Coventry University

DOCTOR OF PHILOSOPHY

Tactile, Show and Hide Interface Design & Visual Distraction

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Award date:
2017

Awarding institution:
Coventry University

Link to publication

TACTILE, SHOW AND HIDE INTERFACE DESIGN & VISUAL DISTRACTION

By

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December 2017

A thesis submitted in partial fulfilment of the University's requirements for the Degree of Doctor of Philosophy

ETHICS REVIEW FEEDBACK FORM
(Review feedback should be completed within 10 working days)

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Research project title: TACTILE SHOW AND HIDE INTERFACE & VISUAL DISTRACTION

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1. Evaluation of the ethics of the proposal: The main ethical issues have been adequately addressed and risks have been minimised.
2. Evaluation of the participant information sheet and consent form: These are comprehensive, clear and fit for purpose.
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ABSTRACT

The context of this research derives from the increased integration of Information Technology into the interiors of motor vehicles through interactive screens. Evidence has since shown that these devices can be distracting and visually demanding - in certain cases, fatally. This research explores the use of in-car interactive screens and a potential design solution; A Tactile, Show and Hide Interface (TSAHI).

This potential solution was developed to systematically explore the benefits and flaws of a TSAHI, assessing if it would produce less visual distraction than a touchscreen. A prototype demonstrator that explicitly embodied psychological ideas of tactility and hide-away interaction was developed to test the ideas of a TSAHI against a touchscreen demonstrator. The demonstrators were developed to ISO, NHTSA and JAMA regulations to ensure levels of quality.

The VISual Demand (VIS-D), Lane Change Test (LCT) and User eXperience (UX) experiment were conducted in a custom-built driving simulator that complied with automotive test regulations set by ISO and NHTSA.

The VIS-D results showed significant differences in favour of the TSAHI in terms of number of glances, information perception, visual demand, magnitude and amount of visual distraction. The UX and LCT results were mixed. No significant results were found, although a trend was noted for high mental and physical demands in all the demonstrators. There were also no significant findings for the system's usability tests between the demonstrators but all were above the threshold of usability.

The measures of visual demand show that there is a successful alternative to current solutions and problems with Visual Manual (VM) tasks with in-car IT could be alleviated with the notions of TSAHI.

This study provides interface designers with a rationale for selecting design approaches, an example of evaluation techniques that can provide an objective evidence base and results that can inform future design development.

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PART

THESIS STRUCTURE AND MOTIVATION

CHAPTER ONE
INTRODUCTION

1.1 - OVERVIEW AND MOTIVATION

PROBLEM STATEMENT

Like many design-oriented studies, this thesis originates from a problem. Driver distraction contributes significantly to road traffic accidents (Patel, Ball, Jones 2008) and interactive screens in automobiles demand a high amount of visual attention (Burnett & Porter 2001). In tests, participants have commented that using screens 'needed maybe 75% of my attention!' (Hutchinson & Timonen 2003). There is mounting evidence indicating serious problems in the way interactive screen based controls systems are used and it could be claimed that there is a need for a new and alternative interface design approach. This is warranted both by the evidenced problems and the severity of their effects. These problematic interactive screens have been evidenced to cause accidents and death (Green 1999) because driver inattention has been identified as one of the leading causes of car accidents, accounting for an estimated 78% of all accidents (Ho & Spence 2008). Reasoning therefore indicates that a design solution is needed for this problem.

It could be argued that the problem would be solved by ceasing to use interactive screens. However, manufacturers favour them because they are easy and cheap to produce and update, allowing a high level of functional integration into automotive vehicles, an ever-growing digital market. Such evidence points to the need for a design solution which supports screen usage, reduces visual distraction and allows drivers to retain situational awareness by concentrating on the road. Consequently, this is very much the focus of the thesis.

THESIS MOTIVATION

The author's academic career began with a BA honours in Product Design at Coventry University and my Master of Arts degree in Vehicle Design at the Royal College of Art, sponsored by the Ford Motor Company and later research by the Arts and Humanities Research Board. His relevant professional experience includes emplyment at Ford Motor Company European Design, Visteon Design, a creative design consultancy and a post as a Research Associate at the Helen Hamlyn Research Centre. He was then appointed to his current teaching position at Coventry Univesity as a lecturer in Automotive and Transport design.

Whilst studying and working for automotive organisations he repeatedly noted a lack of connection between design and ergonomics. He observed a seeming lack of willingness to 'compromise' either discipline which could become dogmatic and sometimes create divisions, with designers preferring art and aesthetics and ergonomists preferring science and human factors. The result was that ergonomists often take on the role of firefighters in a design environment and designers saw ergonomists as negative elements of their environment who stifle creativity. In the past he was actually asked to leave an area of an automotive design studio in a large international corporation because he informally mentioned an ergonomic aspect; suggesting that larger door openings on modern cars would assist occupant ingress and regress. Surprisingly these words were deemed highly contentious. Further interaction suggested that some of his colleagues perceived that such suggestions hampered their creative processes. This anecdote highlights the gap between the two disciplines. Although he has had many positive encounters with fellow designers in terms of human factors, he often reflect on this negative event and why this mutual lack of understanding happens, because design and human factors can facilitate some innovative and practical designs when integrated effectively. As a young designer he revered creative professionals and designers such as Luigi Colani, famed for his eccentric "biodynamic" designs inspired by the human form and Dieter Rams, a functionalist who designed products that have directly influenced the likes of Apple's Sir Jonathan Ives. Witnessing the success of these iconic designers is inspirational, as establishing new design methods and techniques that encompass human factors could be of great value to the design industry. In this thesis, such an opportunity is explored by the author. Similar ground to those aforementioned icons of design is covered; even going so far as to produce principles of design, as did Dieter Rams in 1985 to help other designers achieve positive design results.

RESEARCH POSITIONING

As a graduate from an art school it is fair to say that the author has not been trained or qualified in any scientific subjects. Hence it would not be appropriate for him to claim to be an ergonomist, the customary stake holder with respect to driver operation or distraction problems. Instead he can speak only as a designer, therefore in terms of the position of this research, design forms the fundamental interest of the thesis.

The research and discussions conclusively align with design methods, validity, scope, and beliefs that focus on visual distraction. Consequently, the focus of the research is manifested as a preference to the 'artefactual' over purely theoretical conclusions. This is because the definition of design is fundamentally based around creating 'a plan

or drawing produced to show the look and function or workings of a building, garment, or other *object [artefact]* before it is made' (Oxford Dictionary 2017).

However, in addition to this design focus a scientific level of understanding was needed to clarify the usefulness of the design. For this reason, a systematic evaluation was also used in the studies. This addition ultimately led to a mixed method approach for the overall methodology.

1.2 - AIM, HYPOTHESIS AND OBJECTIVES

The aim of this research is to explore the effects of automotive interactive screens on visual attention, with an emphasis on investigating a solution to the problems evidenced. An initial hypothesis is proposed that is explicit and runs parallel to the process of research and development over the course of the research. It is proposed that:

"Tactile, Show And Hide Interface (TSAHI) design has the potential to alleviate some of the visual distraction problems caused by interactive screen usage."

The hypothesis was explored through the following objectives:

- To understand the reasons for driver distraction when using interactive displays.
- To specify the requirements of a Tactile, Show And Hide Interface (TSAHI) design and hypothesise where and how such an interface could reduce driver distraction in the use of automotive secondary controls
- To define the methodology and measures to test the hypothesis.
- To produce a physical demonstrator of a theoretical Tactile, Show And Hide Interface design.
- To evaluate the extent to which the demonstrator reduces the driver's visual attention.
- To gain an in-depth original understanding about the impact of a TSAHI on a driver's visual attention.

1.3 - THESIS STRUCTURE

Figure 1.1 illustrates the structure and the chapters of the thesis. Research on driving distraction led to a hypothesis. A physical prototype demonstrating the ideas of the hypothesis was then designed and built. A systematic evaluation was conducted on the TSAHI demonstrator to produce a new understanding.

CHAPTER 1: INTRODUCTION

This chapter provides some background to the thesis, the research problem and the researcher's motivations. The exploratory hypothesis with regard to a potential solution to alleviate the problems of driver distraction is also discussed, along with the aims and objectives of the thesis.

CHAPTER 2: DRIVER DISTRACTION

A review of relevant literature examines the field of driver distraction to understand both the problem and the different approaches currently adopted by automotive HMI designers. Safety, Efficiency, and Satisfaction are identified as headlining factors to define the research lens. Haptics and Show and Hide are examined in detail to uncover elements and principles that would be useful in the design of a new interface.

CHAPTER 3: DESIGN OF DRIVER INTERFACES

Chapter three covers the participatory action research methodology of the thesis. A mixed methods approach was used to enable the study's open innovation platform of design development rather than an incremental pathway of product development. The methods deployed in this research approach aim to fully utilise the strengths of design to compliment the traditional, ergonomic scientific approach to HMI design.

CHAPTER 4: THE DEMONSTRATOR – THE TSAHI EMBODIED

To explore the hypothesis stated in chapter one, a demonstration of its capabilities was required. Chapter 4 analyses the development of the TSAHI design in detail and outlines the fundamental features and concept of the tangiable Tactile Show and Hide interface design.

CHAPTER 5: METHODS

To ensure a systematic and rigourous level of exploration, various methods were used. The methods used in the experiment design are documented, including the custom simulator rig that was built to comply with NHTSA, JAMA, and ISO design and testing standards. The HMI apperatus is outlinied, comprising the TSAHI, the touchscreen and the tactile [control] demonstrators. The design of the study also focussed in detail on quanitative eye tracking to understand Efficient use of TSAHI in terms of VISual Distraction (VIS-D), Safety using a Lane Change Test (LCT), and also measures in various quantitative User eXperience (UX) questionnaires.

CHAPTER 6: RESULTS

The results of the tests conducted on the demonstrators are discussed. SPSS data collected from the study is analysed with a one-tail hypothesis. Mean glance,

Percentage 'Eyes Off Road' Time (PEORT), glance frequency, as well as maximum glance duration are reported to understand VIS-D. The results of the Lane Change Task (LCT) are also reported to expose the participant's driving performance while engaged in the simulation. To add further context to the quanititative results, the UX data was analysed reporting on congnition, usability, tactile interaction, hedonic quality and pragmatic quality.

CHAPTER 7: DISCUSSION

Study limitations are discussed and the results in the previous chapter are noted and brought together under the headlining factors of the literature of driver distraction were uncovered. Issues of aesthetics, tactile interaction, visual distraction in various contexts are discussed along with the design principles that were discovered through the data gleaned in the tests.

CHAPTER 8: CONTRIBUTIONS AND FURTHER WORK

Finally, chapter 8 provides a summary of the study's achievements together with its contribution to knowledge, particularly in design and education. Implications for future designs are also discussed. Suggestions for futher work relating to the knowledge produced are also outlined.

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		Chapter 2 Driver distraction
Pt. 2	Related Work and Design Development	**Chapter 3** Design of driver interfaces
		Chapter 4 The demonstrator - TSAHI embodied
Pt.3	Systematic Evaluation of The TASHI Design	**Chapter 5** Methods
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Pt.4	Conclusions and Contributions	**Chapter 8** Contribution to knowledge and suggestions for further work

Figure 1.1: Thesis structure

1.4 - CONTRIBUTION AND FUNDING SOURCES

Overall the final outputs and original contributions of this thesis are as follows:

- Design of the TSAHI - a new control system.
- Evidence of TSAHI performance when compared to a touchscreen interface, looking specifically at their impact on driver distraction.
- Design principles (verified by user-tests) that are aimed towards automotive manufacturers and designers in a studio environment, to help bridge the gap between design and ergonomics and to direct future automotive design.
- A robust and usable project methodology for designers

CHAPTER TWO
CONTEXTUAL REVIEW

The contextual review begins with the task of driving, discussing how the research is derived from contemporary issues of safety and driver performance. Key issues involved in the research such as driver distraction, visual attention, and mental workload are outlined. Literature including publications and journals in automotive design, ergonomics, interaction design, user centred design, psychology, psycho-psychology, regulating associations, and health authorities were examined in the desk research. Keywords used in journals and scholarly knowledge searches included 'automotive interface design', 'visual demand', 'visual distraction', 'visual attention', 'tactile', and 'show and hide'.

Priority was given to peer reviewed papers. Publications that reflect the mainstream of work in areas of interface design and visual distraction were also considered, as well as journals where opinions differ. Personal interviews with experts were conducted where little or no information was available.

The desk research was followed by a case study of in-car technology usage to better understand the issues from the perspective of drivers, to broaden the scope of the research.

2.1 - DRIVING AND DISTRACTION

SAFETY AND DRIVER PERFORMANCE
Academics have noted that interactive screens in automobiles demand a high amount of visual attention (Burnett & Porter 2001), thus causing injuries and fatalities through drivers looking at and operating screen interfaces, as can been seen in Table 2.1 (Green 1999). Driver distraction is a significant contributor to road traffic accidents. Recently, driver inattention has been identified as one of the leading causes of car accidents, estimated to account for as much as 78% of all accidents (Klauer et al. 2006; Treat et al. 1977; Wang, Knipling, and Goodman 1996; Ho and Spence 2008)

The topic of vehicular accidents in turn links to the increasing availability of in-car technologies (Ashley 2001; Lee, Hoffman, and Hayes 2004; Wang, Knipling, and Goodman 1996). These include complex sound systems (Jordan and Johnson 1993), email (Lee, Caven, Haake, and Brown 2001) and satellite navigation systems (Burnett and Joyner 1997; Dingus et al. 1997; Fairclough, Ashby, and Parkes 1993).

	Looking (At display, mostly maps or route)	Operating	Other	Accident Totals
Injury	43	14	1	*58*
Fatality	0	1	0	*1*
Total Crashes	43	15	1	*59*
Percentages	72.9%	25.4%	1.7%	

Table 2.1: Navigation-System-Induced Crashes in Japan, for 6 months in 1998

DISTRACTION

Driver distraction is clearly defined by Young, Lee and Regan (2009) as: 'the diversion of attention away from activities critical for safe driving towards a completing activity'. Driver distraction can be caused by activities such as eating and drinking, tuning the radio, holding a conversation on a mobile phone, using a navigation system or dialling a telephone number (Schaap, Horst, Arem and Brookhuis 2013; Olson et al. 2009).

Both the ability of drivers to attend selectively and their limited ability to divide their attention between competing sensory inputs have several important consequences for driver performance. This links inevitably to the topic of vehicular accidents. *(*Ho and Spence 2008*)*. It is understood that engagement with Multiple-Additional-to-Driving tasks is almost universally detrimental to driving performance (Lansdown, Stephens and Walker 2015). In a naturalistic driving study with 100 cars, Dingus et al. (2006) noted that 78% of the study's crashes were associated with driver inattention. Klauer et al. (2006) moreover noted that safety critical events, such as a crash or near crash, were associated with complex manual/visual interactions with secondary controls, and that the usage of secondary control amounted to 23.5% of driving time. Therefore, drivers are at risk of being distracted by complex systems for nearly a quarter of the time they are in a car they.

VISUAL ATTENTION

The term "visual attention" is defined as a set of cognitive operations that mediate the selection of relevant and filtering of irrelevant information from cluttered visual scenes(McMains and Kastner 2017). Visual attention and eye movement are very closely, but not always perfectly, correlated (Salvucci 2000; Konstantopoulos, Chapman and Crundall 2010). Dewar & Olson (2002) note that visual attention can also be directly related to visual perception, suggesting that driving makes intense demands.

It has also been observed that the rapid development of in-vehicle technology and electronic devices place additional visual demands on drivers, which might lead to distraction and the diminished capacity to perform driving tasks. (Yekhshatyan 2010).

Liang, Reyes and Lee (2007) describe visual distraction as being straightforward, occurring when drivers look away from the roadway (e.g., to adjust a radio); it can be reasonably measured by the length and frequency of glances away from the road. However, there are those who argue that understanding attention workload and its motivations are more complex.

DRIVER WORKLOAD

Workload is fundamentally defined as 'the amount of *work* an individual has to do'. (Jex 1998). This definition traditionally refers to either physical or mental workload. Mental workload can be correlated to the physiological interaction of the tasks in driving (Paxion, Galy, Bertelon 2014), therefore mental rather than physical workload was of most interest for this research. Kantowitz & Simsek (2001) observe that 'research is consistent to assume that accident risks are strongly associated with driver mental workload'.

To further discuss the subject of mental workload, Hart and Staveland (1988) describe it as 'the perceived relationship between the amount of mental processing capability or resources and the amount required by the task'.

Certain issues are known to be key to investigating attention. Originally proposed by Moray (1967), Kalsbeek and Sykes, (1967) the terms 'pool of mental effort' and 'resources' become essential to the close examination of mental workload. These studies are also closely tied to the growing body of multitasking research in experimental literature (Wickens 2008: p449)

MULTITASKING

An area of relative interest for this study of the field of attention are the terms 'divided attention in performance' and 'multiple resources'. In experiments, Kantowitz & Knight (1976) and Wickens (1976) have noted that

> 'all tasks did not compete for a single undifferentiated pool of demand-sensitive resources'

Instead, tasks use multiple pools. These pools of resources have been mapped by Wikens (2008) as a three-dimensional metric that partitions spatial and verbal

resources as two major pools for coding. This pooling partitions further into visual and auditory pools that are mapped onto modalities. The three-dimensional partitioning can be seen in figure 2.1.

There are also states of task demand (Wickens & Hollands, 2000). The first is 'residual capacity', unused in task performance so that a worker has some resources available in unexpected circumstances. Secondary tasks such as using a radio, use 'residual capacity' that is not used for the primary task. The second is a state where the demand exceeds the capacity. At that point, performance will break down. Grier (2008) describes the distinction between these two states as a 'red line' of workload.

Behavioural, electrophysiological and neuroimaging researchers agree that a shift of attention in one sensory modality to a particular location, typically results in an associated shift of attention in the other modalities to that same spatial location, at least in the case of audition, vision and touch. (Spence 2002).

