls, and lower the volume. They will find the tuning knob and locate a radio station. They will eject the cassette player holder. They will insert a cassette and forward wind it for a short period. They will play the cassette.

Task elements (products)

Portable Hifi

Initial examination performed *Yes* / No

Assumed task stages

If assistance required = Verbal Physical

Turn the HIFI on

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = "push button with a click" She could not find the power on switch after 2 mins, and becoming frustrated. Verbal assistance given.

Find the CD open button, and open the CD player

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Push button next to CD tray Initially the she confused the CD eject button with the microphone. She stated she was expecting the CD eject button to be next to the CD player on the left or the right.

Switch the machine to CD function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options

Around 30 secs was needed for this task. She focused on the front panel for sometime and then started to explore the rest of the device. She knew that CD was selected due to the sound of the CD spinning

Play the third track of the CD

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Skip rotary dial
She expected the CD skip to be found in the circular array. She spent 15 seconds playing with the array, and then moved on. She said that she would expect the skip control to be next to the play control and was surprised when she found it under the power button

Adjust the volume lower

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Rotary dial or push button like her machine
She stated that she expected that the volume control would be the right hand option of the two similar big turning knobs. She found the control, and noted the blip on the knob.

Select the radio function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options
Initially played with the radio frequency selector, when no feedback was gained, she said that that must be the radio frequency selector. Then she found the correct control and used the sound of the radio station as the feedback showing success

Tune in a radio station

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Rotary dial
She found the radio tuner by virtue of it being next to the previously discovered frequency selector

Select the Tape function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options
As she had previously used the control, and there was only of three functions left unused, she found the cassette function straight away

Eject the tape holder

Notes on coping stratergies/ Differences to assumptions above / safety implications

Not sure of expected control as doesn't use tapes

She could not tell the function of the buttons with the indented cassette buttons, and did not know the order of the buttons from memory. She worked her way along the buttons until the cassette holder ejected.

Insert a tape and close

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Find the slot and insert

This was straight away. There were cassette orientation problems

Fast forward the tape for a short period and play the tape

Notes on coping stratergies/ Differences to assumptions above / safety implications

As she had already used the controls she said that she expected a push button. The button order was not remembered, so she did not know if she was fast forwarding or rewinding.

The participant owned a Nintendo 64 games console. She said that she liked the controller for this device due to the fact that it had an analogue joystick centrally placed, that could be used for a lot of the functions of scrolling through system screens etc. She mentioned that when her hands started to get sweaty, that her thumb sometimes slipped off the analogue joystick. She liked the fact that there was a trigger button, mounted in a gun handle type config. She said that she had used a play station controller that had the four main select buttons in the shapes of triangles, circles, crosses and squares. She said that this helped to distinguish the buttons from each other, and she found it easier to use than the Nintendo controller. She could only really see blobs on the screen. Another person would tell her what action to take in platform games.

Task Sheet- Using a piece of HIFI equipment

Subject No._L6

Name: LP_A19_OP8

Visual Impairment _Not known

OPCS Vision score__ 8

Assumptions

The participant will turn the device on, take a CD and insert it into the player. They will select a track using both the controls on the main device and on the remote control. They will find the volume controls, and lower the volume. They will find the tuning knob and locate a radio station. They will eject the cassette player holder. They will insert a cassette and forward wind it for a short period. They will play the cassette.

Task elements (products)

Portable Hifi

Initial examination performed *Yes* / **No**

Assumed task stages

If assistance required = Verbal Physical

Turn the HIFI on

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = latching push button Found the on switch after 8 secs, but as the machine was in cassette made, no feedback was received to let him know. Verbal assistance require. It was noted that when the button was initially found, the finger passed repeatedly from the CD skip buttons to the on switch indicating that the higher protrusion level of the power switch was the tactile cue. This was confirmed by the participant

Find the CD open button, and open the CD player

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Push button next to CD tray The CD eject button was found due to the raised bumps on it's surface. This took 10secs. The participant stated that it would have helped to find the CD eject button if it was not flush with the surrounding surface

Switch the machine to CD function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options
The CD function button was found due to the flashing LED display when the CD mode is selected, in combination with the sound of the CD spinning

Play the third track of the CD

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Skip push button

The CD skip button was found earlier in the process, recognised by the changing number on the LED display, although the numbers could not read. Therefore the track skip button was found straight away.

Adjust the volume lower

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Rotary dial

The user stated that he expected the volume control to be a large rotary knob. The volume had been left high from a previous pass, and therefore when the CD played the volume was loud. The user responded rapidly to quite the device, and found the volume after first twisting the radio tuner.

Select the radio function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options

The radio function was found due to the white noise when the function was selected

Tune in a radio station

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Rotary dial. The tuning control was found straight away due to the fact that he had got no reaction from the control when looking for the volume. He therefore assumed that it was for tuning and went straight to it

Select the Tape function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options. The participant stated that he would expect the tape function to be the central function of the three available. This was based on the design of the HIFI that he owned. He said he hardly ever used the tape function on his machine, and that he knew to slide the control to left for radio, and the right for CD. He said that most of the machines that he had used had this arrangement

Eject the tape holder

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Second cassette button from the left The user asked if the machine was a single or double cassette deck. Therefore verbal assistance required. He then counted from the left to the right of the cassette buttons, and pushed the right one first time. He said that he remembered the layout, but that single deck machines had one more button for the record function.

Insert a tape and close

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Find the slot and insert

There were cassette orientation problems

Fast forward the tape for a short period and play the tape

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Cassette controls below the cassette tray

Again, the participant counted along the buttons and found the correct one first time

The participant owned a playstation games console, which he liked the controller of. He said that he liked it due to the fact that you have your thumbs on the two main control pads, and could feel in which direction the up down left right option were froma central location. Also the four buttons mounted on the front of the device were easily distinguishable from the size and shape on the buttons, in combination with their location.

The participant also demonstarted the use of a hifi remote control which he liked. However, he could not name the majority of the functions of the device, as he could not read the lables. He used the main control functions for mode select, play stop, etc. and said he had never needed to do anything else.