Cognitive load uniformly diminishes as participants become inattentive as does their sensitivity to changes in events and objects [such as pedestrians]; and their confidence in detecting them (Lee, Lee, Ng Boyle 2016). In figure 2.2, research completed by the National Safety Council (2012) perfectly illustrates this effect with on-board footage overlaid with the participants' areas of gaze. Gaze distributions are significantly smaller while drivers performed certain levels of the secondary task multitasking; peripheral vision is thereby reduced. (Reimer 2009)

Paxion, Galy and Berthelon's (2014) review of 'mental workload and driving' discussed that overload can be a considerable factor in mental workload:

> 'a low complex situation (e.g., highways), or conversely a high complex
> situation (e.g., town) can provoke an overload. Additionally, performing
> the driving tasks implies producing a high effort for novice drivers who
> have not totally automated the driving activity'

In terms of how new interfaces and technological systems affect mental workload, Silva (2014) has profoundly defined mental workload in relation to driving tasks, through the work of various researchers.

Engström et al. (2005) and Brookhuis et al. (2009) state that complex technological systems in cars induce secondary tasks that are concurrent to the primary task of driving. This in turn has increased concerns about the potential negative effects

particularly related to excessive workload and distraction, especially in potentially dangerous situations. That is, they may inherently contribute to increased levels of mental workload, to the extent that they add information to those situations (Hancock & Verwey 1997; Jahn et al. 2005; Pauzié & Manzano 2007; Verwey 2000).

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

Figure 2.1: Wickens' (1984) three-dimensional matrix of attentional resources

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

Figure 2.2: The effect of multi-tasking mental demands on a driver's visual attention. In this case the distraction was the use of a hands-free mobile phone. Without distraction, the subjects gazed widely, detecting change and the environment, but with distraction the participant's physical field of visual attention was decreased so detecting changes in the environment such as pedestrians and vehicle movement outside the square are not identified.

THE CONTEXT OF DRIVING

The context of driving has importance because different contexts can affect the way drivers use interfaces.

Naturalistic driving

Naturalistic driving contexts such as making sharp turns, speeding up and lane changing manoeuvres influence the overall propensity to engage with Visual Manual (VM) tasks.

The timing of VM also changes during different contexts. For instance, drivers wait to engage with VM until after sharp turning manoeuvres are completed. This is because this context is associated with high driving demand. The driver has to estimate curvature, steering control and check for potential threats such as oncoming vehicles and compensate for this high driving demand by waiting to use interfaces (Tsimhoni & Green 1999; Land & Lee 1994; Lappi, Lehtonen, Pekkanen & Itkonen 2013; Lehtonen, Lappi & Summala 2012). Furthermore, drivers are less likely to engage with VM interface tasks when a passenger is present for both social and safety reasons (Walsh, White, Watson and Hyde 2007; Lerner et al., 2008) . Moreover, drivers in general tend to reduce speed when they are about to engage with VM tasks. It is thought that they do this to increase their safety margin to compensate for the increase risk from distraction.

Neither the presence of other drivers on the road nor the presence of a lead vehicle seemed to influence a driver's propensity to use VM interfaces in Tivesten and Dozza's (2015) naturalistic driving study.

Age

However, age did prove to be an influence in VM tasks and driving. Tests with both younger and older drivers using a hands-free device reported increases in reaction times for both groups. Older drivers however displayed slower overall reaction times than younger drivers in both the distracted and undistracted tests (Strayer and Drew 2004). Both Funkhouser and Sayer, (2012) and Pöysti, Rajalin and Summala (2005) note that young drivers are more likely than mature drivers to initiate VM tasks, such as using a phone, while driving.

An Institute of Advanced Motorists (IAM) driver distraction report by Kinnear and Stevens (2015) indicated that in younger drivers:

'long glances away from the road for more than two seconds are rare but strongly associated with the use of mobile electronic devices, and that young drivers were more likely than older drivers to look away from the road for longer periods of time.'

The report also indicated that young drivers were a greater crash risk because of a lack of mature visual search patterns, poor calibration of expected risk with actual risk, over-confidence and an inability to anticipate hazards effectively. The same report suggests that older drivers also experience problems as they exhibit slower reaction times in general, suggesting that:

> 'age-related decline in visual perception and cognitive executive functions affect older drivers' driving performance.'

However, it was reported that they appear to compensate for their limitations with self-regulation (Molnar, and Eby 2008; Donorfio et al., 2008; Devlin and McGillivray, 2016), choosing when, where and how they drive. A paper produced by Molnar, et al., (2015) for he AAA Foundation in Washington also reports self-regulation as a strategy handle limitations.

2.2 - DRIVING CASE STUDY

The above research on safety and driving performance serves as evidence indicating that modern interactive screens, that provide a driver with in-car information and entertainment, can be intensely distracting and overwhelming. Until now, a scientific and academic viewpoint has engaged with the problems. However, it is also valuable to understand that a more subjective viewpoint could produce a richer level of evidence as a context for the research because this can not be attained from much of the scientific data and publications avalible.

To gain a further understanding of the problem, a case study of in-car technology devices was conducted.

As case studies represent only a small sample of a driver's total experience with a vehicle during a period of time, the data is not typical of a wider population. They are analyses of persons, events, decisions, periods, or other systems that are studied holistically by one or more methods, creating in-depth studies of a situation, rather than presenting a statistical survey. However, these short case studies are indicative, allowing further elaboration and hypothesis creation about visual distraction and screen use. (Thomas 2011). Overall, the intention was to provide the researcher with useful tacit knowledge about usage that could only be obtained from the subject physically engaging with a product through an intense, immersive experience (Polanyi 2009; Sternberg and Horvath 1999; Krogh et al. 2000). The results were subjective but

have a high degree of conceptual validity, which is one of the strengths of case studies (George and Bennett 2004).

CASE STUDY PROCEDURE

To give details of how the tests were conducted; five differently branded in-car screens were sampled to represent the growing trend of car interiors fitted with a multi-functional interactive screen. An Audi A8, a Mercedes Benz S-Class, a Lexus-RX300, a BMW 7-Series and a Nissan Primera were tested. These vehicles can be seen in more depth in Appendix 1, where the test-drive notes are also documented. Figure 2.3 shows a typical test environment. One of the vehicles were touch screen based. The remainder were multimodal controlled by a physical multi-functional joystick that the driver could twist, pull, push, press, or operate directly with screen side buttons.

Two subjects were used for the the six cars. One was an experienced Finnish driver, with a licence to drive any vehicle including HGV articulated haulage trucks. The other was the researcher, whose low level of experience was useful as a comparison to the other highly experienced driver.
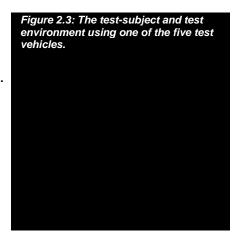
Each test drive took approximately 30-60 minutes. Vehicles were recruited from dealerships and contained no aftermarket modifications. Audio recordings of the subject and the researcher were taken and in certain cases, photographic and video evidence was collected. Following this, written notes were made about the experience. The subsequent analysis of the data concentrated on problematic areas of screen usage in addition to positive areas of experience.

A 'self-witnessing', a qualitative research method regularly used by Leon James of Hawaii University was deployed to collect the data during these road tests. James claims that:

> 'Self-witnessing reports yield data that are not retrospective but on-going: the driver speaks out loud into a tape recorder at the very time the emotions, thoughts, perceptions and actions arise spontaneously and concurrently with the act of driving. Later transcriptions of the tape allow us to display in concrete and visible terms the overt expressions of feelings, thoughts, and perceptions that accompanied a particular driving episode. This method does not claim to obtain a complete and accurate record of the driver's inner reactions, but rather a sample of these'.
> (James 2008)

This method is not new, but has been used for nearly a century to monitor inner activities such as thinking and feeling (Watson 1924), in assessing types of interaction. This method is essentially a 'think aloud protocol' and was also used by Herbert Simon in the early 1960's in the creation of Artificial Intelligence.

To clarify the results, certain activities were omitted from the test conditions to maintain the safety of the subjects. These included eating, writing, using a calculator, dialling a cell phone or reading a book or newspaper (Olson et al. 2009) as these distractions are generally illegal in the UK, or not related to the task of driving.

Figure 2.3: The test-subject and test environment using one of the five test vehicles.

CASE STUDY CRITERIA

The case study was judged on several specific criteria:

Size of graphic

Large graphics that were easy to comprehend were rated as 'good', and small hard to comprehend graphics were rated a 'bad'.

Spacing of graphics

Spacing of graphics referes to the amount of information that was on a screen while driving. A screen filled with information was considered 'cluttered' and a screen with minimum but useful information while driving was considered 'uncluttered'. A cluttered screen was rated as 'bad' and an uncluttered screen was rated as 'good'.

Eye & head position

At least 90% of the information used by drivers is visual, (e.g., Booher 1978; Bryan 1957; Sivak 1996), hence keeping a driver's eyes and head up is imperative if the driver is to see the road, hold lane and avoid potential accidents. In this criteria 'eyes

and head up' is rated highly and 'eyes-down and head down' is rated badly, as was 'head-up and eyes to ceiling'.

Touch Interaction
The level of touch was rated in terms of interaction. If a system was 'interactive' it was rated as good. If it was senseless and didn't engage the touch senses then it was rated as 'bad'. There was a mid-point rating of 'reactive'.

Kinesthetic (reach)
In terms of reach, 'Lots' of controls was rated as 'bad'. 'None' was also rated as 'bad'. A medium to low amount, (minimum), was seen as the optimum. Spacing of controls was also rated in the case study. A spaced out level of clustering was rated as 'good' and a tight cluster was rated as 'bad'.

Colour coding
Colour coding was also considered. If a screen system utilised colour coding it was rated as 'good'. If it did not, it was rated as 'bad'.

Ease to remember
If the test driver found it easy to remember functions and their locations, a system was rated as 'good' and if it was hard to remember functions, it was rated as 'bad'.

CASE STUDY RESULTS
Various aspects of the case studies indicated that screen use was distracting and required a high level of visual attention, as noted by Burnett and Porter (2001), Eby and Kostyniuk (2003) and Tijerina, et al. (2000). This was exemplified by the more experienced subject, who commented that:

 'It is a hard task, mainly because of the confusing interface. You cannot
 focus enough if you have to divide your observation to the traffic and the
 interface… when you focus more on traffic you are already back in the
 basic starting point where you cannot do any tasks… I have to tell you it
 needed maybe seventy-five percent of my attention, not the easiest task'

Table 2.2 shows the results data of the test drives and figure 2.5 summarises the good and the bad issues in a chart. Looking at these in more detail, overall the best interactive screen system of all the test cars was undoubtably the Audi. The uncluttered, colour coded and organised bold graphics of each functional area in the GUI was a successful feature. Processes were easy to remember in the Audi and the

well-spaced physical function buttons made the functional areas easy to access. Recent research by Rümelin and Butz has emphasised that for GUI usage, large graphics were advantageous. In their research, they use a large screen with 30mm x 30mm buttons (Figure 2.4b); an increase in the 20mm touch button size as suggested by Colle and Hiszem (2004) in their recommendations for kiosks. Fitts' law (1954) also suggests that an increase in size can make targeting easier. Manufacturers such as Tesla (Figure 2.4a), have taken advantage of this perspective to make interactive screens that are considerably larger that the conventional 6-7 inch screens used in the Lexus.

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

Figure 2.4: 2013 Tesla with a 17inch large screen GUI interface. (B) The Rümelin and Butz research demonstrator that uses oversized buttons on large touch screens.

Second best overall in the road tests was the Nissan. 'Familiarly simple' is the best way to describe the general experience when compared to the others. The manipulation of the screen felt very direct. The fact that most of the physical controls were dedicated to a bold screen graphic helped this. The disadvantageous attribute for the Nissan GUI was clutter. The third place belonged to the BMW. The easy reach of the physical controls meant that there was no vision required to grab the few physical instruments. The cluttered small graphics led to a lengthy search for the functions. The haptic feedback controller in the BMW however was very effective. The Mercedes and the Lexus were close to being an equal fourth. The Mercedes suffered from a very poor screen position, cluttered GUI and buttons that had to be looked at because they all felt the same to touch. The Lexus suffered from poorly sized GUI graphics, a similar problem to the Mercedes, but with a better screen position. A near senseless touch-screen with no haptic feedback determined its ranking order as last amongst the other cars.

In general, all the low scoring cars required too much visual attention because their screens were cluttered, graphics too small, there was no colour coding, sentences

were over-long and fonts were too small or too similar. These factors made them difficult for the driver to view or to make discriminations in the area graphical user interface. Thus, decision making was both difficult and lengthy.

Figure 2.5: Results of the test-drives

CASE STUDY CONCLUSION

In summary, the results provide some evidence that there is potential to make simple fixes to a GUI to improve both the design and the in-car screen interaction. These include making the GUI screens less cluttered and the graphics larger, using colour codes, shortening sentences so that they can be viewed faster and using different font sizes; for example larger graphical headers to facilitate driver orientation and navigation around the screens. The in-car system for screen A performed well with respect to the above. All of the test cars had a common problem however, in that the driver still had to look at the screen instead of the road. A major comment made by the experienced driver was:

'I don't feel very happy driving here with the driving situation and having to look at the screen.'

This raises the question as to whether a more fundamental problem exists about in-car interaction between the driver and the system.

Is the real problem that the driver must direct vision from the road to use the system? The evidence presented through these case studies strongly indicates that this is a probability. It aligns to the perspective of Burnett and Porter (2001), Eby and Kostyniuk (2003) and Tijerina, et al. (2000), who agree that visual attention to car systems is the primary problem, concluded via a differing method of investigation.

Table 2.2a: Visual interaction with screen functions

	Graphical User Interface					Eye & Head Position				
	Small graphics	Medium graphics	Large graphics	Cluttered	Un-cluttered	Head-down & Eyes-down	Head-up & Eyes-down	Head-up & Eyes-up	Head-up & Eyes-forward	Head-up & Eyes to ceiling
Nissan			●	●			●			
Audi			●		●		●			
BMW		●		●			●			
Lexus		●			●		●			
Merc			●	●		●				
	bad	←→	good	bad ←→ good		bad	←	good	→	bad

Table 2.2b: Haptic interaction with screen functions

	Touch					Kinesthesis (reach)									
	Type of Controls					Amount of controls					Spacing of controls				
	Senseless	←→	Reactive	←→	Interactive	Lots	←→	Medium	←→	None	Tight cluster	←	Loose cluster	→	Spaced out
Nissan			●					●					●		
Audi			●					●						●	
BMW				●					●						●
Lexus	●						●					●			
Merc			●				●					●			
	bad	←		→	good	bad	←	good	→	bad	bad	←		→	good

Table 2.2c: Memory interaction with screen function

	Colour coding of areas		Ease to Remember		
Nissan		●			●
Audi		●			●
BMW	●		●		
Lexus	●			●	
Merc	●				●
	no	yes	bad	neutral	good

THE NEED FOR AN ALTERNATIVE APPROACH TO AUTOMOTIVE INTERFACE DESIGN

The above references and research provide ideal background data and evidence to warrant research into the way that interfaces influence drivers. Different research has

provided similar conclusions. They indicate the complex relationship between design and information technology issues, with respect to car interfaces.

The previous sections evidenced the proposition that modern interactive screens that provide in-car information[1] can overload drivers, attract high amounts of visual attention and distract them from the task of driving. There is mounting evidence of a serious problem in the way that interactive screen-based controls systems are used. Potentially, a new approach is needed to the interface design of these controls to investigate other ways of reducing visual distraction so that drivers can focus on the road.

The research position of this study parallels this perspective. Design is initiated as a problem-solving activity that is perfectly suited to finding new solutions through the concept of a new artefact.

2.3 - OTHER DESIGN OPTIONS

Design organisations often concerned about interaction often take a 'Sensorial Design' (Jacobson 2000) approach to help propose a new design solution. This would mean that a thesis would look towards senses other than vision to broaden the range of sensorial interaction (McAra-McWilliams 2004).

SENSORIAL PERSPECTIVE
Potentially, this ideal seems attractive as the problem of visual distraction is sensorial; with human machine interaction spread out over various senses as McAra-McWilliams suggests, it is therefore plausible to suggest it could promote less demand on a driver's vision. To better comprehend the Sensorial Design approach, a review of the human senses and the human mind is requried as an introduction.

Ocular (vision)
The sense of vision needs to be focused on the primary task of driving. Sivak (1996) claims that 90% of all information used for driving is visual. Hence, all efforts should be made to alleviate the visual demands of tasks such as secondary controls.

Auditory (hearing/sound)

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1 In 2001 Burnett & Porter noted that Galer Flyte (1995, pp. 159-160) categorises the control we are interested in as "Those which are unrelated to driving" - e.g. entertainment devices & climate control. This study concentrates on this area of information systems because they are less regulated by law.

Audio in the form of voice command has been investigated intensely by manufacturers to perfect the use of voice recognition (Rabiner and Juang 1993). However, it should be noted that voice recognition can be unreliable, as social and medical events and conditions can render such an interface useless. Poor speaking techniques and ill health such as depression, gastric illness caused by stomach acid, voice overuse or even the common cold can easily alter speech patterns (Ellgring and Scherer 1996. University of Michigan Health System 2003). Regional accents can also prove problematic for auditory interfaces. Forsberg (2003) suggests that the potential use base for Automatic Speech Recognition needs to be widened.

Haptic (touch/feel)
The sense of touch and movement holds the most potential in the context of this review. It is ideal because touch is less directly dependant on vision.

MODALITY APPROPIATENESS

Welch and Warren's 1980 modality appropriateness hypothesis assumes that 'the sensory system that has the greatest precision for a given task will dominate perception'. In the case of in-car interactions, this means that any interaction within the vehicle will be dependant on both the operation and the context of driving. Visual dominance plays a large role within this scenario. The visual dominance model (Hecht and Reiner 2009; Calvert, et al. 2004; Hatwell, et al. 2003) basically suggests that whenever possible, vision will lead interaction and that the remaining senses will react to visual stimuli. Within the framework of modality appropriateness, this means that occular senses cannot be ruled out of any solution, *but* unlike current touch screens, a system could be designed so that vision confirms the goal of the interaction rather than being used for a high level of feed-forward and feedback.

HAPTIC HYPOTHESIS

Now that it has been established that haptic senses should be used as a potential solution. A hypothesis is proposed.