Task Sheet- Using a piece of HIFI equipment

Subject No._L7

Name: KD_A29_OP_8

Visual Impairment _Not known

OPCS Vision score__ 8

Assumptions

The participant will turn the device on, take a CD and insert it into the player. They will select a track using both the controls on the main device and on the remote control. They will find the volume controls, and lower the volume. They will find the tuning knob and locate a radio station. They will eject the cassette player holder. They will insert a cassette and forward wind it for a short period. They will play the cassette.

Task elements (products)

Portable Hifi

Initial examination performed *Yes* / **No**

Assumed task stages

If assistance required = Verbal Physical

Turn the HIFI on

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = latching push button She found the power switch almost straight away, using the cues of different protrusion height of the power switch, and the fact that the machine made a noise when it was switched on

Find the CD open button, and open the CD player

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Push button next to CD tray The CD eject button was found due to the raised bumps on it's surface. This was done almost immediately, as she expected the control to be next to the CD cavity lid.

Switch the machine to CD function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options The CD mode was recognised due to the flashing LED display

Play the third track of the CD

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Skip rotary dial The participant played with the circular array of controls, and when she saw the LED display change three times she assumed that she had performed the task. The skip track buttons were pointed out to her.

Adjust the volume lower

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Rotary dial The volume control was found straight away as it was assumed that it would a rotary knob.

Select the radio function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options The radio function was found due to the white noise when the function was selected

Tune in a radio station

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Push button The tuning control was found straight away as it was assumed that it would a rotary knob, and the other knob of that type had already been identified as the volume

Select the Tape function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options She spent some time looking for some form of feedback when sliding between the three main function types. She said that should couldn't be sure, but assumed that the device was in tape mode as it was the only remaining option.

Eject the tape holder

Notes on coping stratergies/ Differences to assumptions above / safety implications
Second cassette button from right. Counted buttons to find eject

Insert a tape and close

Notes on coping stratergies/ Differences to assumptions above / safety implications
No problems

Fast forward the tape for a short period and play the tape

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = 3rd button from the right of the cassette controls and second button from the left

Counted from the right to left, and found both keys with no problems

She decribed the use of her hifi. The function select buttons were arranged around a central LCD. They were made of soft rubber, and were identical. She used the fact that rubber distorted when depressed to find the boundaries between the keys, which were otherwise not distinguishable.

She also stated that she found it hard to distinguish some of the controls, such as tone and balance, and had to use them when music was playing to determine their function.

She also stated that some of the features were good. She was able to select the functions modes with few erros because it reflected the vertical separation of the controls in the overall machine layout

Task Sheet- Using a piece of HIFI equipment

Subject No._L8

Name: LY_A21_OP8

Visual Impairement _Not known

OPCS Vision score__ 8

Assumptions

The participant will turn the device on, take a CD and insert it into the player. They will select a track using both the controls on the main device and on the remote control. They will find the volume controls, and lower the volume. They will find the tuning knob and locate a radio station. They will eject the cassette player holder. They will insert a cassette and forward wind it for a short period. They will play the cassette.

Task elements (products)

Portable Hifi

Initial examination performed *Yes* / **No**

Assumed task stages

If assistance required = Verbal Physical

Turn the HIFI on

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = latching push button This took quite a long time, around 30 seconds. She spent a long time playing with the circular array. Then resorted to playing with the controls and found the on switch using the CD spinning up as the cue to know the device was on.

Find the CD open button, and open the CD player

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Push button next to CD tray The button was found by use of the texture on the button.

Switch the machine to CD function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options When exploring the device the hands surrounded the device on either side and worked from the back of the device to the front. Therefore the large turning knob in association with the slider was noted quickly. The radio frequency slider was played with first and when no feedback was gained (the machine was in cassette mode) she played with the mirrored control and found the CD function. The feedback used was a combination of the flashing LEDS and the CD spinning (auditory)

Play the third track of the CD

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Skip push button She played with the circular array for some time. She recognised that the programme function was part of the array when an LED flashed, which she associated with the programme function on her own machine. She stated that she was expecting the skip CD track controls to be part of the circular array. She then spent some time finding the CD skip buttons and said that she had found it difficult.

Adjust the volume lower

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Rotary dial Noticed the blip on the volume control (by touch) and described the fact that this described a scale which would have finite range of motion. This distinguished the volume control from the radio tuning control for her

Select the radio function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options Slid the control straight from CD to Radio using white noise as the feedback for completion.

Tune in a radio station

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Rotary dial

The radio tuner was found because it was a big turning knob. It was noted that there was duplication in the radio tuning and volume control, in combination with an associated slider.

Select the Tape function

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Slider control with multiple options

There was no problem finding the tape function. The user had some vision, so the CD function was identified by the flashing LED display. The radio function was identified by the white noise from the speakers. Therefore the tape function was found as being the only other option

Eject the tape holder

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Push button at top left of cassette tray opening

Felt the symbols on the cassette player buttons and could not tell the function by the symbol. She could remember the order of cassette player buttons and so found the eject button quickly.

Insert a tape and close

Notes on coping stratergies/ Differences to assumptions above / safety implications

Find the slot and insert

Had some trouble finding the orientation required for the cassette

Fast forward the tape for a short period and play the tape

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Cassette controls below the cassette tray

The button was found quickly due to the participant knowing the cassette button order

Discussion about control designs in general

Gave an example of controls that she found useful, a Motorola mobile telephone with an array, central select button with a scroll left and scroll right button on either side. She stated that she found this kind of control easy to use without looking because she knew how many depressions are required to find a certain phone number.

Likes remote control buttons to have a shape that describe their function. Has modified her remote control by removing the buttons for all non-essential functions. She says it makes it easier to use because all of the buttons are the same. She prefers to have different shaped buttons, that describe their function.

Task Sheet- Using a piece of HIFI equipment

Subject No._L9

Name: BJ_A24_OP12

Visual Impairment _Not known

OPCS Vision score__12

Assumptions

The participant will turn the device on, take a CD and insert it into the player. They will select a track using both the controls on the main device and on the remote control. They will find the volume controls, and lower the volume. They will find the tuning knob and locate a radio station. They will eject the cassette player holder. They will insert a cassette and forward wind it for a short period. They will play the cassette.