H1: 'TSAHI will result in less driver distraction than the Touchscreen'
H2: 'TSAHI will be perceived as more usable than the Touchscreen'

The rationale for this hypothesis is as follows; In terms of tactility, it is argued that if information flows through the fingertips there could be less need for vision when using controls. To add to that, a Show & Hide approach is hypothesised because it has the potential to reduce the amount of choices a driver has; if undesirable functional

clusters are hidden, then there will be less to search for and therefore lessen the need for visual selection.

2.3.1 - HAPTIC DISPLAYS

TACTILE STATE OF THE ART

Interview with BMW - Haptic approach

The automotive company BMW have claimed that when the 7-series was first launched in 2001, the need to focus on the road strongly influenced in the design. During a personal interview held in BMW's Munich headquarters, the Design Director, Christopher Bangle, described their car of the future as a:

> 'crucifix that overlays the interior [as seen in figure 2.6c]. Everything at
> the top should be optical and everything under a horizontal line is haptic'
> (Bangle, Assmann, & Künzner, 2003).

Künzner - the designer of the iDrive - further commented that they spent a considerable time developing 'haptic profiles' for their haptic controller. Dr. Assmann were also asked whether they set time limits on how long a driver uses a function. Assmann replied:

> 'No, we work under a principle of interrupt-ability. We like to ensure that
> the driver can use the controls, take a break to look at the road and then
> pick-up where they left off'... 'They discovered in aircraft that if you force a
> person to do things in a set amount of time they will look down at the
> controls to speed things up. This means they look away from the window,
> it's unsafe (Assmann, Bangle, Künzner 2003).'

Renault - 'Touch design' approach

Renault and Citroën for example, have referred to tactility in their theoretical design strategies for control interaction, but with relevance to pleasure, tactile appeal or ease of use with vision (Borroff 2002, Citroën 2005, Visteon 2008 and Renault 2001). Renault's World of Touch Design encompasses the notion of 'tactile appeal' and intuitive controls that explicitly focus on tactility. The appearance of a control enables the driver to know whether to rotate, push or to pull (Borroff 2002). Some of the most inspirational work to date is found in the Talisman Concept, the 2001 flagship of Touch Design (Figure 2.6b). Finger shapes were sculpted into the respective control stems, making them resemble 'spatulas' (Renault, 2001). However, although such controls

may seem logical and inviting, it has never been publicly claimed that their focus is to keep a driver's eyes on the road.

Alpine - 'Pulsetouch' approach
Alpine is another manufacturer aiming to increase the tactility of their control areas. When a driver presses a graphical button on the Pulsetouch screen (figure 2.6a), an electronic pulse with a 'click' like sound replicates the sensation of a mechanical button.

Product design approaches
It is notable that tactile approaches are currently used in product design. Figure 2.6e shows a 2013 remote control with tactile raised buttons. The buttons are shape coded to metaphorically match their functions (Green, Levison, Paelke & Serafin 1994). This is suggested to be an effective way to facilitate mapping abilities (Norman 2005).

A recent development in tactile designs is the TactusTM touchscreen (figure 2.6d). This is a design that manipulates the polymer surface of a touchscreen to create an actual tactile surface, rather than replicating a sound.

TACTILE INTERFACE RESEARCH
Knowledge is limited with respect to the development of tactile interfaces in automotive companies. Further research into the design of tactile secondary control interfaces will promote the understanding of the fundamental knowledge.

However, academic studies have been conducted about the design of tactile secondary automotive controls (Lomas et al. 2003; Moore 1974 and Prynne 1995). In rarer cases, secondary controls with and without vision have been specifically studied (Summerskill, Porter and Burnett 2003; Burnett and Porter 2001 and Summerskill et al. 2005).

The 2003 study, cited above, discusses the need for different types of interaction to reduce 'eyes off road' times. However, in the later 2005 studies, an essential element of vision was not considered in that various experts in psychology have proved that memories of vision continue to be used, even when no vision is available (Lederman et al. 1987 and Rieser; Lockman and Pick 1980). Rather than consider this essential element. the design process of the studies by Burnett, Porter and Summerskill et al. were instead based on guidelines attained from user-group tests with physically blind users. Although this idea was novel, in reality drivers of conventional vehicles must use vision when driving.

Figure 2.6: Car interiors' controls with a focus on touch & movement. (a) Alpine's Pulsetouch™ screen. (b) Renault's Talisman stalks and a sketch of Zoe's gear paddles. (c) BMW's 7-Series haptic iDrive controller & interior with a crucifix overlay indicating optical and haptic areas. (d) Tactus touch screen, designed to give real tactile feedback. (e) 2013 TV remote that uses shape-coding.

The drivers of research for blind and tactile interactions outside the context of driving are nevertheless similar to those for haptic in-car interfaces. Therefore, if there is a need to use interfaces that do not rely on vision, it is worth discussing both haptic

devices and the state of the art in general, to create a broad picture of the area's existing knowledge.

HAPTIC DEVICES

Various devices such as The Phantom by Geomagic, the Logitech iFeel mouse, force feedback joysticks (Sjöström 2002, and force feedback steering wheels/pedals are popular physical haptic interfaces. Those seen in figure 2.7 use motors, vibrators, and actuators to provide a user with haptic feedback and information relative to the task.

Figure 2.7: haptic devices available on in the marketplace. A) Phantom by Geomagic, B) Wingman iFeel mouse by Logitech, C) Force feedback joystick by Thrustmaster, D) Force feedback steering wheel by Thrustmaster.

For devices such as the Phantom, various software is available for specialised uses including virtual clay sculpting, industrial design, game development, dental surgeryy and forensic reconstruction (Geomagic 2017). Devices such as the iFeel mouse by Logitech and a variety of force feedback joysticks, steering wheels and pedals have a much wider application as consumer goods that can be used in the lucrative industry of computer gaming as well as in driving simulation studies. (Toffin et al. 2007; Switkes et al. 2006; Liu and Chang 1995)

Some of the most recent haptic devices for the blind have been developed in the field of navigation. Spiers and Dollar (2017) note that:

'Haptics has often been considered for VI interfaces. Most common to this application is the use of vibrotactile feedback, which has been implemented in numerous prototypes for almost 50 years… vibration has dominated haptic guidance research, primarily due to ease of technical integration and effectiveness at eliciting user response.'

This type of vibrating devices include the 'Sentiri' proximity sensing headband (Sentiri.chaoticmoon.com, 2017), although dogged with complaints about being

uncomfortable (Nordahl et al.2010: p.139), torso mounted devices such as the 'feelSpace' belt (Nagel et al. 2005; Kärcher et al. 2012, 'Tacit' and other hand mounted proximity feedback devices. In the past, many different body areas have been utilised for haptic interaction feedback. Nordahl et al. (2010: p.140) list the more common body contact areas as being the head, shoulders, back torso, waist, wrist, fingers, and feet in their classification of tactile wearable interfaces.

A recent design derived from research that is counter to the current trend of wearable devices however is the 'Haptic sandwich'. This haptic product seen in figure 2.8b investigates the possibility of a handheld shape changing device to guide pedestrian navigation.

HAPTIC DESIGN GUIDELINES

In 2005, Carter and Fourney surveyed research papers in the field of tactile and haptic interaction, producing a level of guidance regarding the subject of haptic design. These guidelines cover the following:

- Tactile / haptic inputs, outputs, and / or combinations
- Tactile / haptic encoding of information
- Content-specific encoding
- User individualization of tactile / haptic
- Interfaces / Interaction Tasks

The survey, by admission of its authors, is however limited and covers only 16 papers and is not comprehensive, although these include guidance, guidelines, principles, recommendations, requirements, standards and similar concepts.

Guidelines have been collated by societies and groups to enable those with limited vision to cope with daily living. The World Blind Union and the Royal National Institute of Blind People (RNIB) are two prominent examples. However, the driving force in these guidelines is the 'built environment' rather than products.

KNOWLEDGE IN THE FIELD OF HAPTIC PSYCHOLOGY

Knowing the details of the haptic perceptual system is useful to inform the design process that could influence a consequential tactile design. The process of haptics and the exploration of the real world through touch is well understood in the work of Roberta Klatzky and Susan Lederman. Although a lot of their seminal haptic research was conducted in the 80's and 90s there understanding of haptic with and without

vision is comprehensive and extremely detailed in comparison to Carter and Fourney (2005).

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

Figure 2.8: A) Tacit - A range finding haptic device to help the blind with object avoidance. B) The Haptic Sandwich – A navigational haptic device that changes shape to direct blind users. C) the feelSpace navigation belt using vibrotactile devices to orientation users. D) Sentiri- a proximity sensing headband for direction finding.

Lederman and Klatzky et al. describe three key haptic features: preview, reach, and contact (as seen in figure 2.9). A brief summary of the process is as follows.

Stage one: Preview
During preview, haptics are used as early as possible in the case of difficult, unsatisfactory visual judgements. During the haptic process, late-vision[2] facilitates sequential pre-reach. Also, if semantic accessibility is low, reach and contact is less frequent. (Klatzky, Lederman and Matula 1993; Purdy, Lederman & Klatzky 1999).

Stage two: Reach
The task of reach involves three main elements: transport of the arm to an end point, pre-shape[3] and orientating the wrist position. Overall, when vision is not available, reach speed can be faster due to a lack of anticipatory responses. When aiming is slower, the sight of the initial hand position improves accuracy and grasping would appear to be unaffected by the absence of vision[4]. Pointing accuracy is considerably higher when the target is continuously available than when it disappears shortly after the onset of movement[5]. However, without initial vision, pre-shaping is very low and leaves the hand unprepared for contact and is also less accurate. (Purdy, Lederman & Klatzky 1999)

Stage three: Contact
Once reach has been made, contact with the object is established through stereotypical hand movements called Exploratory Procedures (EP) (Klatzky, Lederman & Reed 1987). Certain EP extract a particular property known as a Most Diagnostic Attribute (MDA). Known EPs and their MDAs are listed in Tables 2.3, 2.4 and 2.5 below (Klatzky, Lederman & Reed 1987; Lederman & Klatzky 1990; Klatzky & Lederman 1992). The sequential order of the EPs is also described.

Information extracted during brief contact can be used to guide hypotheses about an object's identity (Lederman and Klatzky, 1997). Haptic glances[6] however are relatively ineffective. (Klatzky & Lederman 1995).

Contour Following has been found to be the *slowest* EP in matching tasks and can cause heavy memory loads (Lederman & Klatzky 1997; Klatzky, Lederman & Matula,

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2 The last viewing a subject has had of an object.
3 In the task of reaching for an object a hand will prepare a mould or shape with the fingers to match the object to be grasped.
4 Expectations about targets regulate initial grasp forces.
5 For this reason, it is important that the target or object never moves once a subject has started to reach for it.
6 Spatially constrained contact that involves little or no movement of the fingers

1993). Raised graphics are *not* very affective. The success rate for recognising pictures using raised graphics is also very low. (Klatzky, Loomis, Lederman & Fujita 1993). In terms of making a feature salient, Klatzky, Lederman and Reed (1987) note that 'If all objects have similar values [in a haptic search], there can be no salience'

	PREVIEW	REACH	CONTACT	
DIMENSION IS NAMED	OBJECT IS EXPOSED	SUBJECT REACHES	SUBJECT CONTACTS	SUBJECT RESPONDS
	TOTAL REACTION TIME			

Figure 2.9: Trials with touch. A diagram created by Klatzky, Lederman and Matula (1993: p731) to aid the construction of their experiments.

Table 2.3: Exploratory Procedures for Geometric properties

Order	EP	MDA		Physical action
1st	Contour Following	Exact Shape.		A tracing or edges using the fingers.
1st	Enclosure	Size & Gross Shape		A static moulding of the fingers and hand to the contours of an object.

Table 2.4: Exploratory Procedures for Material properties

Order	EP	MDA		Physical action
2nd	Pressure	Hardness		Produced by applying torque or normal forces to an object, while the object is stabilised.
2nd	Lateral Motion	*Texture*		A rubbing movement using the fingers and the hand.
3rd	Unsupported Holding	*Weight*		When object lifted without a supporting surface.
4th	Static Contact	Temperature		When contact by a large area of skin surface is made without effort to mould the hand around the object.

Table 2.5: Exploratory Procedures for Functional properties

Order	EP	MDA		Physical action
5th	Part Motion Test	*Motion*		The act of making a part move by applying force to it while the body it stabilised.
5th	Function Test	-		The execution of movement that performs certain functions.

2.3.2 - SHOW/HIDE AS OBJECT MANIPULATION

SHOW AND HIDE STATE OF THE ART

Jaguar - show and hide approach

The second element of this sensorial design tactile, show and hide approach involves the showing and hiding of controls. Showing and hiding functional areas has been used as a design approach in the past, but infrequently and without emphasis on visual distraction. For instance, functional areas are currently shown and hidden to create a greeting 'handshake' between the driver and the car. An example of this can be found in the in the 2007 Jaguar XF (fig. 2.10d):

> "Get into an XF and the start button in front of the JaguarDrive
> SelectorTM pulses red, like a heartbeat. Press this button to start the
> engine and the cast alloy JaguarDrive SelectorTM rises into the palm of
> your hand. Simultaneously ... the rotating vents turn from their flush,
> 'parked' position to their functional open position (Jaguar 2007)."

Nissan - show and hide approach

The 2015 IDS concept by Nissan, (shown in figure 2.11), is another example of a design that transforms showing and hiding functional areas. In this case, the vehicle transforms as it converts to automated mode to make a more relaxed environment for its occupants. Then, the interior becomes more driver focused when the vehicle needs to be controlled by a driver. To elaborate in more detail:

> "The cabin becomes even more spacious when the driver selects Piloted
> Drive. In this mode, the steering wheel recedes into the centre of the
> instrument panel and a large flat screen comes out... It's like relaxing in a
> living room. When the driver selects Manual Drive, the roomy interior
> transforms to put the driver in control." (Nissan 2015)

Interview with BMW and Rolls Royce - show and hide approach

In other cases, such as the BMW 7-Series (Fig 2.10a), the phone pad slots in and out of the dashboard. Rolls Royce, owned by and run by BMW, also use hide away control covers. In the personal interview conducted by the researcher, BMW stated that their designs are features that simply make the interior more aesthetically pleasing for customers:

> 'even though they [the customers] could afford all the new technology
> they didn't want to see it' (Bangle, Assman & Künzner 2003).

Interview with Renault - show and hide approach

Renault Wind controls are hidden with covers (Fig 2.10b). In another such personal interview, a Renault design director declared that customers want to

'make it [controls] go away when you don't need it' (Melville 2005).

Visteon - show and hide approach

In a recent Visteon prototype, lights switch on and off to show and hide static screen buttons. In a press release Visteon expressed that they wanted a 'clean, "dead-front" look'. (Visteon 2008)

SHOW AND HIDE RESEARCH

In the cases of BMW, Renault and Rolls Royce, the personal interviews with designers, design directors and ergonomists, conducted by the researcher, clearly indicated that they had neither the design intention nor ergonomic evidence to understand what effect 'show-hide' control panels could have on visual distraction. Apart from these above examples, public knowledge about designed products that explicitly use show and hide techniques in the field of automotive design is rare. However, similar to the discussion of tactile designs undertaken in the last section, there is a body of fundamental knowledge from the psychological professions. The following paragraphs therefore utilise this field to better understand fundamental ideas involved in the task of showing and hiding objects with which a subject needs to interact.

To date there are no studies that aim to measure the effects of a show and hide interface on visual distraction in the field of automotive design. This indicates a substantial research gap that could potentially make this research a pioneering study for the discipline of automotive design and ergonomics. However, in the discipline of product design, psychological theorist Donald Norman (1988) noted that organisation can help overcome complexity when hiding controls.

This complexity factor seems relevant and could be adopted for this study. Psychophysically, choice overload, as described by Schwartz (2004), could be reduced through considering the show-hide approach and also the visual dominance model (Calvert, et al., 2004; Hatwell, et al., 2003; Hecht and Reiner 2009). Minimal choice, therefore, could reduce the amount of time spent by the driver in making spatial and temporal visual scans (Kruger and Shapiro 1980) used for the cognitive survey-type maps (Rieser, Lockman and Pick 1980) and calibrations that guide the motor programmes of the arm (Johansson et, al 2001), rather than looking at the road.

Notwithstanding, it should be noted that as yet there is no design, human factors knowledge or conclusive evidence to support, validate or dismiss the worth of using a 'show-hide' control panel while driving. Moreover, its potental effects on the driver are completely unknown.

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

Figure 2.10: Show and hide features of current production and concept cars. (a) BMW's telephone pad on the dashboard. (b) Rolls Royce's controls under covers. Both are to make the interior look more appealing to customers. (c) Renault's Wind concept 'hide away' climate controls that are done to make the interior simple. (d) Jaguar central console showing the vents and central knob that show and hide for theatrical effect.
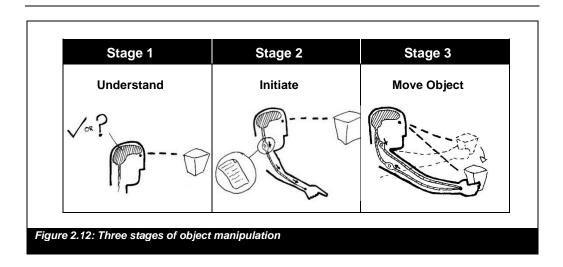
Figure 2.11: Nissan's IDS concept from the 2015 Tokyo Motor Show that has a transformable interior for different modes, showing and hiding the controls as desired. The top photo is the driving mode, and the bottom the piloted mode.

KNOWLEDGE IN THE FIELD OF SHOW/HIDE AS OBJECT MANIPULATION PSYCHOLOGY

There is little cohesive material that can document the complete picture of object manipulation. This is mainly because the subject is so wide, spanning from neurology to mechanical robotics. For this reason, the literature review focussed on the knowledge of learning (heuristics), memory, limb action (kinesthetics) and human monitoring systems of vision and nerve activity. The scope of the literature search was: *The exploration of objects within arm's reach*.

The following briefly summarises knowledge in the field of object manipulation. It is split into three stages with the following sequential order: Understanding the task, initiating the performance, and moving the object (Figure 2.12).