Task elements (products)

Portable Hifi

Initial examination performed *Yes* / **No**

Assumed task stages

If assistance required = Verbal Physical

Turn the HIFI on

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = latching push button Even though there was no initial exam the power switch was found within five seconds. The cue he used was the different level of protrusion of the power switch when in the off position.

Find the CD open button, and open the CD player

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Push button next to CD tray The CD eject button was found in 7 secs. Said that the texture was what allowed him to know that it was the eject button, in combination with the location being next to and on the right of the CD player. He explored the texture of the mic. But did not push it. The texture was wrong for a button, which is why it wasn't pushed.

Switch the machine to CD function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options

Initially just the front panel was explored for a period of 10secs. Then the rest of the device was explored. The mode switch slider was then found within 5 sec and switch ed from the Tape to radio mode. The audio feedback of the radio let him know that that was the wrong direction. He slide straight past Tape to CD. He heard the CD spin and knew he had selected the right option.

Play the third track of the CD

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Skip push button

Found the CD skip buttons straight away but had trouble finding the play button in the none standard array. The volume had been accidentally set to zero when he playing with the controls, but recognised that the CD had been played because of the sound of the CD player spinning up. He stated that he expected play=top, stop=bottom, skip back = left, skip forward = right, in the circular array.

Adjust the volume lower

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Rotary dial

Done straight away

Select the radio function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options
Slid the control straight from CD to Radio

Tune in a radio station

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Rotary dial

Initially twisted the volume control. Then went straight to the opposite control, the radio tuner, and tuned in a station straight away

Select the Tape function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options
Went straight from Radio to Tape

Eject the tape holder

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Second cassette button from right

Felt the symbols on the cassette player buttons and could not tell the function by the symbol. He stated that he preferred protruding symbols over indented. He could remember the order of cassette player buttons and so found the eject button quickly

Insert a tape and close

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = Find the slot and insert

Had to try twice as he was unsure what orientation was required.

Fast forward the tape for a short period and play the tape

Notes on coping stratergies/ Differences to assumptions above / safety implications

Expected control or controls = 3rd button from the right of the cassette controls and second button from the left

Again, he remembered the cassette button order and performed the task quickly.

Discussion about control designs in general

Likes simple remote controls with as few buttons as possible

Likes the remote control buttons to have a shape that describe their function

Likes to use location coding, He described having the important buttons on the four corners of the remote face to allow them to be easily found.

Task Sheet- Using a piece of HIFI equipment

Subject No._L10

Name: PH_A24_OP12

Visual Impairment _Not known

OPCS Vision score__ 12

Assumptions

The participant will turn the device on, take a CD and insert it into the player. They will select a track using both the controls on the main device and on the remote control. They will find the volume controls, and lower the volume. They will find the tuning knob and locate a radio station. They will eject the cassette player holder. They will insert a cassette and forward wind it for a short period. They will play the cassette.

Task elements (products)

Portable Hifi

Initial examination performed *Yes* / **No**

Assumed task stages

If assistance required = Verbal Physical

Turn the HIFI on

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = "push button with a click" Task took around 30 seconds. She spent a long time playing with the circular array. Noted the 'blank button' (as it didn't click) and asked if it was broken. When I said no, she moved on without prompting and found the control, noticed the sound from the CDspinning up as the cue to know the device was on.

Find the CD open button, and open the CD player

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Push button next to CD tray The button was found by use of the textured embossed dimples on the control

Switch the machine to CD function

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Slider control with multiple options When exploring the device the hands surrounded the device on either side and worked from the back of the device to the front. The large rotarys were noted with an 'ahhh' comment. She played with both sliders and found the option quickly

Play the third track of the CD

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Skip push button She played with the circular array for some time. She recognised that the programme function was part of the array when an LED flashed. She stated that she was expecting the skip CD track controls to be part of the circular array even with the 'false control. She then remembered the controls below the power button. She was irritated by their location.

Adjust the volume lower

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Rotary dial Noticed the blip on the volume control (by touch). This distinguished the volume control from the radio tuning control

Select the radio function

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Slider control with multiple options Slid the control straight from CD to Radio using white noise as the feedback for completion.

Tune in a radio station

Notes on coping stratergies/ Differences to assumptions above / safety implications Expected control or controls = Rotary dial She had already noted the two large rotaries and so went to the one she had not used yet.

Select the Tape function

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Slider control with multiple options
There was no problem finding the tape function. The only not used. Good memory!

Eject the tape holder

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Second cassette button from right

She could remember the order of cassette player buttons and so found the eject button quickly.

Insert a tape and close

Notes on coping stratergies/ Differences to assumptions above / safety implications
Had some trouble finding the orientation required for the cassette

Fast forward the tape for a short period and play the tape

Notes on coping stratergies/ Differences to assumptions above / safety implications
Expected control or controls = Cassette controls below the cassette tray
The button was found quickly due to the participant knowing the cassette button order

Discussion about control designs in general

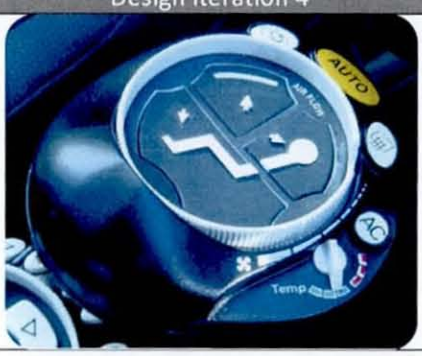
Gave an example of controls that she often found useful, a Nokia mobile telephone with a joystick that allowed her to scroll through the list of telephone numbers after the joystick had been depressed. She stated that she found this kind of control easy to use without looking because she knew how many joystick clicks are required to find a certain phone number.

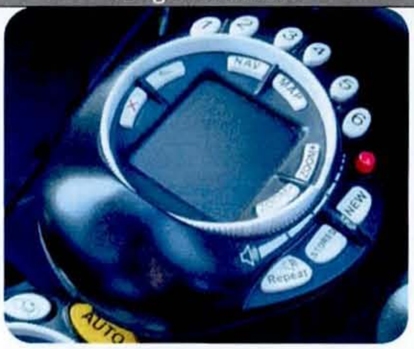
Appendix 3: The glance duration data collected during the simulator study

	Participant number (Glances in secs)									
Task	1	2	3	4	5	6	7	8	9	10
3rd radio preset	1.6	0.96	NG	1.52	0.68	0.56	1.32	1.08	1	1.2
		1		1.52		0.68		1.16	1.84	
						1.64			1.32	
AC on	1.36	1	1.1	1.48	1.68	1.08	NG	1.2	1	1.18
						1.56			1	
Airflow	1.8	1.08	1.16	1.6	1.52	1.4	1.16	1.08	1.68	0.92
	2.12	1.4		1.4		1.04		1.08	1.32	
		0.92		0.92				1.28		
Airflow2	1.68	1.32	1.4	1.1	1.3	1.45	1.3	1.5	1.5	0.96
	1.55	1.55	1.4	1.5	1.68	1.55	1.2	1.55	1.5	1.4
Audio on	1.84	0.92	1.08	1.84	1.08	1.44	1.16	0.96	1.44	1.12
		1.04				1.6		0.96		
CD mode	1.4	1.3	1	1.3	1.52	1.76	1	1.01	1	1.12
Demist rear screen	1.2	1.52	1.1	1.2	1.2	1.52	1.28	1.52	1.08	1.29
		1.51								
Increase fan speed	1.24	1.28	1.12	1.12	NG	NG	NG	1.08	1,08	1.08
									1.36	
increase temp	1.1	1.4	1.31	1.88	1.45	1.45	NG	1.1	0.8	1
		2.2		1.32					1.2	
Change volume	0.8	ng	NG	NG	NG	0.8	0.84	1.08	1.08	1.02
	1.04					1		1.28		
SATNAV preset	1.08	NG	1.01	1.36	0.96	1.1	1.08	1.2	1.15	1
	1		1.03		1.04	1.11		1.3		1
	1				1					1.2
Navigation mode	1.08	1	1.1	0.96	NG	1.51	NG	0.93	1.3	0.92
	2.36									0.92
New destination	0.96	1.64	ng	1.56	0.8	1.12	1.2	0.9	2.32	1
		0.9		1.01	1.8	1.4	0.9			1.08
SATNAV on	1.76	1.4	1.16	0.84	1.5	1.01	1.12	1.21	1.16	0.84
Map view	1.1	1	1	1.44	1.01	1.2	0.72	1.12	1.1	1.01
				1.56	0.9		1.2			
				1.32	0.8					
Skip within track	1.3	1.6	0.92	1.32	0.92	1.96	1.1	0.92	2.04	1
			1.56					1		
Zoom map	1.52	1.56	1.48	1.4	1.3	1.55	1.4	1.56	1.48	1
	1.92				1.1					
Radio mode	1.7	1.5	1.6	1.3	1.72	1.4	1.6	1.6	1.1	1.5
	1.7		1.4	1.5	1.7	1.4	1.9	1.7	1.7	1.4

Re-circulate air	1.1	1.01	1.2	1.23	1.2	1.24	1.21	0.84	1.2	0.84
							1.19			
Skip track	1.64	1.1	1	1.3	0.8	0.8	1.12	0.85	0.81	0.8
SAT NAV Volume	1.2	NG	1.16	NG	1.4	1	NG	1.12	1.2	0.88
										1.08

Appendix 4: The design changes made between each iteration of the ICE, HVAC and SATNAV arrays

HVAC Array design development stages	
Design iteration 1	Rational for the first design iteration
	• Circular shape with an indented interior for the mounting of controls • Stereotypical layout of the standard airflow direction and screen clearing controls using a plan view model • Rotary controls for the selection of fan speed and temperature
Design iteration 2	Modifications made between iterations 1 and 2
	• Addition of rotary bezel for the control of fan speed • Stereotypical layout of the standard airflow direction and screen clearing controls using a side view model • Addition of an Auto option for climate control within the array centre
Design iteration 3	Modifications made between iterations 2 and 3
	• Addition of the hand rest (HCRP) at the front of the array • Further subdivision of the array controls by moving screen clearing and auto buttons outside of the array centre • Addition of a surface on the right on the array for the mounting temperature and AC buttons
Design iteration 4	Modifications made between iterations 3 and 4
	• Improved tactile coding for the airflow and AUTO buttons using a collar • Increased height of the fan speed bezel • Lowering of the additional surface on the right of the array to improve control differentiation • Use of rotary control for the selection of temperature

<table>
<tr><th colspan="2">SATNAV Array design development stages</th></tr>
<tr><th>Design iteration 1</th><th>Rational for the first design iteration</th></tr>
<tr><td>
</td><td>• Circular shape with an indented interior for the mounting of controls
• Separate location of the controls for destination selection and the incorporation of a touch pad for the use of handwriting recognition for destination entry
• Layout of the map and navigation controls on the array centre</td></tr>
<tr><th>Design iteration 2</th><th>Modifications made between iterations 1 and 2</th></tr>
<tr><td>
</td><td>• Addition of rotary bezel for the control of navigation voice volume
• Relocation of the touch pad in the centre of the array
• Relocation of the destination selection buttons to the front of the array
• Addition of preset buttons for navigation destinations</td></tr>
<tr><th>Design iteration 3</th><th>Modifications made between iterations 2 and 3</th></tr>
<tr><td></td><td>• Addition of the hand rest at the front of the array
• Addition of a surface on the right on the array for the mounting of the destination selection controls</td></tr>
<tr><th>Design iteration 4</th><th>Modifications made between iterations 3 and 4</th></tr>
<tr><td>
</td><td>• Removal of map zoom button from the inner array location closest to the HCRP and redesign of the map and navigation button layout
• Addition of controls for the selection of navigation destinations
• Increased height of the navigation voice volume bezel
• Lowering of the additional surface on the right of the array to improve control differentiation</td></tr>
</table>