Stage 1	Stage 2	Stage 3
Understand	**Initiate**	**Move Object**

Figure 2.12: Three stages of object manipulation

Stage one: Understanding the task

Initially, the subject typically gazes at the object to be manipulated. This achieves several things: obtaining spatial calibration to plan the motion of the object being manipulated (Johansson, Westling, Bäckström, Flanagan 2001: p.6930) and comparing this spatial image to other spatial imagery from experience. Lederman, Klatzky, Collins and Wardell (1987) note that this imagery is also used to estimate Euclidean lines. The imagery is stored in 'survey-type' cognitive maps (Rieser, Lockman and Pick 1980, Siegel and White 1975).

Stage two: getting ready to perform

Once the task is understood, a subject prepares and executes a Motor-programme to move the arm (Lovelace 1989). If either the subject or the target do move, the subject will need to spatially re-calibrate and re-compare the manipulary space to their cognitive maps in order to create a new motor-programme. Motor-programmes containing kinesthetic information (Jones and Connolly 1970; Johansson, Westling, Bäckström and Flanagan 2001) provide the feed-forward effect needed for the initial movement. Motor programmes have been proven to last in the memory for a day and possibly longer. (Flanagan, King, Wolpert, Johansson 2001)

Stage three: Moving the object

Reaching for an object: Once the motor programme has sent the necessary *kinesthetic* information to the arm, the subject will reach for the object. Using feedback from proprioception and vision, the subject will create new motor programmes to correct errors with minimum perturbation. Different states of reach, full-vision, non-vision and partial vision can cause the accuracy to differ. Often a subject can be misled into believing that vision can always lead to a higher accuracy. This is a misconception and will be discussed later in this thesis. To investigate the task of

moving an object in more detail, the areas of full-vision, non-vision and partial vision need to be discussed.

Non-vision in object moving

If no vision is available, memory will guide haptic exploration. Subjects who complete object manipulation without vision have proven to be quite competent. A non-vision peg- in-the-hole experiment conducted by Purdy, Lederman and Klatzky (1990) reported 100% accuracy over a duration of 200 trails. It takes the subject longer to achieve the task (31%), but the lack of vision does not affect the ability to grasp (Westling and Johnsson 1987).

Partial-vision in object moving

Johansson et al. (2001) suggests that peripheral vision and/or memory can be adequate for guiding manipulary hand movement although variabilities of distance travelled when transporting an object from one location to another were experienced. This varability can be up to one-third greater than the actual distance. In tests conducted by Johansson, the subjects remarked about the high amounts of concentration required to perform tasks with a locked gaze. Kustov and Robinson (1996) presume that this 'effort' is required to suppress eye movement.

KNOWLEDGE IN THE FIELD OF VISUAL PERCEPTION

Although the approach taken in the thesis' hypothesis aims to divert some of the usage operations involved in driving towards haptic use in order to ease the need for vision, it is undeniable that vision still plays an important role in the usage of any object even when a user aims to complete an operation mainly via haptics. This was pointed out earlier in this chapter when Klatzky, Lederman & Matula suggested that reach will be implemented when vision is exhausted (1993) and when Lederman et al. 1987 and Rieser, Lockman and Pick 1980 suggested that memories of vision continue to be used even when no vision is available. In some cases, it has been proved that it is necessary due to visual dominance (Colley, Pritchard 1984). Vision therefore requires investigation as it will have implications on any new approaches to haptic designs.

Gestalt perspectives are also relevant in this respect. They include: Grouping, Closure, Simplicity, Figure-Ground, Symmetry, Common Fate, Continuity (Kovacs and Julesz 1993; Soegaard and Mads 2005; Koffka 1935; Todorovic 2008).

It is worth noting that there are perspectives about closure suggesting that although the gestalt perspectives are indeed realistic, the closure rule is not advantageous when it comes to making visual contours salient. In Kovacs and Julesz's (1993)

experiments, it was noted that contours 'pop-out' and were consequently more easily detectable.

2.4 - SUMMARY

To summarise in brief before examining specific points in detail:

- Safety, Efficiency, and Satisfaction identified as headlining issues
- Using modern information technology interfaces while driving is problematic because they cause mental and visual distractions to the driver.
- A new solution that supports screen use is required.
- New haptic interfaces offer a potential solution.
- There is a need for more design guidance for haptic solutions.

2.4.1 - HEADLINING FACTORS

Throughout this contextual review, Safety, Efficiency, and Satisfaction were headlining factors that were pivotal to research conducted by influential authors. Table 2.6 summarises the authors, sources with relation to the headlining issues.

These are components of the well known definition of 'usability', discussed in ISO 9241-11 (1998) and ISO 9126-1 (2001). Understanding designwork through these standardised values provides research with a level of validity, so they will form the 'lens' that will be used for critial discussions and a criteria for evaluation of the Tactile Show and Hide design.

2.4.2 - IN-CAR SCREENS ARE DISTRACTING

In short, as suggested in table 2.6, this chapter has highlighted that usage of in-car interactive screen interfaces in inefficient they can be visually distracting while driving, accidents & deaths have been recording as a resut of this and users are unsatisfied with the use of screen interfaces while driving.

There are standards that are avalible for the design of interactive in-car devices such as JAMA (2004), NHTSA (2010), and ISO 16982 (2010). Traditionally, screens are designed under such levels of standardisation within the discipline of ergonomics and design. However, it is hard to agree that using standards alone is a sufficient step towards safer in-car human machine interfacing. The evidence indicates that there is a fundamental problem with interactive screen use, even with respect to designs well within the currently avalible standards. As a result, this thesis proposes that a new approach to the design of in-car interactive screen usage is explored to contribute a

further layer of knowledge to the field of HMI that can potentially be used for future designs.

Headline	Context	Influential Authors	Summary
Safety	Related to accidents and fatalities	- Green (1999) - Klauer et al. (2006) - Treat et al. (1977) - Wang, Knipling, and Goodman (1996) - Ho and Spence (2008) - Dingus et al. (2006) - Kantowitz & Simsek (2001)	Fatality and accidents caused by driver complex interfaces. Accident risks are strongly associated with driver high mental workload and distraction.
Efficiency	Related to inability to operate interfaces with well.	- Ho and Spence (2008) - Lansdown, Stephens - Walker (2015) - Klauer et al (2006) - Yekhshatyan (2010) - Burnett and Porter (2001)	Visual and mental distraction was the focus of authors considering the problems caused by interactive screens Visual demands on drivers, which might lead to distraction and diminished capacity to perform driving tasks.
Satisfaction	Related to acceptance and drivers feeling happy with controls	- Hutchinson and Timonen (2003)	During the case study of five interactive screens highlight that there is an emotional level of dissatisfaction that was experienced by drivers who operated interactive screen while driving.

Table 2.6: Headlining issues of literature with regards to the use of interactive screens while driving

2.4.3 - A NEW SOLUTION THAT SUPPORTS SCREEN USE IS NEEDED

The case study shows that the design of screens can be good and useable if designed well. However, the problems of visual distraction are still prevalent as the primary function of a screen is visual, which draws visual attention away from the road environment.

The removal of interactive screens from future vehicles is not a feasible solution however, because the capabilities of computers and communication technology have expanded (Barfield & Dingus 1998). Screens have become more prevalent in cars (Bailey 2003) and are seen to provide advantages to commerce and consumers. Moreover, they are a standard rather than an optional feature in many new cars. In an audit conducted by the researcher in 2004 (appendix 2.9) only 5 out of 43

manufacturers selling cars in Europe at that time sold a model with an interactive screen as a standard feature. Initially they were directed at luxury rather than mainstream vehicles. 36 out of the 43 manufacturers offered interactive screens as an option. Five of the six manufacturers offering a screen as standard did so for luxury vehicles.

In 2003 Thirty-six out of the forty-three large commercial car manufacturers in Europe currently offer, as an option, interactive screens and only six of those manufacturers produce models with a screen as standard. Five of those six were luxury vehicles. The BMW 7-series for example had an interactive screen as a standard feature from the year 2000. In 2003 the 5-Series followed, then with the 6-Series and the 1-Series the year after. This was not an isolated occurance. In 2012 that number had substantially grown as screen usage trickled down from luxury vehicles to mainstream consumer cars. Potentially, this marks a new era for car design, as even the motorist with a limited budget will find him or herself eventually using interactive screens, as exemplified in figure 2.13.

It is evident that interactive screen use has grown strongly. The researcher's own industrial experience in tier 1 suppliers such as Visteon or Johnson Controls evidenced that many find interactive screens a more attractive option to sell to OEM companies such as Ford & Renault because they are initially cheap to produce and secondly, the interface is highly upgradable so costs can be cut by lowering hardware development and using the same component from model to model.

For these reasons, it would be unrealistic to consider that interactive screens could be replaced. Instead, supporting them appropriately via a multi modal interface is a preferable option.

Figure 2.13: Screens are now a common feature in many mainstream cars. Left to right: a £12,000 Vauxhall Astra, a £16,500 Renault Megane Hatch

HAPTICS OFFER POTENTIAL SOLUTIONS

Following the investigation of different options, this chapter concluded that for the moment, extra haptic support could be advantagious in helping drivers overcome distraction, especially in situations of high mental workload during visual manual tasks.

Section 2.3.1 looked closely at haptics and how the psychophysical system works. It was noted that reaching and consequential haptic interaction may only happen if a subject has exhausted vision (Klatzky et al. 1993). Concepts of interaction are very much led by the visual dominance model, whilst encoraging the migration of visual manual operations towards the haptic. The implication of shifting visual concentration from the secondary control back to the road should in theory create better attentiveness. However the demands on mental workload are unknown. Testing the hypothesis that positions haptics as a supportive control aims to provide clarity in this respect.

2.5 - DESIGN PRINCIPLES

It has been identified that there is a lack of direct design guidance in the fields of tactile, show and hide interfaces. It is therefore useful to summarise key areas to help condense appropriate knowledge that can then be synthesised into design principles that could eventually be 'codified' (Zimmerman and Forlizzi 2008) into physical designs.

Thus far, several key areas of interest have been addressed, namely screen interaction, a hypothesis to explore the problems it causes; and as part of that hypothesis, haptics, object manipulation, visual perception and visual attention. It is important to contextualise this research and discuss how the preceding material can enable the understanding of how a tactile show and hide interface has the potential to reduce visual interaction in terms of a new design.

EXPLICIT TACTILE SHOW AND HIDE PRINCIPLES

Several headlining principles were formed by the author to structure the codification of knowledge into a tangiable design that can be tested: salience, haptic amplification, hyperbole, simplicity, best attributes for touch, clustering, mind/hand calibration, and mapping.

Table 2.7 summarises and presents the literature that was seen as useful in the creation of the principles that should guide a TSAHI design. Further sections in this chapter contextualise the use of this literature describing how it should best be used.

No.	Principle	Literature	Authors
1	Salience	If physical attributes across a manipulary space are similar no haptic salience can be made	Klatzky, Lederman & Reed 1987
2	Amplification	Contour following is primary form of recognition	Klatzky & Lederman 1992
		Information from brief touch is mapped into existing representations of the environment	Lederman & Klatzky 1997
3	'Hyperbole'	'Course' detail helps extraction and further exploration	Lederman and Klatzky 1997
		1mm detail and 'Haptic glances' gives low haptic recognition	Klatzky, Loomis, Lederman, Wake & Fujita 1993; Klatzky & Lederman 1995
		100mm spacing is best for blind reach	Stephen Pheasant 1996
4	Simplicity	Complex paths cause length distortion	Lederman, Klatzky, Collins & Wardell 1987; Lederman, Klatzky & Barber 1985
		If geometry is uncertain/too complex subjects will make repeated contour following and molding	Klatzky & Lederman 1992
		Poor touch recognition causes heavy memory loads	Lederman & Klatzky 1997
5	Best attributes for touch	Hardness, texture, and temperature are best understood by touch	Klatzky, Lederman & Reed 1987; Klatzky & Lederman 1992
6	Clustering	Natural hierarchy taxonomies	Tversky & Hemenway 1984; Rosch 1978; Norman 1988
		Group colours, sizes, shapes, orientations	Todorovic 2008
7	Mind / hand calibration	Low movement after inspection helps accurate reach	Johansson, Westling, Backstrom & Flanagan 2001
8	Mapping	Survey type cognitive maps	Lederman, Klatzky, Collins & Wardell, 1987; Rieser, Lockman & Pick, 1980
		Landmarks pop-out	Kovacs & Julesz 1993
		Shape coding	Green, Levison, Paelke & Serafin, 1994; Norman 2005

Table 2.7: Audit of literature used to form design principles.

2.5.1 - PRINCIPLE ONE: SALIENCE

The experimental psychology writings of Lederman and Klatzky et al. indicate that there are ways of making an object very salient (noticeable) in a tactile search without vision. (Klatzky, Lederman & Reed. 1987). Put into simpler terms, for an object to be salient, it must be different to its surrounding, that would ideally be continuous in texture, hardness and shape. This is a particularly useful notion from a design perspective as it should enable a driver to understand when he or she has reached a desired control area in a tactile search without vision.

2.5.2 - PRINCIPLE TWO: AMPLIFICATION

A speaker adopting a low volume would probably be asked to speak louder so that listeners could respond appropriately to his or her information. Amplifying information

to an understandable level is therefore important for successful interaction. To achieve this effect for surfaces and controls that need to communicate with a driver, the 3D forms must be appropriately formed to ensure the nerves in the fingers can clearly sense information. A simple way to achieve this is to use acute instead of obtuse edges. Acute edges give larger and louder physical sensations then flat surfaces or obtuse edges. This emphasis on 3D formation could be critical to ensure a driver can understand a surface without vision, as the finger tracing of edges (or 'contour following') has been proven to be a primary way of recognising shapes and components when no vision is available (Klatzky & Lederman, 1992).

Whilst the crux of the amplifying cutaneous interaction has thus far dictated that fine detail needs to be controlled quite specifically, it is also advantageous to remember that more generally, coarser design features would enable a driver to orientate his or her 'mind's-eye'. Detail and information extracted by touch during a participant's initial brief contact with a 3D form is used to guide a hypothesis about the object's identity. These cues are mapped spatially onto existing representations of common environments (Lederman & Klatzky 1997).

2.5.3 - PRINCIPLE THREE: 'HYPERBOLE'

This hyperbole principle, or the deliberate exaggeration for effect, aims to concentrate on physical size. With respect to haptic amplification, Lederman and Klatzky (1997: p1705) noted that 'coarse' detail and information extracted by touch during a participant's initial brief contact with a 3D form is used to guide a hypothesis about the object's identity. To explore this point further in terms of the application of this knowledge, it is useful to contextualise an example. A subject could be reaching for a mug of tea without vision, then on finding the rim of the mug, would understand that their hand needed to move down to find the handle. To relate this process to interface design would suggest that the features of the interface should be large and bold in particular areas in order to help guide hands around it. It has moreover been proven that fine detail of about 1mm is hard to read and has a low success rate (30%) when an area is explored by touch alone (Klatzky, Loomis, Lederman, Wake & Fujita 1993) 1mm therefore should be considered as unacceptable in interface design and should be increased to an expectable level for buttons and edges that need to be read by hand.

Another issue is that of haptic glances. Klatzky & Lederman's 1995 paper entitled: 'Identifying objects from a haptic glance' noted that the chances of successfully identifying an object with a haptic glance (or static hand position) are low - with a 39% success rate. In comparison, a driver using free exploratory procedures such as

'lateral motion' to identify texture and 'contour following' to identify shape would approach a success rate of 93%. Table 2.4 to further explains exploratory procedures. With this in mind, a control area with its dimensions made larger than a hand would encourage movements of the arm and hand, in opposition to a control area that is smaller than a hand and does not require much movement for exploration.

Finally, Stephen Pheasant's (1996) recommendation that controls should be spaced out at 100mm to ensure a user can reach a control without vision augments the evidence. Overall, it can be argued that the physical dimensions of the control areas should be as large as possible in, size, shape and form.

2.5.4 - PRINCIPLE FOUR: SIMPLICITY

Simplicity is thoroughly investigated by Gestalt psychology. This knowledge can be applied practically in that the 3D form of the touchable areas should be as simple as possible. This is for three reasons. Firstly, complex contoured pathways cause length distortion (Lederman, Klatzky, Collins & Wardell 1987; Lederman, Klatzky & Barber. 1985) in that the length of a complex pathway will feel longer than what is imagined. As a result, distances are over-estimated in spaces explored by hand when no vision is available. Secondly, if an object's geometry is too complex to recognise immediately, then a driver would have to repeat his or her actions in the face of uncertainty, inaccuracy or low confidence. Thirdly, subsequent explorations are required for following contours and moulding to parts (Klatzky & Lederman 1992: p.665-669). The more often a user must do this, the worse their recognition may become because poor touch recognition can be attributed to heavy memory loads imposed by such sequential contour following (Lederman & Klatzky 1997). Undoubtedly, complexity could be a significant barrier between the successful interaction of driver and interface. Simplicity of design therefore should be prioritised.

2.5.5 - PRINCIPLE FIVE: BEST ATTRIBUTES FOR TOUCH

In 1987 Klatzky, Lederman and Reed noted that there are certain attributes that are can be better understood by touch than by vision. These are substance-based material attributes, typically: hardness and texture and temperature. For example, when deciding if a loaf of bread is good, touch is needed to decipher whether it is soft and fresh or hard and stale (Klatzky & Lederman, 1992). The material attribute of texture is similar. With respect to car interior controls, when a particular area needs to be easy to find without vision, hardness and texture could help to differentiate areas so that a driver can understand when he or she has reached a desired control area. Consequently, more time can be dedicated to viewing the road.