SATNAV Array design development stages	
Design iteration 1	Rational for the first design iteration
	• Circular shape with an indented interior for the mounting of controls • Stereotypical layout of the standard play, stop, skip forward and skip back buttons in the array centre • Incorporation of preset buttons for the selection of radio stations and CDs
Design iteration 2	Modifications made between iterations 1 and 2
	• Addition of rotary bezel for the control of the sound volume • Use of the rotary bezel as a method for the subdivision of the array using tactile coding • Addition of separate buttons for the sound options
Design iteration 3	Modifications made between iterations 2 and 3
	• Addition of the hand rest at the front of the array • Sound options buttons replaced by selection by depression of the array centre • Addition of a surface on the right on the array for the mounting of sound source selection buttons
Design iteration 4	Modifications made between iterations 3 and 4
	• Increased subdivision of the preset buttons • Increased height of the sound volume bezel • Lowering of the additional surface on the right of the array to improve control differentiation • Addition a button for the selection of sound options • Removal of the skip within buttons

Appendix 5: The glance duration data collected during the 'on the road' study

Task: Select map view

Participant No 1			Participant No 2		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1.08	Screen	0.96	0.76	PTI Arrays	1.64
		1.48	2.08	Screen	1.28
		0.76	0.76	PTI Arrays	0.68
		1.56			
		0.92			

Participant No 3			Participant No 4		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1.28	PTI Arrays	1.44	0.4	Screen	3.68
0.56	Screen	1.12	0.96	PTI Arrays	0.88
		0.92	0.84	Screen	
		0.52			
		0.88			
		0.76			

Participant No 5			Participant No 6		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.45	Screen	1.12	0.45	Screen	1.12
1.12	PTI Arrays	0.88	1.12	PTI Arrays	0.88
		1.04			1.04
		0.76			0.76
		2.76			2.76

Participant No 7			Participant No 8		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.96	PTI Arrays	1.08	1.04	Screen	0.84
		1.04			

Participant No 9			Participant No 10		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.84	PTI Arrays	0.92	1.36	PTI Arrays	1.38
0.76	Screen	1.08	0.68	PTI Arrays	1.1

Participant No 11		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.64	PTI Arrays	0.92
0.6	Screen	1.04
0.64	Screen	1.36
		1.68
		2.32

Task: Zoom map

Participant No 1			Participant No 2		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (secs)
0.68	Screen	1.16	1.4	PTI Arrays	1.52
0.8	PTI Arrays	1.56	0.76	Screen	0.88
0.64	Screen	0.84	1.44	PTI Arrays	1.08
		1.36			1.08
		0.88			0.92
		0.52			1.6
		0.92			1.18

Participant No 3			Participant No 4		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (secs)
1.36	PTI Arrays	1.44	0.64	PTI Arrays	1.76
1.16	Screen	1	1.08	Screen	1.04
		1.52	0.86	Screen	1.6
		1.16			1.44
		0.96			3.24

Participant No 5			Participant No 6		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (secs)
1.4	PTI Arrays	1.24	0.8	PTI Arrays	2.04
0.8	Screen	1.04	1.6	Screen	1
0.64	PTI Arrays	1.08	0.88	Screen	1.04
0.72	Screen	2.04	0.84	Screen	0.76
		1.6	0.72	Screen	
		1.96			
		2.28			

Participant No 7			Participant No 8		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (secs)
1.36	Screen	1.92	1.16	PTI Arrays	1.32
1.16	Screen	0.92	1.92	Screen	1.52
1.44	Screen	0.84	0.84	PTI Arrays	1.28
1.52	Screen	0.76	1.32	Screen	1.36
		1.24	0.68	Screen	1.96
		0.84	0.76	PTI Arrays	2.04
		0.76	1.6	Screen	1.04
			1.28	PTI Arrays	1.8
			0.92	Screen	1.76

	2.92	PTI Arrays	0.88
	1.44	Screen	1.52

Participant No 9				Participant No 10	
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1.08	PTI Arrays	1.52	0.52	PTI Arrays	1
0.72	Screen	1.52	1.68	PTI Arrays	1.52
		1.48	1.4	Screen	1.16
		0.72			2.16
		0.4			

Participant No 11		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1.2	Screen	2.68
0.68	Screen	1.36
0.8	Screen	0.76
1.04	Screen	

Task: Select Stored Destination

Participant No 1			Participant No 2		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.6	PTI Arrays	1.04	1	Screen	1.16
0.48	Screen	0.84	1.08	Screen	1.56
0.76	Screen	0.88	1.52	PTI Arrays	1.64
1.2	Screen	0.8	0.8	Screen	2.04
1	Screen	0.96	1.88	Screen	3.76
1.16	Screen	1.08	2.16	PTI Arrays	1.8
1.2	Screen	1.24	0.92	Screen	
1.4	Screen	1.28	1.08	Screen	
0.8	Screen	0.8	1.44	Screen	
0.68	Screen	1.64			
0.76	PTI Arrays	0.92			
0.56	Screen				

Participant No 3			Participant No 4		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.88	PTI Arrays	0.64	1.16	PTI Arrays	2.72
1.36	Screen	1.36	0.8	Screen	2.08
1.36	Screen	0.56	0.8	Screen	1.4
0.68	PTI Arrays	1.16	1.52	PTI Arrays	0.56
0.72	PTI Arrays	1.12	1.48	Screen	1.16
1.44	Screen	1.96	0.8	PTI Arrays	0.96
0.76	Screen	2.24	0.8	Screen	1
1.8	Screen	1.12	2.6	Screen	2.88
1	PTI Arrays	0.96	0.72	Screen	
0.88	PTI Arrays		1.4	PTI Arrays	
0.92	Screen		0.6	Screen	
			1.24	Screen	

Participant No 5			Participant No 6		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.96	PTI Arrays	1.08	0.76	PTI Arrays	1.32
0.8	PTI Arrays	1.36	1.44	PTI Arrays	0.92
0.56	PTI Arrays	1.12	2.68	Screen	1.28
0.4	Screen	0.88	1.92	Screen	1.2
1.16	PTI Arrays	1.04	1.6	PTI Arrays	0.6
0.56	Screen	0.76	0.84	Screen	1.44
1.52	Screen	2.76			1.36
1.48	Screen	1.24			0.88
1.08	PTI Arrays	1.04			1.88
0.72	PTI Arrays	1.08			1.44
		2.04			1.96
		1.6			1.4
		1.96			1.28
		2.28			2.12
					0.76

Participant No 7			Participant No 8		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1	PTI Arrays	0.92	0.76	PTI Arrays	0.72
1.56	Screen	1.56	2.28	PTI Arrays	1.2
1.68	Screen	2.68	0.8	PTI Arrays	1.24
1.68	Screen	0.64	1.36	Screen	1.12
0.36	Screen	0.36	0.96	PTI Arrays	0.68
0.72	Screen		0.6	Screen	1.08
			0.96	Screen	1.2
			1.36	PTI Arrays	1.08
			0.8	Screen	2.08
			1.04	Screen	1.32
			0.8	PTI Arrays	1.4
			1.84	Screen	2.08
			0.4	PTI Arrays	1.56
			0.68	PTI Arrays	2.04
			0.56	Screen	2.24
			1.04	PTI Arrays	2.52
			1.32	PTI Arrays	1.56

Participant No 9			Participant No 10		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1	PTI Arrays	1.08	0.76	Screen	1.56
0.64	Screen	0.68	1.16	PTI Arrays	0.96
1.16	PTI Arrays	1.08	2.36	Screen	1.6
0.76	Screen	1.08	1	Screen	1.36
1.2	Screen	1.32	2.08	Screen	2.56
0.84	Screen	0.96	2.24	Screen	2.2
1.12	Screen	1.08	2.84	PTI Arrays	2.16
1.12	Screen	0.76			1
1.28	Screen	1.36			1.68
1.28	Screen				
0.8	PTI Arrays				
0.4	Screen				
0.56	PTI Arrays				
0.64	Screen				

Participant No 11		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.64	Screen	0.8
0.6	Screen	1.04
1.32	PTI Arrays	1.04
1.08	Screen	0.76
0.72	Screen	0.8
0.96	Screen	1.12
1	Screen	0.8
0.6	PTI Arrays	
0.76	Screen	

Task: Increase fan speed

Participant No 1			Participant No 2		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.92	PTI Arrays	0.92	1.16	PTI Arrays	1
		0.92	0.48	Screen	1.68
		0.96	0.96	Screen	1.48
					1.36
Participant No 3			**Participant No 4**		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.84	PTI Arrays	1.08	1.28	PTI Arrays	1.88
		1.08	1.28	Screen	1.52
Participant No 5			**Participant No 6**		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1	PTI Arrays	0.84	0.88	PTI Arrays	1.8
			0.8	Screen	
Participant No 7			**Participant No 8**		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1.32	Screen	0.76	0.88	Screen	1
0.36	Screen	1.28	0.88	PTI Arrays	1.04
					1.24
					1.24
					0.8
					1.12
					1
					1.76
Participant No 9			**Participant No 10**		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0		1.56	1.36	b	3.56
Participant No 11					
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)			
0.68	Screen	0.8			
0.68	PTI Arrays	0.52			
0.6	Screen				

Task: Change airflow direction

Participant No 1			Participant No 2		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1.04	PTI Arrays	0.56	0.28	Screen	0.8
1.08	PTI Arrays				1.2
0.52	Screen				
Participant No 3			**Participant No 4**		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.8	PTI Arrays	1.96	0.96	PTI Arrays	2.72
0.48	Screen	0.92	1.12	Screen	1.36
Participant No 5			**Participant No 6**		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.84	PTI Arrays	1.28	1.28	PTI Arrays	1.44
		1.28	0.44	Screen	1.16
		1.24	0.84	Screen	1.4
		1.16			1.16
Participant No 7			**Participant No 8**		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1.4	PTI Arrays	2.28	1.44	PTI Arrays	1
		1.24	0.84	PTI Arrays	1.04
					1.24
					1.24
					0.8
					1.12
					1
					1.76
Participant No 9			**Participant No 10**		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1	Screen	1.36	0.48	b	2.16
0.72	Screen	0.56	0.76	Screen	1.28
0.72	Screen		0.28	Screen	1.28

Participant No 11					
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)			
0.92	b	0.92			
1.16	b	1.24			
		1.52			

Task: Change airflow direction 2

Participant No 1			Participant No 2		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.84	PTI Arrays	1.76	0.68	s	0.8
0.88	Screen	0.92			1.2
0.56	Screen				
Participant No 3			**Participant No 4**		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.8	PTI Arrays	1.32	0.96	PTI Arrays	2.24
0.96	Screen	1	1.12	Screen	0.76
1.24	Screen	0.56			0.64
Participant No 5			**Participant No 6**		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1.04	PTI Arrays	1.44	0.68	Screen	1.92
0.76	PTI Arrays	0.72	0.96	PTI Arrays	0.4
		0.36	0.84	Screen	
		1	0.64	Screen	
		1			
		0.76			
Participant No 7			**Participant No 8**		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1.96	PTI Arrays	0.92	1.44	PTI Arrays	1.2
2.32	Screen		0.84	PTI Arrays	0.92
0.92	PTI Arrays				
Participant No 9			**Participant No 10**		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1.32	PTI Arrays	1.4	1.4	Screen	2.4
0.71	PTI Arrays	0.99			1.2

Participant No 11		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1	Screen	1.64
1	Screen	
0.68	Screen	