2.5.6 - PRINCIPLE SIX: CLUSTERING

Psychological theorist Donald Norman (1988) noted that hiding controls can help overcome complexity through organisation. For this reason, organising the controls logically is important. By means of an example to illustrate organisation, hearing the word 'table' would probably initiate the recall of associated sub-ordinate words such as 'forks', 'plates' and 'seats' without seeing the objects, as these items would naturally be associated with the super-ordinate item that is a table. The accumulation of life experiences contributes to these associations. Tversky & Hemenway (1984) and Rosch (1978) explored these notions as semantic memory, as did Ulric Niesser (1976), a fundamental cognitive psychologist of the 1970's. As this is a well-known and natural system of organisation, it is reasonable to suggest that it could form a basis for logic in design work. Gestalt psychologists have suggested that there are various ways to achieve this natural style of organisation or grouping using similarities in lightness, colour, size, orientation, or shape (Todorovic 2008). This enables an observer to group items naturally as well as through taxonomies of superordinate and subordinate thinking. Grouping related functions such as climate and temperature, etc. under the superordinate category is an example of semantic memory as defined by Tversky and Hemenway and Rosch. Colour coding the functional categories of buttons is an example of the inclusion of Gestalt ideas into conceptual design work.

2.5.7 - PRINCIPLE SEVEN: MIND / HAND CALIBRATION

If the target (control area) moves at any time during a task, a driver is unable to send an accurate programme to the arm. The driver will then need to spatially re-calibrate and re-compare the manipulary space to cognitive maps to create new and accurate motor programmes (Johnansson, Westling, Backstrom and Flanagan 2001). This reinforces the need to cluster controls effectively, to reduce the need to visually search for them, which distracts a drivers' vision from the road.

2.5.8 - PRINCIPLE EIGHT: MAPPING

The human mind uses visual imagery known as survey-type cognitive maps to guide hand movements when a tactile search must be made without vision (Lederman, Klatzky, Collins & Wardell, 1987; Rieser, Lockman & Pick, 1980).This is similar to a traveller using the memory of a map to trek through unknown terrain. With this in mind, the principle suggests that the shape and form of the control areas should be a major landmark in the vehicle's cabin. Moreover it should be sufficiently memorable amongst other shapes and forms to ensure that the driver has a clear vision of the desired area of interaction in his or her mind while driving. Therefore, there is less need to look at

the controls and more attention can be given to the road. A way to achieve this is to close the visual contours of a shape. It has been proven that perception can make a shape 'pop-out' of its background Kovacs & Julesz (1993). In this way, 'landmarks' create a clearer map of the interior; therefore less time is spent looking at the controls to guide hand movements. Figure 2.14 shows an example of this idea.

Another way to increase mapping is to shape code areas to match functions (Green, Levison, Paelke & Serafin, 1994). This is suggested as an effective means to increase mapping abilities (Norman, 2005).

Figure 2.14: Closing visual contours makes a more considerable landmark. The top set of pictures show line experiments based on the 1993 perceptual work of Kovacs & Julesz and the bottom set of drawings show the translation of the line experiments into a car interior environment.

2

PART

METHODOLOGY AND DESIGN DEVELOPMENT

CHAPTER 3
DRIVERS OF INTERFACE DESIGN

3.1 - INTRODUCTION

Chapter two argued that the available research literature and case study evidence served as evidence towards the idea that in-car screens are intensely distracting because a fundamental problem potentially exists in how drivers use in-car screens. Consequentially, there could be a need for a more *innovative* approach to finding a design solution. Finally, a hypothesis was proposed stating that a radical Tactile Show & Hide design could potentially to be a solution to the problems of distraction. To test this hypothesis a methodology should be formulated that will demonstrate and test the ideas behind a Tactile Show and Hide design.

3.2 - AUTOMOTIVE DESIGN AND INNOVATION

At this point it is worth mentioning that there are different types of innovation, including the area of design (Norman 2014):

1 - Incremental innovation: Improvements within a given frame of solutions ('doing better what we already do')
2 - Radical innovation: A change of frame ('doing what we did not do before')

It could be argued that incremental innovation is at the heart of the problems exposed in chapter 2. Originally, screen interfaces were added incrementally to existing vehicles for their enhanced functionality rather than considering any potential problems.

A business often refers to incremental development in terms of its 'core capabilities'. In design management, the descriptors of core capabilities can be collective learning (Prahalad and Hemel 1990), employee knowledge and skills and values and norms associated with various types of embodied and embedded knowledge (Leonard-Barton 1992). It is much the case that business in general finds that security in core capabilities can enable competitiveness. This can be acheived by outward expansion from a reliable compilation of knowledge and skill, without overrunning the capacity to develop products. In a fast moving environment such as technology development

however this is not always possible. In 'Core Capabilities and Core Rigidities', Leonard-Barton's 1992 Strategic Management Journal paper, it is noted that although 'core rigidities' can they enhance development, they can also inhibit project development. Quinn and Cameron (1988) also identify a particular cause of this paradox stating that:

> 'Over time, some core capabilities are replaced because their dysfunctional side has begun to inhibit too many projects. However, that substitution or renewal will not occur within the lifetime of a single project. Therefore, project managers cannot wait for time to resolve the paradox they face.'

Barton goes on to comment that in projects that he has observed, the paradox was handled in various ways, three of which are applicable to this discussion:

1 - Abandonment (to give up completely)
2 - Recidivism (return to core capabilities)
3 - Reorientation (find a new route)

What is interesting with respect to the automotive industry is that points 1 and 2 are very much the case in many instances of development, with the term 'the dinosaur of the business world' (MacDuffie and Fujimoto, 2010) being a label that the industry has arguably held for many years. However, movement towoards 're-orientation' can also be observed in crucial issues such as the environment; a case in mind being the reduction of carbon emissions to satisfy UK regulations. Recently, automotive manufacturers have been compelled to develop radical hybrid electric/combustion and hydrogen fuel-cell vehicle designs that more than satisfy emissions regulations. In their case they have reached a metaphoric wall that traditional combustion engines cannot climb.

In the case of driver distraction, a similar event has occurred. A problem has been caused because conventional visual GUI screens do not have the capacity to alleviate visual distraction, as fundamentally, they need visual attention to function.

As to whether it is valid to employ a more *radical* approach to solve these problems of visual distraction instead of 'fixes' and improvements in GUI design; a solution that blends radical innovation in design may be possible. In view of the problems uncovered in the literature and the case study results, it is arguable that a wholly

incremental approach that does not address the fundamental visual issues is less likely to provide a solution.

3.3 - AN INTERDISCIPLINARY APPROACH IS NEEDED

To produce an innovative solution, more than one discipline is needed. In the automotive industry for example design brings a solution to fruition. Therefore, it is important to review the available methods and identify an appropriate disciplinary approach to support research that would build knowledge around the problems of visual distraction and design, to eventually indicate possible solutions. Several disciplines conventionally contribute to the automotive field: engineering, ergonomics and design. The preferred definitions of the disciplines are as follows:

Engineering

A common definition describes engineering as 'the branch of science and technology concerned with the design, building, and use of engines, machines, and structures' (Oxford Dictionary 2017). Furthermore, Koen defines the engineering method as 'a strategy for causing the best change in a poorly understood or uncertain situation within the available resources' (Koen 1984: p.10). The main task of engineers is to apply their scientific and engineering knowledge to the solution of technical problems and then optimise those solutions within various requirements and constraints. (Pahl, Beitz, Feldhusen and Grote, 2003). Systematic methodology forms the backbone of engineering. Within the Automotive industry, mechanical, software and electrical engineers are most likely to engage in the task of engineering and building secondary controls.

Ergonomics

'The study of people's efficiency in their working environment' (Oxford Dictionary 2017). The definition of ergonomics developed by the Human Factors and Ergonomics Society and the International Ergonomics Association is: 'The scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and other methods to design in order to optimize human well-being and overall system performance'. In addition to this, Vianen, Thomas and Van Nieuwkasteele (1996) identify key issues that ergonomists address as: specification of participants, design of tests, measures to be taken, questionnaires to be used, tasks to be executed and presentation of results. Within the automotive industry, ergonomists that specialise in

the task of understanding driver psychology and physiology are most likely to engage in the task of analysing and making recommendations for secondary controls to designers and engineers.

Usability is pivotal to the discipline of ergonomics. ISO 9241-11 (1998) defines usability as: '[the] extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use'. This view has been extended in ISO 9126-1 (2001) to include 'safety': the adverse consequences of use.

Of late, User eXperience (UX) has evolved to become a prominent category of ergonomics. ISO 9241-210 (2010) defines UX as : '[a] person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service.' However, as a relatively young category of ergonomics, UX is still being debated, defined and explored by researchers. (Petrie and Bevan 2009). Bevan (2008) suggests that the definition of usability can be extended to encompass user experience by interpreting satisfaction as including:

- Likability: the extent to which the user is satisfied with their perceived achievement of pragmatic goals, including acceptable perceived results of use and consequences of use;
- Pleasure: the extent to which the user is satisfied with the perceived achievement of hedonic goals of stimulation, identification and evocation (Hassenzahl 2003) and associated emotional responses, for example Norman's (2004) visceral category;
- Comfort: the extent to which the user is satisfied with physical comfort; and
- Trust: the extent to which the user is satisfied that the product will behave as intended.

Design
A plan or drawing produced to show the look and function or workings of a building, garment, or other object before it is made (Oxford Dictionary 2017). Durling and Niedderer (2007) take this very basic definition further to define the act of designing as having characteristics that include speculating on possibilities for modified or new artefacts, systems and environments and modelling what is required in the mind, symbolically, graphically and in three-dimensional forms. Durling and Niedderer (2007) interpret the writings of Hubka and Eder to quote:

'Designing as a process is more or less creative. This usually includes: intuitive, iterative, recursive, opportunistic, innovative, ingenious, unpredictable, refined, striking, novel, reflective, searching for elegance, beauty, etc.'

Design can be involved in many disciplines. The branch of the discipline most relevant for automotive design would be Industrial Design (ID). The Industrial Design Society of America describes ID as: 'The professional service of creating and developing concepts and specifications that optimise the function, value and appearance of products and systems for the mutual benefit of both user and manufacturer.' Industrial designers develop these concepts and specifications through the collection, analysis and synthesis of data guided by the special requirements of the client or manufacturer. They are trained to prepare clear and concise recommendations through drawings, models and verbal descriptions. Within the automotive industry, Human Machine Interface (HMI) designers are most likely to engage with the conceptualisation and design of secondary controls. In summary, an industrial designer's responsibility is to determine the appearance and ergonomics of a product (Tovey 1997). In addition however, Tovey notes that there is a difference between automotive designers and traditional industrial designers as they invest more time to determining style and surface formation.

A RADICAL APPROACH

Now that definitions of the relevant disciplines have been established, the discussion can proceed. It would be fair to say that the principles of many engineering methodologies are predominantly incremental, relying primarily on previous knowledge of a system or problem. As a result, the establishment of a new, or even improved design can become problematic. In the case of screen interactions, increased usage buy consumers and pressure from automotive tier suppliers could act as a barrier to new design. The researcher's industrial experience in a tier one automotive supplier confirms the predominance of the incremental approach, which indicates that interactive screens could offer a more attractive option to Original Equipment Manufacturer (OEM) companies. Firstly, they are cheap to produce and secondly, the interface is highly upgradable so development costs can be cut by lowering hardware production; using the same component from model to model with new upgraded software in higher spec. cars. With respect to these factors, a degree of incremental development is arguably necessary as a completely 'blank page' design would not be easily accepted. Similarly, Norman and Verganti (2014) note that radical innovations take considerable time to be accepted.

A MIXTURE OF DISCIPLINES

Ergonomics is a major stakeholder, usually involved in interface development in the automotive field. This discipline's interests are directly related to the interaction between the design and the end user. Unlike engineering, radical factors can be exposed in ergonomics when testing current interfaces. However, it require the testing of a new design to yield any new knowledge about interfaces.

Design as a discipline has the potential to have a high impact in terms of radicalism. Both newness and retrospective design are very much embraced by the discipline of design although designers tend to be stereotyped as professionals whose works are ingenious, unpredictable and create artefacts that are innovative and novel (Durling and Niedderer 2007).

Nigel Cross documents that a radical philosophy can offer a greater platform to increase a design's effect, stating:

> 'Given the situation and the pressure at any one time, you do get to the brick wall. I mean, you're doing all these normal modifications, you know you can't go any quicker, you need to make the step forward...- a radical new concept' (Cross, 2011, p.36)

This approach to radical product development is also supported by Dell'Era and Verganti (2009) and also Norman and Verganti (2014), who note that a radical approach will often elicit an innovative solution.

3.4 - DESIGN RESEARCH METHODOLOGY

A MIXED METHODS APPROACH TO RESEARCH

The previous section defined the disciplines involved in the process of automative design and concluded that a combination of these is required to enable the possibility of radical design within an industry that has a predominately incrememtal approach. In view of this, the research uses a mixed methods approach to extract the unique values of design and ergonomic evaluation. Fundamentally, design is a discipline that requires a high level of creative thinking, in comparison to the scientific and formulated discipline of ergonomic evaluation.

To explain further; the 'fuzzy front end' (Marcus 2013) and prototyping of product development is subjective. It is the point at which innovation managers question the validity of products to go into further development, when little is fully understood about

the implications of a design. However, this phase is necessary as it offers the rewarding opportunity for transformational innovation as obstacles are overcome that may have been caused by years of incremental product development. Testing with lead users (Urban and Hippel 1988) and open innovation strategies (Vrande et al. 2009; Chiaroni, Chiesa and Frattini 2011) have been proven to enable the desired approach that is more radical than incremental.

Nevertheless, the research requires an objective view point to validate any new ideas. It is moreover essential that this viewpoint is synthesised by a systematic and rigorous method to both create and achieve an objective conclusion to alleviate doubt and thoroughly explore the implications and potential of the design ideas.

For these reasons, a mixed methodology was used (Creswell 2003: p 211). A sequential strategy was preferable over a concurrent strategy because of the different requirements of the separate parts of the research. To this end the design study was completed first, so that there was a tangible object to analyse through the experiment design.

Figure 3.1 diagramatically describes the mixed methods research design approach undertaken in this thesis.

3.4.1 - DESIGN RESEARCH METHODOLOGY

The interdisciplinary discussion indicated that the most probable discipline to produce an innovative solution is design. Hence it would be rational to place the discipline of design the centre of the project to elicit an innovative output. To exploit the potential of design however, the discipline needs to be further understood to gain the best use of it. There are critical issues that can problematise new knowledge produced through the act of designing, one issue being the other disciplines that impinge on the design process.

> 'One of the dangers in this new field of design research is that
> researchers from other, non-design disciplines will import methods and
> approaches that are inappropriate to develop an understanding of design.
> Researchers from psychology or computer science, for example, have
> tended to assume that there is nothing special about design as an activity
> for investigation, that it is just another form of problem solving' (Cross
> 2007)

This statement is crucial to the discussion. It highlights the importance of using methods that are native to the discipline of design . However, it is critically important to understand how these practices can fit into a shared framework that can be clearly understood by other disciplines to enable communication and understanding between the engineering and ergonomic disciplines, to enhabce the credibility of design research knowledge.

Archer (1999) & Frayling (1993) both discuss the overall approaches of research in the design process as 'Research about design, research through design, and research for the purposes of design'. *'Research through design'* is the area of importance for practice based research, as is research for the purpose of design. Pedgley and Wormald (2007) also suggest this in integration of design projects into post-graduate research.
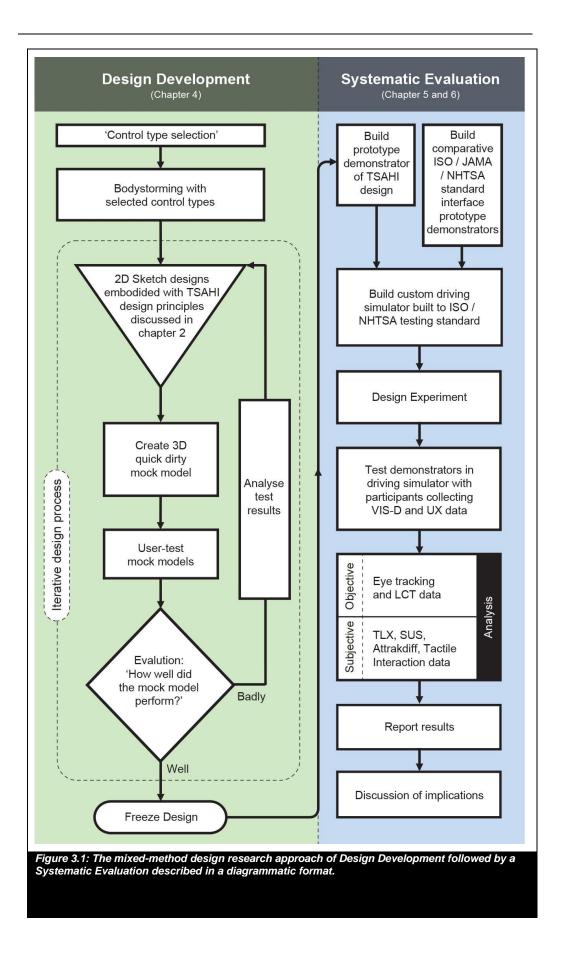
Agnew (1993) however warns that research through design can be fraught with pitfalls in that research through product design has been:

> 'hindered by the lack of fundamental documentation of the design
> process which produced them. Too often, at best, the object itself, and
> even that evidence is surprisingly ephemeral. Where a good sample of
> the original product can still be found, it often proves to be enigmatic.'

To reduce the enigma of design practice for other disciplines - i.e. ergonomics and engineering - the process of design research must be explicitly documented where new ideas about in-car interfaces are concerned.

A second issue is that the activity of design does not always constitute or resemble research because a variety of characteristics specific to research are not normally met. Pedgley and Wormald (2007) describe the two activities when contemplating this perspective as:

- Research: '... critically, while the broad goal of research practice is new knowledge,'
- Design: '... the broad goal of design practice is new artefacts and designed outcomes (Archer and Roberts 1979).'

Figure 3.1: The mixed-method design research approach of Design Development followed by a Systematic Evaluation described in a diagrammatic format.

Theoretically, an almost reciprocal relationship exists between design and research in a conceptual framework of researching through design, because research needs a designed object, artefact, or computerised system to function. In practice this approach of using design as an enabler in the search for new knowledge seems appropriate.