Task: Turn off AC

Participant No 1			Participant No 2		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1	PTI Arrays	1.08	1.04	PTI Arrays	1.4
1.12	Screen	0.64	0.96	Screen	0.6
Participant No 3			**Participant No 4**		
PTI Glances	PTI Glance direction	Baseline Glances	PTI Glances	PTI Glance direction	Baseline Glances
(secs)		(Secs)	(secs)		(Secs)
0.96	PTI Arrays	0.84	1.72	SCREEN	0.44
0.92	Screen		1.12	PTI ARRAYS	0.64
0.72	Screen		1.48	SCREEN	1.16
0.52	Screen		1.44	SCREEN	1.24
			0.92	PTI Arrays	0.8
			1.12	Screen	
Participant No 5			**Participant No 6**		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances	PTI Glance direction	Baseline Glances
			(secs)		(Secs)
1.68	PTI Arrays	1.52	1.4	PTI ARRAYS	2.44
0.76	PTI Arrays	0.84	1.72	SCREEN	2.24
			0.6	SCREEN	1.96
					1
					0.8
Participant No 7			**Participant No 8**		
PTI Glances	PTI Glance direction	Baseline Glances	PTI Glances	PTI Glance direction	Baseline Glances
(secs)		(Secs)	(secs)		(Secs)
0.76	PTI Arrays	0.84	0.96	PTI Arrays	0.96
0.6	Screen	0.76	0.68	PTI Arrays	1.24
Participant No 9			**Participant No 10**		
PTI Glances	PTI Glance direction	Baseline Glances	PTI Glances	PTI Glance direction	Baseline Glances
(secs)		(Secs)	(secs)		(Secs)
ND	ND	ND	2.36	Screen	1.8
			1	Screen	0.64

Participant No 11		
PTI Glances	PTI Glance direction	Baseline Glances
(secs)		(Secs)
1.2	PTI Arrays	0.6
		0.8
		0.52

Task: Classic FM Preset

Participant No 1			Participant No 2		
PTI Glances	PTI Glance direction	Baseline Glances	PTI Glances	PTI Glance direction	Baseline Glances
(secs)		(Secs)	(secs)		(Secs)
0.96	PTI Arrays	1.04	0.96	PTI Arrays	1.04
1.32	Screen	1.08	1.6	PTI Arrays	1.08
0.8	Screen	0.48	0.8	Screen	0.48
0.64	Screen		1.12	Screen	
			1.24	Screen	
			0.96	Screen	
			1.28	Screen	

Participant No 3			Participant No 4		
PTI Glances	PTI Glance direction	Baseline Glances	PTI Glances	PTI Glance direction	Baseline Glances
(secs)		(Secs)	(secs)		(Secs)
0.72	PTI Arrays	1.52	1.04	PTI ARRAYS	3.36
0.96	Screen		1.32	s	1.92
0.8	PTI Arrays				0.84
0.96	Screen				
0.6	Screen				

Participant No 5			Participant No 6		
PTI Glances	PTI Glance direction	Baseline Glances	PTI Glances	PTI Glance direction	Baseline Glances
(secs)		(Secs)	(secs)		(Secs)
ND	ND	ND	0.72	SCREEN	1.56
			0.88	SCREEN	1.04
			0.4	SCREEN	0.8
			0.8	SCREEN	

Participant No 7			Participant No 8		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1.28	PTI Arrays	1.16	1.72	Screen	1
1.64	PTI Arrays	1.76	0.92	Screen	1
1.44	Screen		1.04	PTI Arrays	1.24
0.8	Screen				1.8
					1.52
					1.36
					1.44
					1.16

Participant No 9			Participant No 10		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.4	Screen	0.8	0.92	PTI Arrays	2.08
0.16	Screen	1	1.28	Screen	2.76
1.12	Screen	0.68	1.88	PTI Arrays	2.56
0.84	Screen	1	0.96	Screen	
0.64	Screen	1.04			
		0.96			
		0.76			

Participant No 11		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.64	PTI Arrays	2.2
0.96	Screen	1.84
		1

Task: Turn on Radio

Participant No 1			Participant No 2		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1	PTI Arrays	0.92	0.2	Screen	2.48
0.72	Screen	1.48			1.08
1.12	Screen	1.44			1.96
		1.04			

Participant No 3			Participant No 4		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.64	PTI Arrays	0.8	0.2	Screen	0.8
0.84	Screen	0.68	0.96	PTI Arrays	0.96
0.64	Screen	1.28	0.52	Screen	2.04
		1.2			

Participant No 5			Participant No 6		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.92	PTI Arrays	0.76	0.44	Screen	0.44
		0.68	1.2	Screen	2.48
		0.76			0.76
					0.96
					1.52

Participant No 7			Participant No 8		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1.04	PTI Arrays	1.04	0.84	PTI Arrays	1.36
1.4	Screen	0.88	0.28	Screen	0.88
		1.92	2.32	Screen	0.84
		1.64	1.28	PTI Arrays	1.56

Participant No 9			Participant No 10		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1.16	Screen	0.92	0.6	PTI Arrays	0.6
			0.8	PTI Arrays	0.72
			2.52	PTI Arrays	0.76
					0.56

Participant No 11		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.6	PTI Arrays	0.52
0.72	Screen	1.12
0.76	Screen	1.6
0.56	Screen	3.12

Task: Select CD track 7

Participant No 1			Participant No 2		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.8	PTI Arrays	0.44	0.84	PTI Arrays	1.08
1	Screen	0.92	1.36	Screen	0.84
0.4	Screen	0.84			0.96
		1			
		0.72			
Participant No 3			**Participant No 4**		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
0.68	PTI Arrays	1.4	0.96	PTI Arrays	0.84
1	Screen	0.68	0.96	Screen	0.92
0.92	Screen	0.88	1.48	Screen	1.56
1.24	Screen	1.04			0.88
0.64	Screen	0.36			0.68
Participant No 5			**Participant No 6**		
PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)	PTI Glances (secs)	PTI Glance direction	Baseline Glances (Secs)
1.16	PTI Arrays	0.84	1.04	PTI Arrays	0.88
1.08	Screen	0.76	1.16	Screen	0.84
1.64	Screen	0.8	0.96	Screen	0.4
0.8	Screen	1.24	0.64	Screen	1.32
0.88	PTI Arrays	0.92	1.24	Screen	
1.08	Screen	1.12			
		0.8			
		1.04			