There are differing ways however of using a designed artefact to elicit knowledge. Rust et al. (2000) break down these different types of usage into four general concepts: simple forms, communication of process, artefacts within the research and knowledge elicited by artefacts. Rust et al. define the terms as:

a) Simple Forms: An artefact demonstrates or describes a principle or technique.
b) Communication of Process: Artefacts from a process make the process explicit.
c) Artefacts within the Research: Artefacts are instrumental in advancing the research by communicating ideas or information.
d) Knowledge Elicited by Artefacts: Artefacts provide a stimulus or context which enables information to be uncovered.

All these definitions have validity but in certain cases they may overlap. For instance, a designer could begin with the intention of making (a) a Simple Form but find that the artefact evolves to type (d) as ergonomic testing takes place through systematically obtained experimental data analysis.

What is critical is that any type/s chosen provide a high level of engagement between the disciplines of design, ergonomics and engineering to increase the analytical powers of the methods. Participatory Action Research (Denzin and Linclon 2003; Draper 2001; Reason and Hilary 2001), is a qualitative technique of design research that offers an appropriate number of attributes to umbrella these activities. Participatory Action Research would allow design methods such as Iterative design, which is noted to be especially applicable when a designer needs to take user values into consideration (Nielsen 1993; Baecker, Nastos, Posner & Mawby, 1993; O'Grady 2009: pp,54; Stanton, 1998) and conduct a discovery led process for speculative projects (Laurel 2003: p86).

For the purpose of testing the hypothesis proposed in chapter 2, type (d), 'Knowledge Elicited by Artefacts' was undoubtedly the best way to demonstrate the theoretical hypothesis in a way that could be used in a shared framework, where a designer conceives a design with psychological underpinnings, (as discussed in the conclusion

of chapter 2). From this, an embodied physical demonstrative prototype of the study's design ideas was formed, to be evaluated ergonomically to test in-car levels of distraction.

To achieve this, an embodied TSAHI design was created. A TSAHI prototype was produced, then evaluated with a controlled experimental design to create new knowledge; exploring the theoretical hypothesis.

To explore the hypothesis, an investigative design approach was needed: 'the act of designing, set wholly within a research study for the generation of new knowledge' (Durling and Niedderer 2007), to create a demonstrator that could undergo a series of robust systematic user-tests under standardised conditions.

STANDARDISATION IN INTERFACE DESIGN

Standards form an important part of interface development in the automotive industry from a professional production perspective and also to ensure high levels of safety, effectiveness, and quality. Some of the most influential bodies for in-car interfaces are the International Standards Organisation, SAE and JAMA (Green 2012). The documents produced under these organisations serve different roles, guiding product testing, evaluation and development.

Discourse with automotive ergonomists close to the field of automotive manufacturing made it clear that several standards were pivotal for the development of in-car interfaces.

- JAMA 2004
- Docket NHTSA 2010-0053
- ISO 16982:2010 - Usability methods

Other standards were also of interest and regarded as influential to Original Equipment Manufacturers (OEMs) such as Jaguar Land Rover. For instance, the following are particularly interesting to automotive ergonomists as they focus on human-centred design, human-system interaction, a simulated lane change test to assess in-vehicle secondary task demand and the measurement of driver visual behaviour:

- ISO (1998) 9241-11
- ISO (2010a) 26022 and ISO (2010b) 9241-210
- ISO (2014) 15007-2

To maintain standards of effectiveness, quality, and credibility it was important that the thesis complied with these standards.

USABILITY

Although following standards is important to help maintain quality, safety, and effectiveness, following standards alone will not produce an appropriate design solution that can be explored to create new knowledge. Additional methods for design are instrumental in creating practical product solutions for automotive interiors.

Traditionally, the task of an industrial designer determines both the appearance and ergonomics of a product (Tovey 1997). With an automotive interior, a high focus is placed on ensuring that the driver and passengers are at the centre of the development process. Therefore, when designing an interface the functional aspects are of vital importance. 'Usability' therefore is highly relevant.

3.4.2 - DESIGN DEVELOPMENT

HUMAN CENTRED DESIGN

The degree to which something is able or fit to be used (Oxford Dictionary 2017), or its 'usability', plays a large role in the development of any product that has a level of functionality. As mentioned earlier in this section, there are standards set around the issue. The specific details of how these are implimented are discussed later in this chapter and the following chapter 5, but firstly it is useful to understand the reasons and implications of why particular elements in the field of usability were useful to explore the hypothesis of this thesis.

Usability is highly regarded by ergonomists, whose task is traditionally scientific and analytical; focusing on the performance of a design, user research and evaluation. The problem with 'usability' from this ergonomic perspective is that it focuses primarily on *how well* a design works. To be able to produce a usable design, it is also necessary to understand *what* makes a design work and *how* to implement these ideas to create a design that performs well.

Human-Centred Design serves as an ideal framework to ensure that there is less of a disjoin between how well a design works, what makes it work and how it performs. It is a practical, repeatable approach to arriving at innovative solutions (Designkit.org 2017).

'The process is designed to get you to learn directly from people, open yourself up to a breadth of creative possibilities, and then zero in on

what's most desirable, feasible, and viable for the people you're
designing for.' (IDEO.org 2015)

It is useful to discuss the project's methods within this framework to make sense of
what may seem like an unorganised and intuitive process. Figure 3.2 visually maps
the overlap of IDEO's three foci of Inspiration, Ideation, and Implementation. They are
similar to those used by a range human-centred organisations such as Design for
America (based in Ford Motor Company's engineering centre in Illinois, USA), the
LUMA institute and FROG; a consultancy that 'kick-started' Apple Design in its early
years, by advancing the human experience through design.

Within the framework of this thesis the final process of 'implementation' - as described
in figure 3.2 - is redundant because the aim is not to produce a commercial product
but to explore a hypothesis. However, as a sub-framework to problem solve with
human capability at the centre of the design process, the first two phases of
'Inspiration' and 'Ideation' serve the thesis perfectly with respect to how the mixed
method is implemented. A leading design development phase includes the inspiration
and ideation phases that is then examined with a more scientific approach, omitting
the implementation phase in exchange for a rigorous testing procedure that explores
and tests the hypothesis.
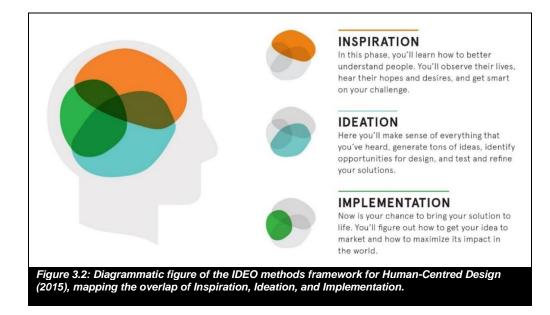
INSPIRATION
When taken literally, the term inspiration is widely defined as 'the process of being
mentally stimulated to do or feel something, especially to do something creative'
(Oxford Dictionaries 2017). Within human-centred design, the term is specifically
narrowed to a phase where mental stimulation is caused by the understanding of
people and their actions during instances of their life.

Typically, various tasks can be performed within the initial inspiration stage of a
human-centred design approach. These include framing the design challenge,
performing group and expert interviews, pulling together secondary research,
immersions and peers observation. These are useful methods of understanding the
problems in depth.

The literature review examined the problems that modern in-car interfaces occasion to
secondary research. Expert interviews were conducted to gain a contextual
perspective relating to research, manufacturing and design. The case study examining
screen based in-car systems is an immersion method implemented to achieve a
detailed and empathetic perspective of the problem (Kouprie and Visser 2009; Wright

and McCarthy 2008; Clarkson et al. 2013). These approaches manifested a broader perspective that informed the design process of (Moreno-Ger et al. 2012).

IDEATION

Ideation is defined as 'the formation of ideas or concepts' (Oxford Dictionary 2017). This fits within the defined framework of inspiration as the 'creative' activity mentioned in the wide interpretation of the inspiration phase. In the inspiration phase of the human centred design process, a certain level of linear order can be followed and linear logical steps can be mapped. However, the ideation phase also requires flexibility.

The features of a TSAHI demonstrator should be explicit, so a very controlled design had to be synthesized. Several phases of the design were implemented: initial body-storming, design ideation with design principles, followed by rapid prototyping, and quick 'dirty testing' (defined below). An iterative process was useful for refinement within the qualitative research process.

Body-storming

Briefly, body-storming, is a simulated flow of interactions within a design process that are recorded and reflected upon. Schleicher, Peter and Kachur (2010) argue that body-storming should be one of the first steps taken in the problem-definition stage. Simsarian (2003) suggests that generative body-storming fits the process well after the field observations. For this study, the body-storming followed the field observation and the test driving of car interfaces documented earlier in chapter 2, where efforts were made to understand interactive in-car interfaces in depth.

Design principles / Concept design

In the ideation phase, it is common for both iteration and hopping to and from conceptual thoughts and ideals to take place during a concept or sketch programme. For this reason, focusing and framing the project is important. The use of design principles (IDEO.org. 2015: p105) can be an instrumental method of focusing a designer's direction or a theme that needs to be maintained throughout a design process.

Good examples of design principles are found in the commercial design practice of Dieter Rams (Lovell 2011) and in the research of Preiser and Ostroff (2001) who designed universal principles to make products more usable.

Design practitioners such as IDEO suggest that designers and other beneficiaries of design:

> 'Think of design principles as the guardrails of your solution — quick, memorable recipes that will help keep further iterations consistent.' (Designkit.org 2017)

French (1994) notes that designing 'from first principles' is often advocated as a way of generating good and/or creative designs. Moreover, first principles are seen as the core of any significant understanding of a design. Cross suggests that:

> 'designing by first principles assumes the theoretical position that designing proceeds by identifying requirements, or desired functions, and arguing from these appropriate forms or structures.' (Cross 2007)

This position was appropriate because the requirements and desired functions *undoubtedly* needed to be 'tactility' and 'showing and hiding', ensuring that other requirements, however current, were disregarded to safeguard a pure theoretical model of a TSAHI design for hypothesis testing, in-turn producing a high level of robust methodology to underpin this study. Using custom tactile show and hide principles will embody the ideas of the hypothesis at the core of preceding designs.

Rapid prototyping

Through technological advances, designers can create CAD data and physically create three dimensional models with robotic machinery. This is widely referred to as RP (Rapid Prototyping). In the human-centred design process, the rapid prototyping phase is <u>not</u> related to this definition of RP, but to the activity of quickly and rapidly

creating a 3D mock model, storyboard, or roleplay. The goal is to make something tangible that conveys the idea to be tested, either by hand or machine (IDEO.org. 2015., p119). The emphasis on rapid creation as an activity ensures that a designer can quickly move through a variety of iterations.

Quick and dirty testing / Observing users
To quickly understand the effect of a design idea on a user, it is imperative that feedback takes place to inform development. This is a critical part of the human-centred approach. It is at this point that a human becomes the sole focus of attention and gives feedback that is used to guide further design ideas. There are many ways to engage with this phase of the human centred design method. Co-creation sessions, group interviews, expert interviews and lead-user market interviews with the prototype being the focus of the activity. These processes are generally used in the discipline of human-centred design.

Iteration
Iteration is closely tied to Rapid Prototyping. Reacting to the feedback from those who have been observed is an essential element of the human-centred approach. Synthesising feedback and understanding what it means to the design ideas, then making new prototypes serves to refine the design until it is appropriately desirable or functional.

Within the process of ideation, whole tasks of concept design > rapid prototyping > dirty testing > and iteration are repeatable until a measure of success is achieved.

Many fields including human computer interaction design, graphic design and more relevantly, the industrial design field of product design, use 'iterative design' as a creative method. This is especially applicable when a designer needs to take user values into consideration (Nielsen,1993; Baecker, Nastos, Posner & Mawby 1993; O' Grady 2009: pp,54; Stanton 1998) and conduct a discovery led process for speculative projects (Laurel 2003: p86).

The iterative design process began with the application of current knowledge about Tactility, Showing And Hiding to inform 'dirty models' (Bramston 2008) which could undergo 'experience prototyping' (Moggridge 2006; Kelley and Littman 2002; Buchenau and Suri 2000) and redesign until an appropriate design is found. Durling and Niedderer (2007) also refer to this method as 'designing quick and dirty'. A process when:

> 'an intervention is made that is intended more in the nature of a local
> probe than research that leads to generalizable findings.'

Although there will be no generalisable findings from this approach in the larger framework of research through design, Durling and Niedderer go on to note that:

> 'What can be claimed is that, within the scope of the project and the
> limited means for research, an intervention was made that led to
> improvement.'

Overall this is an important perspective to appreciate because the methodology of the experiment design in this thesis relies on the fact that an optimised design that would demonstrate a theoretical model of a TSAHI be tested, so the evaluation and exploration of the hypothesis is robust. Often a design will not reach optimal conditions until it has been improved and refined because most designs start as a rough sketch that eventually evolves into a purposeful design through improved iterations of drawings that continuously take into consideration elements such as aesthetics, usability, and mechanical operations. These are a few of the critical elements that are blended together to make an optimal design.

If a less than optimal design is produced for evaluation, then corrupt results will be gathered from the tests. Therefore, ensuring a viable claim can be made as to the optimality of the demonstrator designs is important (as mentioned in the discussion about design principles), to make a durable design methodology that contributes to a robust framework for research.

3.4.3 - SYSTEMATIC EVALUATION OF THE DESIGN

Once an appropriate design was synthesised, the methodology (as mentioned earlier) breaks away from the original IDEO model to incorporate a level of testing that questions the artefact. Standardised and specific automotive test methodology was implemented. A controlled test environment and regulated apperatus and test procedure were used to ensure that a robust, systematic, and repeatable methodology was deployed.

The critical lens of Safety, Efficiency, and Satisfaction (discussed in section 2.4.1) is of vast importance when justifying the use of the methods to evaluate the TSAHI design. Figure 3.3 diagramatically shows how these methods were drawn together under the critical lens.

Efficiency - VISual Demand (VIS-D)

Understanding the levels of visual demand gives an indication of how efficient a design is in terms or operation when considering driver distraction. Eye tracking is a well known method that is used throughout the automotive industry to indicate visual demand. The data that can be collected from eye tracking is numeric and can be related to objectively. This is an advantage and will help to build an objective conclusion.
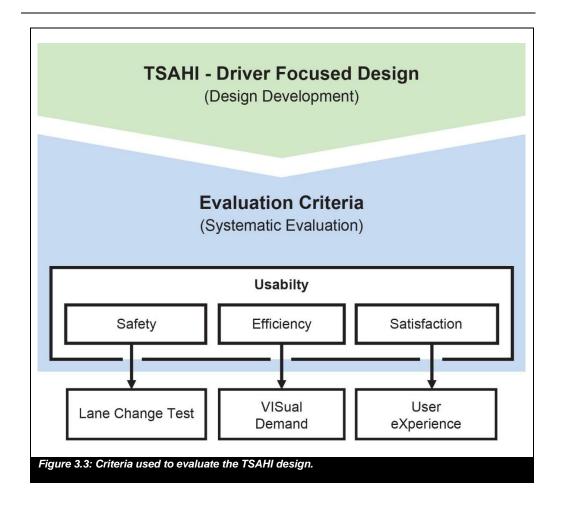
There are specific guidelines for the use of eye tracking measures where visual distraction is concerned. For example, Rockwell (1998) suggests that 'Drivers loath to go for more than 2 seconds without information from the road'. This measurement features in ISO 15007-1:2014, a standard that aims to define the measurement of driver visual behaviour with respect to transport information and control systems, to propose what is good and bad in terms of the visual gaze while driving. These exact measures are discussed later in section 5.11.

Safety - Lane Change Test

To understand the levels of safety, a Lane Change Test (LCT) was used. Like the measure used in the VIS-D, the LCT, and the measures associated with it, are also an ISO standard (ISO 26022 2010). It is well used within the automotive industry and is concidered best practice. LCT measures lane deviation, this has been identified as being closely correlated to accidents in studies (Ikeda and Mori 2005; Olson et al 2009). Hence it is advantagious to scrutinise this measurement.

Satisfaction - User eXperience (UX)

Understanding user experience is crucial. Sometimes comparative situations can differ in terms of demographic background as well as personal taste. Thus, it was important that a set of measures were put in place that were subjective. This enables a richer level of understanding. Standardised questionnaires such as the NASA TLX Raw (NASA 2008), Systems Usability Scale (Brooke 2015), Attrakdiff, were used to measure the satisfaction levels of participants. Comparative and a 'Tactile Interaction' questionnaires were also used in the exploration of the TSAHI hypothesis to gain an understanding of how participants ranked the different interfaces and to understand how well the principles functioned. Section 5.12 gives more detail on these qualitative measures.

Figure 3.3: Criteria used to evaluate the TSAHI design.

3.5 - PROTOTYPE DEVELOPMENT

To ensure there was a systematic level of evaluation of the hypothesis, the robustness of the apparatus was important for consistency and also to rule out random variables. This section describes the level to which this was achieved.

SIMULATOR RIG

The dimensional and equipment specifications of the simulator rig that would satisfy ISO and NTSHA standards are discussed later. However, the design and fabrication of the simulator also had the potential to affect the test results.

To ensure that a reliable and consistent driving experience could be maintained throughout the tests, a frame was fabricated from square steel tubing. This formed the solid framework for the additional parts, to ensure there was no movement. Panels that mounted the push buttons were fabricated from fibre glass or polyurethane rigid foam that used a metal sub-frame for extra strength before being mounted to the main framework. Devices such as a seat, pedals and a steering device were bolted directly to the custom framework. All this was done to reduce movement in the rig and

improve the quality of the driving experience so that no mechanical driving problems interfered with the control usage task. The steel framework with the attached driving devices can be seen in figure 3.7.

During the design of the framework, ergonomic tasks were carried out: matching the design to the package as seen in figure 3.8 and quick and dirty ergonomic testing with a 2.5%ile female and a < 95%ile male to ensure the frame was usable in the various positions that could be required by different test participants. Evidence of the test work can be seen in figure 3.9.

Any necessary ergonomic assessments were conducted using anthropometrically correct manikins, 3D design surfaces and 3D scans of components, to test the sight lines for the controls. Examples of this type of testing can be seen in figure 3.9, where the control area behind the steering wheel had to be seen without the wheel obscuring vision.

TSAHI DEMONSTRATOR PROTOTYPE

Similarly, the demonstrator interfaces used in the evaluations were designed to be robust. 500 grade high molecular weight polyurethane was used in the subtractive milling process of fabrication to ensure high physical strength in structural components such as the casework, that can be seen in (e) figure 3.9. Where flexibility and no structural properties were needed, such as the switch panels (a) in figure 3.9, a lower grade was used. A 0.5mm layer of Plastidip was used to apply the soft rubberised surface finish to the demonstrators, where needed.

The custom master PCB, seen in figure 3.10, that controlled the actuation of the interfaces to show and hide the tactile interfaces was professionally designed, engineered and fabricated to ensure reliability and consistency of use.

The PCB design followed a Human Machine Interaction (HMI) design that ordered the human inputs and machine responses step by step. This HMI can be seen as a diagram in figure 3.11. This was also followed by a second software developer who coded the screen shots designed and produced by the author, so that the demonstrator mechanics and supporting screen displays co-ordinated perfectly. The design of the supporting screens will be discussed later.

The Master PCB was used to activate the pneumatic strut assembly that manipulated the tactile control panels, moving them up and down; showing and hiding them on demand. The struts were professionally specified to the author's design and donated

to the project by Festo Ltd, a leading world-wide supplier of automation technology and pneumatic development.

THE TOUCHSCREEN DEMOSTRATOR PROTOTYPE
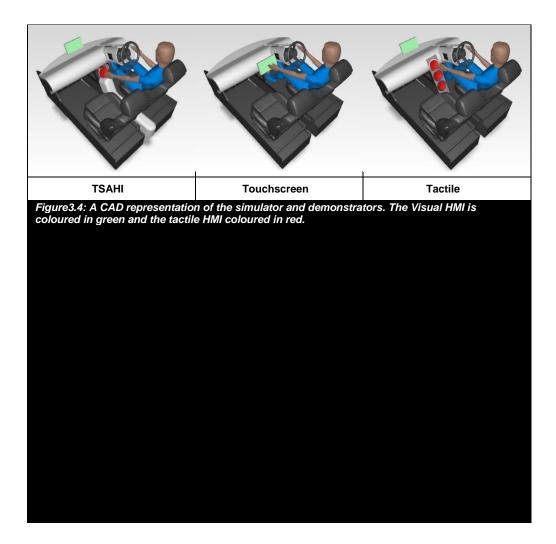
The TSHAI's touchscreen and the visual display screen were designed using the Japan Automobile Manufacturers Association's (JAMA 2004) guidelines. The JAMA guidelines commissioned by the Road Transport Bureau of the Ministry of Land, Infrastructure and Transport consider regulations set by the Australian Regulation, EU Directives, Association of Radio Industries and Businesses, International Standard Organisation and the Japanese Standards Association. In summary, the main points and their resolution are as follows. Various sections of the JAMA document were addressed.

Section 3 in JAMA 2004 focused on the installation of display systems. The displays and the touchscreen was placed beside the driver on the centre console away from the pedals or steering wheel. To ensure that the position of the system did not interfere with the steering or vision necessary for driving and did not cause the driver to be substantially displaced from the driving posture (Section 3 - JAMA 2004). This is illustrated in figure 3.4. No information that would potentially impair safety and the smooth flow of road traffic was presented to the drivers.

 Section 4 in JAMA 2004 focused on General Display Function. Various design elements ensured that the displayed visual information was small in volume to enable drivers to comprehend it in a short time. The use of simple stereotypical graphics was prolific throughout the touchscreens used for the comparison. It was also ensured that the screens were uncluttered, the graphics made bigger so they were easier to view, colour codes were used for faster mapping, sentences made shorter for quicker comprehension and different word sizes used. Large graphical headers for example facilitated navigating around the screens and driver orientation. Figure 3.5 Illustrates how these elements combined to create an intuitive GUI that could be comprehended in a short time. [red in photo]

These noted Graphical User Interface features had been successful in the original case study of existing interfaces described in Chapter 2.

Section 5 in JAMA 2004 focused on display system operation while the vehicle is in motion. To ensure a driver is not required to remove both hands from the wheel. the operation of the touch screen was one handed and the TSAHI/Tactile interfaces could be operated with a single finger.

| TSAHI | Touchscreen | Tactile |

Figure3.4: A CAD representation of the simulator and demonstrators. The Visual HMI is coloured in green and the tactile HMI coloured in red.

To ensure that the information did not cause a driver to gaze continuously at the screen, it could be discontinued by driver at any time as suggested in the guideline. This is achieved by ensuring that the system did not demand an immediate response when input is necessary, so visual attention could be dedicated to the road. Also, functions restricted by regulation while the vehicle is in motion were inaccessible and inoperative.

Section 6 in JAMA 2004 focussed on the presentation of information to users. The visual reporting of the state of the system should be quick and easy to comprehend. A simple stereotypical graphics style for the system state was implemented using the methods of design discussed earlier. An example of this system state display can be seen in figure 3.6, where the temperature, air flow and air speed details are displayed.
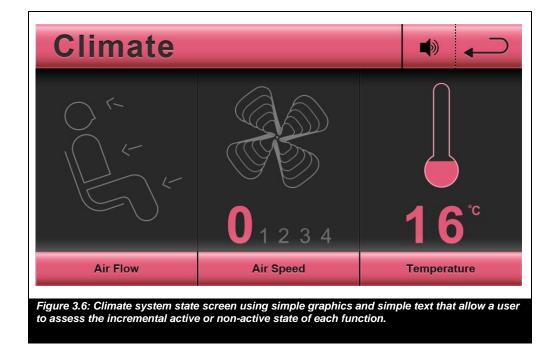
Figure 3.5: Example of screen shots of the Graphical User Interface used for the demonstrators.

Pilot runs checked the effectiveness of the design features on a web based test bed and through a desktop.

Overall responses to the pilot runs were positive. The participants comments (appendix 3.1) included:

- 'straight forward',
- 'no need to look at lists',
- good response time,

- 'Nice clear layout – easily understood the format'.
- Stereotypical graphical representation was 'really good'
- 'Good to see all parameters at a glance'
- There was a 'back' button on all screens which made it easy to return to the top of a category. Features such as 'climate' focused on state screen issues discussed earlier and seen in figure 3.6.

Figure 3.6: Climate system state screen using simple graphics and simple text that allow a user to assess the incremental active or non-active state of each function.

Negative comments were made about the initial pilot screens:

- Would prefer 'buttons changing colour as I press them so I have feedback'; To resolve this, buttons brightened considerably to indicate feedback upon interaction.
- 'prefer to have the albums as a list or something like that not only scrolling through a cascade'; To resolve this, the buttons on the graphical list were made touchable so direct activation of an album was possible.
- Would prefer to 'hold down on button for incremental tasks'; Single press adjustments enabled the incremental functions such as volume.

These changes were resolved in the final GUI product with a software programmer who refined the initial mock designs in Microsoft Visual Basic, a programming application that would allow the mechanics to easily send serial data to the controlling PCB microprocessor as well as manipulate the screen graphics.
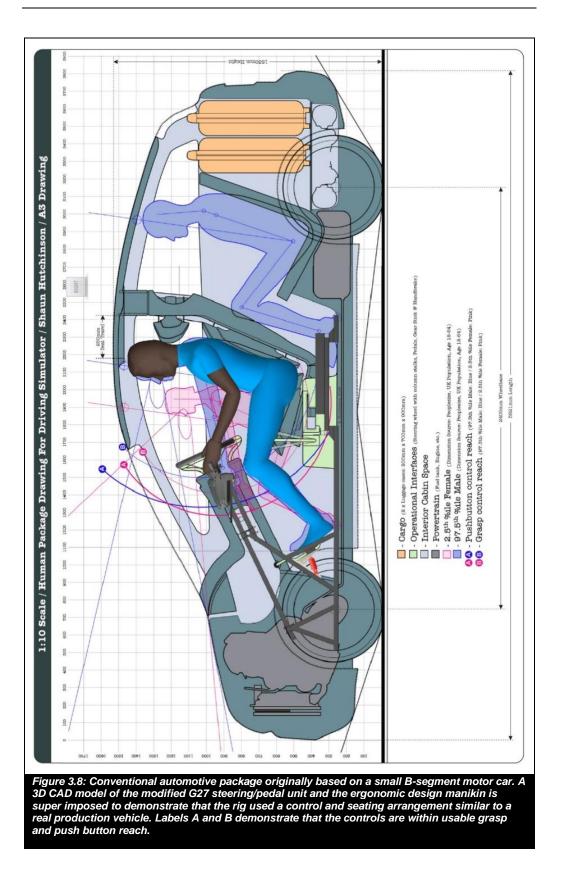
PURPOSEFUL DEMONSTRATOR PROTOTYPES
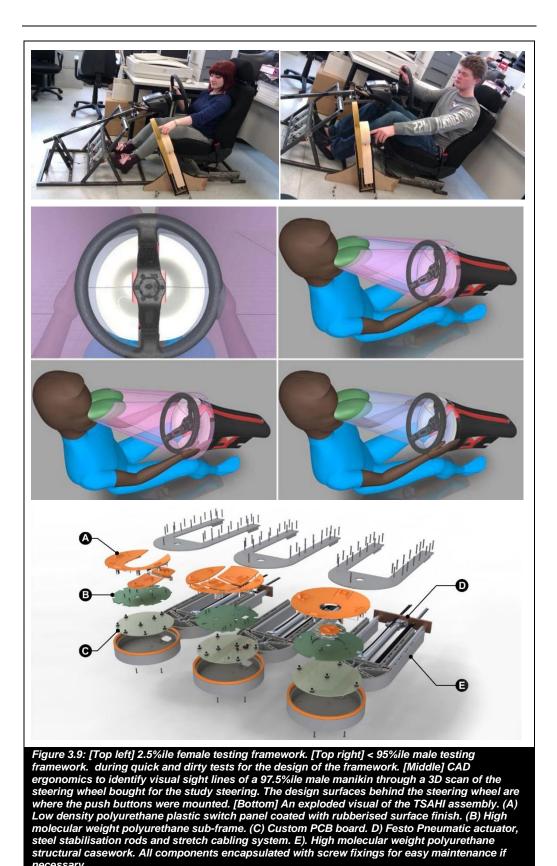
Most of the tasks mentioned above are traditionally outside the scope of industrial design, hence it was important that professionals were employed to ensure that the prototype was robust so there could be no doubt that the interactions experienced by the subjects were from the designed conditions and not from material defects, mechanics or electronics.

This said, it is important to remember that quality levels appropriate for mass manufacture could not be attained due to finance and time constraints. However, the interactions experienced by the subjects were successfully aligned with the desired themes of the hypothesis of tactility and showing and hiding.

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

Figure 3.7: Shows the bare bones of the driving rig that was designed to be like the production ergonomic automotive package of a small B-segment motorcar. With (A) Volkswagen driver side seat, and modifications to the standard Logitech G27 simulator controls, such as (B) reverse mounted pedals, and (C) full sized 350mm steering wheel to meet NHTSA and ISO regulations.

Figure 3.8: Conventional automotive package originally based on a small B-segment motor car. A 3D CAD model of the modified G27 steering/pedal unit and the ergonomic design manikin is super imposed to demonstrate that the rig used a control and seating arrangement similar to a real production vehicle. Labels A and B demonstrate that the controls are within usable grasp and push button reach.

Figure 3.9: [Top left] 2.5%ile female testing framework. [Top right] < 95%ile male testing framework. during quick and dirty tests for the design of the framework. [Middle] CAD ergonomics to identify visual sight lines of a 97.5%ile male manikin through a 3D scan of the steering wheel bought for the study steering. The design surfaces behind the steering wheel are where the push buttons were mounted. [Bottom] An exploded visual of the TSAHI assembly. (A) Low density polyurethane plastic switch panel coated with rubberised surface finish. (B) High molecular weight polyurethane sub-frame. (C) Custom PCB board. D) Festo Pneumatic actuator, steel stabilisation rods and stretch cabling system. E). High molecular weight polyurethane structural casework. All components encapsulated with screw fixings for easy maintenance if necessary.

Figure 3.10: PBC designer and fabricator Nikolay Tsanov. Etched master PCB controller and Festo (A) air regulator, (B) pneumatic solenoid valve terminal and (C) cylinder piston drives.

Figure 3.11: HMI (Human Machine Interaction) design use by the screen coding programmer and electrical engineer who developed the movement of the panel and the push switches.

CHAPTER FOUR
THE DEMONSTRATOR
 - TSAHI EMBODIED

In this chapter, a design task was undertaken to produce a demonstrator that embodied the ideas of a Tactile, Show and Hide interface on order to posit a solution to the problems of visual distraction discussed in chapter 2.

In certain areas, new knowledge needed to be created. Therefore, documenting the results and processes had additioinal significance.

4.1 - DESIGN FUNDAMENTALS

Before the 2-D sketch work could begin, some fundamental issues were addressed. The types of controls and their appropriate locations for the control areas in the interior were a major concern.
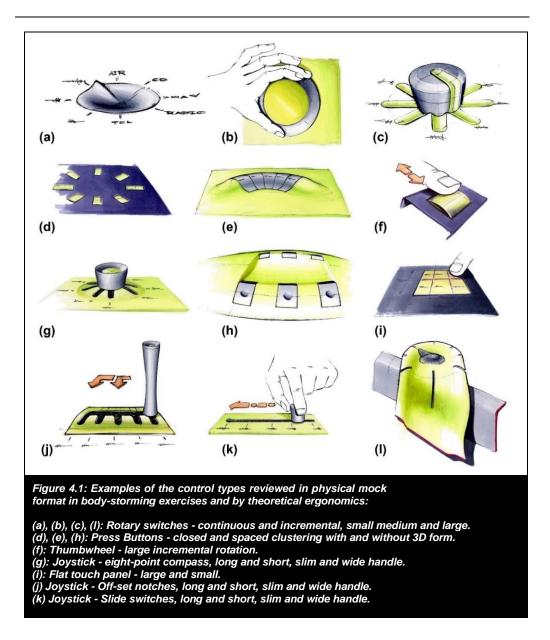
4.1.1 - SELECTION OF CONTROLS

To resolve this issue, a review of 23 different control types was conducted:

- 4 types of Push Button (Closed-cluster & spaced-out, with & without 3D form)
- 4 types of Joystick (Eight-point travel with long and short, wide & thin handles)
- 8 types of Slide Switch (Straight & off-set travel with long & short, wide & thin handles)
- 4 types of Rotary Switch (Small/medium & large with continuous & incremental settings)
- 2 types of Flat-panel (Large and small size)
- 1 Thumbwheel

Examples of these control types can be seen in Figure 4.1. Full details can be seen in appendix 4.1a.

The controls were reviewed under conditions influenced by issues from the literature and the case study described in chapter two.

Figure 4.1: Examples of the control types reviewed in physical mock format in body-storming exercises and by theoretical ergonomics:

(a), (b), (c), (l): Rotary switches - continuous and incremental, small medium and large.
(d), (e), (h): Press Buttons - closed and spaced clustering with and without 3D form.
(f): Thumbwheel - large incremental rotation.
(g): Joystick - eight-point compass, long and short, slim and wide handle.
(i): Flat touch panel - large and small.
(j) Joystick - Off-set notches, long and short, slim and wide handle.
(k) Joystick - Slide switches, long and short, slim and wide handle.

Physical properties of the actual controls were addressed in the review of the control types:

- *Easy operation in position:* 'Body-storming', as discussed in section 3.4 above was used as guidance to judge the most appropriate control type.
- *Action of use:* Guided by the principles of simplicity to judge the most appropriate control type, as discussed in section 2.5 above
- *Speed of operation:* Uses the hyperbole principle discussed in section 2.5 above to judge the most appropriate control type.
- *Touch:* Principles of haptics salience and haptic amplification from section 2.5 are used to enable judgements about the appropriateness of the different control types.

- *Reach:* Discussion in section 2.5 about dimensional specifications for clustering functions enabled to disipher which control was best for reach.

RESULTS

The following discusses the results of the review to indicate the most appropriate control type for a haptic interface to be used in a vehicle.

Easy Operation In Position

The highest score for the push buttons were seen in the Lexus, Mercedes, Audi, and Nissan case study (section 2.2). From this control type review, it was understood that they were operable in various areas such as the side door, centre dash, central console, ceiling and steering wheel. The scores were slightly lower in the spaced out versions as a larger area is needed to accommodate this type of control panel. Overall, the push buttons were among the highest scoring controls in the body-storming exercise. For the joysticks, the general size prohibited use in many of the locations due to the longer handles. With respect to the sliding switch, its length (50mm gap between each function) meant that like the joystick, it could not be placed in many locations. With the rotary knobs, their generally large size proved problematic in locations such as the steering wheel. For many of the larger controls, the ceiling position was problematic as it might obscure mirror usage. This was less of an issue for the smaller and flatter controls.

Action Of Use

The actions for the control types ranged between touch, twist and press. With simplicity in mind as a better option, a control that used just one function, such as 'press', ranked the highest. Consequently, the push buttons and flat panels were viewed as the superior options under the criterion of simplicity. The joysticks required pressure and a variety of movement. The rotary knobs had a similar issue with a variation of twisting and pressing. The thumb wheels again suffered from the variety of movement being more complex than a simple press. It was noted however that some thumbwheels can lock in on a function to make it stationary, converting it to a pushbutton style switch that creates less operational actions and is simpler to use.

Speed of operation in position

Using the hyperbole principle (section 2.4) results indicated that push buttons with closed clusters (with or without 3-D form) scored highly in the body-storming exercise with a total of 100. The joystick proved slightly slower but still scored well, as did the slide switches. The rotary was the slowest as its more complex format required more operation as a user must twist and click the knob to operate it.

Touch

It was earlier discussed that haptic salience and haptic amplification (discussed in section 2.4) were the main focus for judging the standard of touch . To further clarify; three main categories were used:

Senseless

- None: No tactile stimulation
- Reactive: Passive tactile stimulation found when a user searches for edges, ribs and notches.
- Interactive: Active tactile stimulation such as forced feedback that a user will have delivered without a search.