Participant No 7			Participant No 8		
PTI Glances	PTI Glance direction	Baseline Glances	PTI Glances	PTI Glance direction	Baseline Glances
(secs)		(Secs)	(secs)		(Secs)
0.92	PTI Arrays	1.04	1.68	PTI Arrays	2.52
1.44	Screen	0.96	0.92	PTI Arrays	0.92
1.36	Screen	0.8	0.8	PTI Arrays	1.12
0.48	Screen	0.76	1.12	Screen	2.04
		0.6	1.76	Screen	1.24

Participant No 9			Participant No 10		
PTI Glances	PTI Glance direction	Baseline Glances	PTI Glances	PTI Glance direction	Baseline Glances
(secs)		(Secs)	(secs)		(Secs)
0.68	Screen	1.16	0.8	PTI Arrays	1.6
0.68	Screen	0.68	1.2	Screen	2.04
		0.8	0.61	Screen	1.72
		0.68	0.72	Screen	1.2
		0.8	0.4	Screen	1.32
					1.32
					0.84

Participant No 11		
PTI Glances	PTI Glance direction	Baseline Glances
(secs)		(Secs)
0.76	PTI Arrays	1.32
1.08	Screen	0.84
1.24	Screen	1.92
0.64	Screen	0.6

Task: Increase volume

Participant No 1			Participant No 2		
PTI Glances	PTI Glance direction	Baseline Glances	PTI Glances	PTI Glance direction	Baseline Glances
(secs)		(Secs)	(secs)		(Secs)
1	PTI arrays	0.88	0.92	PTI arrays	0.92
1.12	Screen				1.12
0.96	Screen				

Participant No 3			Participant No 4		
PTI Glances	PTI Glance direction	Baseline Glances	PTI Glances	PTI Glance direction	Baseline Glances
(secs)		(Secs)	(secs)		(Secs)
0.88	PTI arrays	0.64	0.44	Screen	0.72
0.64	Screen	0.64	0.72	Screen	1.2
		0.72	0.96	Screen	
			2.04	Screen	
			0.4	Screen	

Participant No 5			Participant No 6		
PTI Glances	PTI Glance	Baseline Glances	PTI Glances	PTI Glance	Baseline Glances
(secs)	direction	(Secs)	(secs)	direction	(Secs)
1.04	PTI arrays	0.6	0.56	Screen	0.68
		0.88	0.72	PTI arrays	0.96
		1.12	2.04	Screen	
Participant No 7			Participant No 8		
PTI Glances	PTI Glance direction	Baseline Glances	PTI Glances	PTI Glance direction	Baseline Glances
(secs)		(Secs)	(secs)		(Secs)
1.12	PTI arrays	1.04	1.24	PTI arrays	1.02
1.52	Screen	1.04	1.24	PTI arrays	1.04
		1.16			1.18
Participant No 9			Participant No 10		
PTI Glances	PTI Glance direction	Baseline Glances	PTI Glances	PTI Glance direction	Baseline Glances
(secs)		(Secs)	(secs)		(Secs)
0.72	PTI arrays	0.68	0.32	Screen	0.89
0.68	Screen				
Participant No 11					
PTI Glances	PTI Glance direction	Baseline Glances			
(secs)		(Secs)			
0.92	PTI arrays	0.88			
0.84	Screen	0.68			
		0.52			

Appendix 6: The functions selected for the PTI interface and the associated stereotypical control types

HVAC	Push button (push to make)	Latching push button	Two paired push buttons	Slider	Rotary control (continuous, Clockwise increases)	Rotary control (detents, Clockwise increases)	Toggle switch (on/off)
Temperature							
Air flow direction							
An automatic mode							
Front screen demist							
Rear screen heating							
Re-circulate air							

Navigation	Push button (push to make)	Latching push button	Two paired push buttons	Slider	Rotary control (continuous)	Rotary control (detents)	Toggle switch (on/off)
On/off							
Select map view							
Zoom the map view							
Turn by turn arrows view							
Select a previous destination							
Navigation voice volume							
Add a new destination							
Add a POI							

ICE	Push button (push to make)	Latching push button	Two paired push buttons	Slider	Rotary control (continuous)	Rotary control (detents)	Toggle switch (on/off)
On/off							
Volume level							
Selection of radio or CD modes							
Auto radio frequency scan							
Manual radio frequency scan							
Mute							
Band selection							
Store radio channel							
CD mode							
Play							
Stop							
Skip track							
Adjust Bass							
Adjust treble							
Adjust Fade							
Adjust Balance							

Appendix 7: Publications

Journal Papers - Academic Journals

Porter, J.M., Summerskill, S.J., Burnett, G. and Prynne, K., "BIONIC - 'eyes-free' design of secondary controls", *British Computer Society Workshops in Computing (eWIC) Series: Accessible Design in the Digital World Conference*, August 2005, ISSN 1477-9358, [WWW] Available from: http://ewic.bcs.org/conferences/2005/accessible/session4.htm.

Conference Contributions - Refereed

Porter, J.M., Summerskill, S.J., Burnett, S.J. and Prynne, K., "Design of 'eyes-free' secondary controls for drivers", *'Meeting diversity in Ergonomics' - Proceedings of the International Ergonomics Association Triennial Congress*, Pikaar, R.N., Koningsveld, E.A.P. and Settels, P.J.M. (eds), Elsevier Ltd, Maastricht, The Netherlands, July 2006, ISSN 0003-6870, [CD-ROM].

Lomas, S.M., Burnett, G.E., Porter, J.M. and Summerskill, S.J., "The use of haptic cues within a control interface", *Human-Centred Computing: Cognitive, Social and Ergonomic aspects - Proceedings of the HCI International Conference*, 3, Harris, D., Duffy, V., Smith, M. and Stephanidis, C. (eds), Crete, June 2003, pp 502-506, ISBN 0-8058-4932-7.

Summerskill, S.J., Porter, J.M., Burnett, G. and Prynne, K., "BIONIC - 'eyes-free' design of secondary driving controls", *Contemporary Ergonomics 2006*, Bust, P.D. (ed), The Ergonomics Society Annual Conference 2006, Cambridge, UK, April 2006, pp 630-634, ISBN 0415398185.

Workshops

Keynote speech at the Physicality Workshop at the HCI Conference 2009 in Cambridge.