In terms of the results, the push buttons were viewed as being only reactive, with a medium level of touch sensitivity. The Joysticks and slide switches were similar. The continuous rotary controls gave less guidance in terms of whether a user had reached a goal. However, incremental rotary switches fared better as they would provide a level of haptic feedback, even if limited to a click. It should be noted that more sophisticated rotary knobs, as seen in the BMW iDrive tested in section 2, have electromagnetic profiles that change clicks to match the number of functions available, but this feature is more similar to an incremental rotary knob. Thumbwheels in general use clicks, so these would also be reactive. Flat panels rated very low in the review as their lack of features gives no haptic feedback.

Reach

The reach was decided with the following criteria:
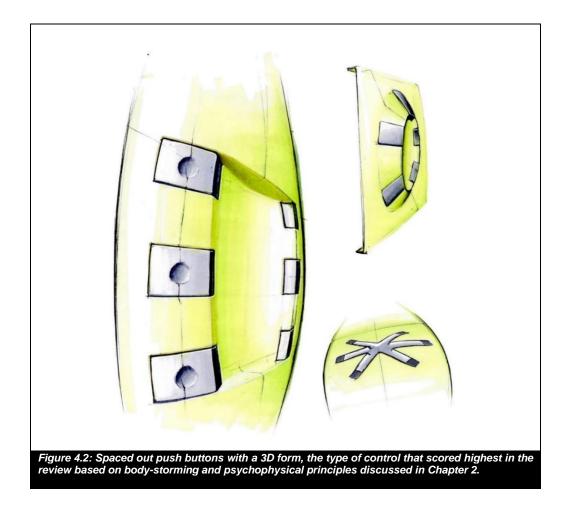
- 'Bad': No gaps or too many, too many to choose from.
- 'Okay': Approx. 50mm apart.
- 'Good': Little choice, or gaps greater than 100mm (corresponding to Pheasent's [1986] description of the ideal separation distance between functions as 100mm - 150mm for blind operation, cited earlier).
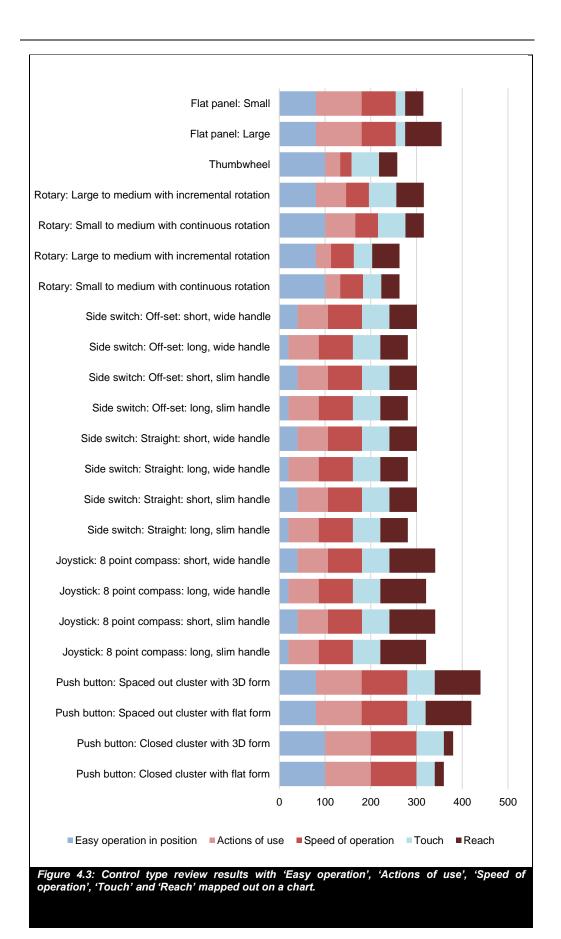
The closed cluster push button rated badly, as it was hard to reach without vision and felt like one large button. On the other hand, the spaced out push buttons ranked highly, as did the joysticks. The functions can be spread out well, so it would be easier to reach them without vision. The slide switch rated as 'okay', with the functions spaced out at 50mm. Body-storming found that a half a meter (500mm) for a control array felt unreasonable. An interesting control type that has evolved (as discussed in

general in chapter 2) is the flat panel display. An example is the tesla (Figure 2.6) that has a 17inch touch screen monitor. It is possible to space out the functions to make reach without vision easier. However, the interface designs need to reflect this, with the touch area taking advantage of the larger area. For this reason, the large touch screen scored very well in this section of the review, with the caveat that the interface design reflects the need to leave gaps in between the functional areas.

CONCLUSION
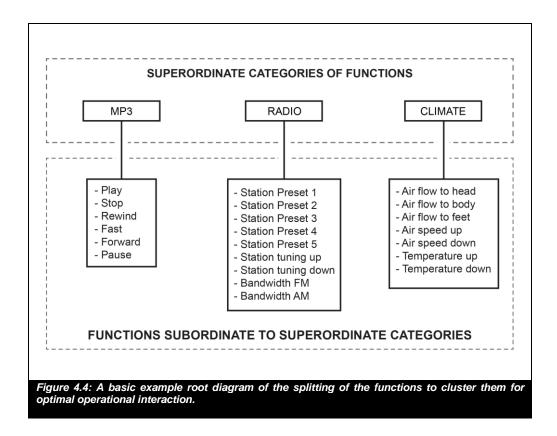
The highest score from the review was attributed to the spaced-out push buttons, as seen in figure 4.2 in various formats and surfaces. The highest scores in general from this 'quick and dirty' style of control type review were all situated in the push button control category, with the spaced out cluster with a flat surface formation ranking second and the third highest score being given to the closed cluster with a 3D form. The lowest score was given to the thumbwheel. However, design is necessarily a subjective discipline. The criteria were picked to approach one particular issue of tactility, as maintaining the purity of the demonstrator design was imperative to ensure that the right theoretical idea was being tested.

Figure 4.2: Spaced out push buttons with a 3D form, the type of control that scored highest in the review based on body-storming and psychophysical principles discussed in Chapter 2.

Flat panel: Small
Flat panel: Large
Thumbwheel
Rotary: Large to medium with incremental rotation
Rotary: Small to medium with continuous rotation
Rotary: Large to medium with incremental rotation
Rotary: Small to medium with continuous rotation
Side switch: Off-set: short, wide handle
Side switch: Off-set: long, wide handle
Side switch: Off-set: short, slim handle
Side switch: Off-set: long, slim handle
Side switch: Straight: short, wide handle
Side switch: Straight: long, wide handle
Side switch: Straight: short, slim handle
Side switch: Straight: long, slim handle
Joystick: 8 point compass: short, wide handle
Joystick: 8 point compass: long, wide handle
Joystick: 8 point compass: short, slim handle
Joystick: 8 point compass: long, slim handle
Push button: Spaced out cluster with 3D form
Push button: Spaced out cluster with flat form
Push button: Closed cluster with 3D form
Push button: Closed cluster with flat form

0   100   200   300   400   500

■ Easy operation in position   ■ Actions of use   ■ Speed of operation   ■ Touch   ■ Reach

Figure 4.3: Control type review results with 'Easy operation', 'Actions of use', 'Speed of operation', 'Touch' and 'Reach' mapped out on a chart.

4.1.2 - SUPERORDINATE / SUBORDINATE CONCEPT

A fundamental concept pivotal for the design of the Tactile Show And Hide Interface is that the manipulation of the controls should minimalise the choices. To aid the operator, this was done logically, clustering functions under categories as discussed in section 2.4 and in figure 4.4. Each category was shown to the participants upon demand.

Figure 4.4: A basic example root diagram of the splitting of the functions to cluster them for optimal operational interaction.
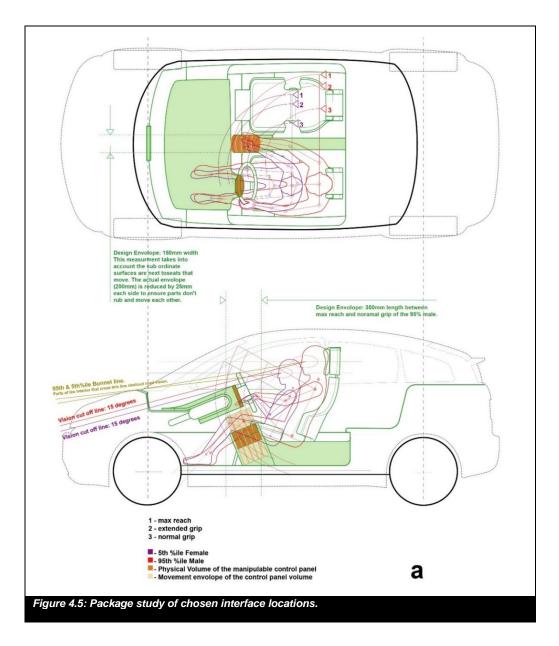
4.1.3 - THE DESIGN ENVELOPE

With the control type and clusters specified, the package of the vehicle was then specified to understand the design envelope that should be used for the overall designs. This also helped to specify sizes for the demonstrator designs.

Body-storming had indicated that a few areas were not appropriate for use with the spaced-out push buttons, such as the side door and the ceiling roof liner. Later studies also eliminated the central dash area as this is where the air vents are situated in many cars. This left the steering wheel and the central console area as locations that were available for design development.

The size of the area controls areas - the design envelope - was determined by completing a package assessment (figure 4.5). The package of an Audi A2 was used

for the study. This vehicle was used because of its size. It is the smallest of a typical brand family and if the designs fitted, they would be appropriate for any car upward in the brand range.

Design Envelope: 150mm width
This measurment takes into account the sub ordinate surfaces are next to seats that move. The actual envelope (200mm) is reduced by 25mm each side to ensure parts don't rub and move each other.

Design Envolope: 300mm length between max reach and noramal grip of the 95% male.

95th & 5th%ile Bonnet line.
Parts of the interior that cross this line obstruct road vision.

Vision cut off line: 15 degrees

Vision cut off line: 15 degrees

1 - max reach
2 - extended grip
3 - normal grip

■ - 5th %ile Female
■ - 95th %ile Male
■ - Physical Volume of the manipulable control panel
■ - Movement envelope of the control panel volume

a

Figure 4.5: Package study of chosen interface locations.

The width of the overall design envelope for the subordinate-ordinate control area was designated as 150mm, comprising a general clearance of 25mm each side to account for 95%ile male finger clearance, 24mm for thumbs and 21mm for index fingers (Pheasant 1996: p.84) This will also avoid rubbing against the seats. For the superordinate area, a finger clearance of 65mm was allowed between the interface and the steering wheel. 58mm (95%ile male hand thickness including thumb) would allow clearance for fingers and hands, as suggested by Bhise (2016 p.87). The
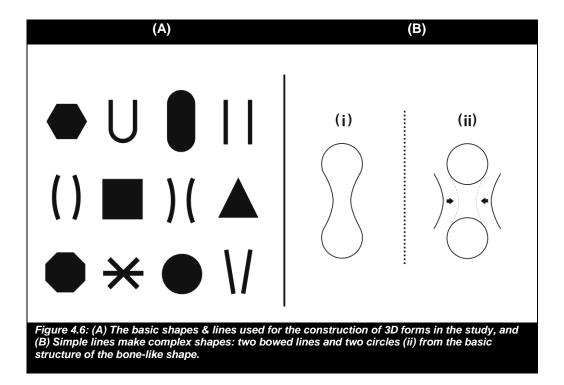
superordinate and subordinate areas had to be within the fingertip reach of the 5th% female and the 95%ile male occupants.

4.1.4 - CONTROL PANEL AREA SURFACE DESIGN FOR TACTILITY

Before the design of the push buttons was established, the overall shape of the panel areas of tactile interaction needed to be defined. As the potential number of shapes and surface formations is almost infinite, a short list of generic shapes was drawn up.
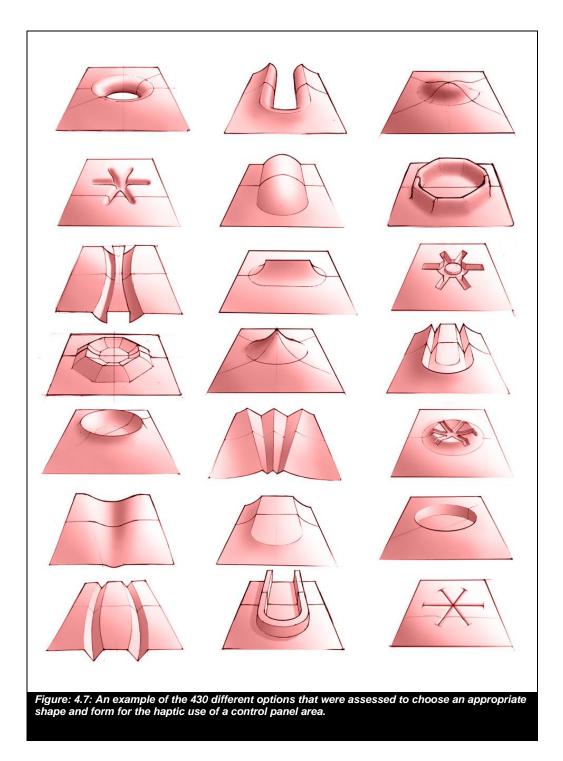
CONTROL PANEL AREA: STUDY PROCEDURE

The study was primarily desk-based. An initial concept study sketch that freely explored options to satisfy the tactile principles was deployed. The outcomes of this process can be viewed in appendix 4.4. In these early design studies, a dome shaped design for the control panel informally showed promise when mapped against the design principles proposed in section 2.4. Even so, there were many other shapes that had not been considered. A study was conducted to assess how other shapes and forms compared to the initial design concept.

Figure 4.6: (A) The basic shapes & lines used for the construction of 3D forms in the study, and (B) Simple lines make complex shapes: two bowed lines and two circles (ii) from the basic structure of the bone-like shape.

There was a basic structure behind the choice of shape and form for this study. Most complex shapes are made of basic geometric forms and lines that are joined together (figure 4.6b). Therefore, understanding the values of the basic shapes can potentially give an understanding of the possibilities of more complex forms. Figure 4.6a shows the basic shapes used in the study. Various combinations of three dimensional

formations were added to these shapes to create different surface areas that could be analysed. Figure 4.7 shows a small selection of formations from a basic shape. In total, 430 different sketch ideas were proposed. These ideas were analysed under a criterion to find the best shape and form for the superordinate control area. As the three-dimensional assessment was more concerned with tactile interaction, the criteria was based on the principles in section 2.5.

Figure: 4.7: An example of the 430 different options that were assessed to choose an appropriate shape and form for the haptic use of a control panel area.

The criteria to judge the most appropriate shape and form for the control panel area was as follows:

Make mapping easy

Based on the mapping principle discussed in section 2.4, this criterion aimed to ensure the tactile interaction had the potential to be a visually salient landmark for the interior in order to assist mapping. The criterion question was: *'Are the contours closed or open?'* as closed contours have been proven to make shapes 'pop-out' of a background. As this is a study that focuses on a generic shape and not a function, the shape coding was not applicable here.

Keep it simple

The general rules of simplicity that featured in section 2.4 were the focus of this criterion. It aimed to enable the driver to effectively match cutaneous information with cognitive maps by simplifying forms; thus lowering memory costs and blockages. The question for criterion three is: 'How many surfaces does the design have?' as too many surfaces can make a design complex.

Amplify cutaneous interaction

This was a new addition to the criteria. It aimed to amplify cutaneous interaction so that the physical attributes are easily recognisable through the fingers. The question for this criterion is: 'How much of the surface joining is acutely edged?' as acute edges give more sensation than obtuse edges.

Overall, these criteria encompass major ideas of how humans interact with objects on a tactile level. This is contextualised pictorially in figure 4.8, where a feedback and feed forward loop is considered and enhanced by the principle theories of how the panel should be designed.
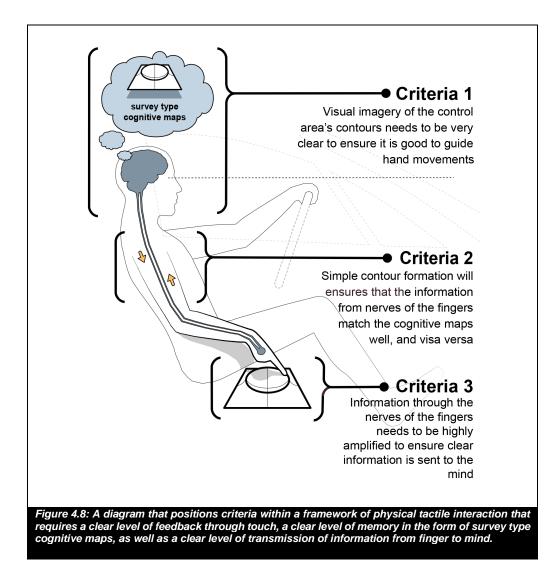
In terms of the other principles of section 2.5 of the literature review; salience is more of an issue where multiple objects compete for attention and is less appropriate for a single panel's shape. Hyperbole is mostly specified by the limitations of the design envelope. The best attributes for touch, such as hardness and texture, were handled later in the design process. Clustering was mainly related to the use of the buttons and will be covered later in this chapter. Mind/hand calibration is an issue of mechanical movement that is resolved later in the programming of software and robotics.

The study was desk based. Each option was drawn and assessed against the criteria on A4 sheets. An example of this can be seen in appendix 4.6.

RESULTS

Briefly, the worst shapes for tactility in this study were four hexagonal forms. Overall, they had no real edge contours because the number of surfaces needed make them was too high.

As for the leading shapes and forms of this study, there were 2 joint leaders (figure 4.9), a circular form and a pill shaped form. Choosing between the two with the current criteria was not possible as the results were too similar. Therefore, to make a favourable choice for the more appropriate design for the experiments, the two surface designs were compared in a package study (seen in figure 4.10) to assess which was the most appropriate for the environment of a car interior. The circular bowl proved the most favourable design, as the pill shaped bowl took too much space and was not fully usable in a horizontal state by 5%ile female drivers.

Criteria 1
Visual imagery of the control area's contours needs to be very clear to ensure it is good to guide hand movements

Criteria 2
Simple contour formation will ensures that the information from nerves of the fingers match the cognitive maps well, and visa versa

Criteria 3
Information through the nerves of the fingers needs to be highly amplified to ensure clear information is sent to the mind

Figure 4.8: A diagram that positions criteria within a framework of physical tactile interaction that requires a clear level of feedback through touch, a clear level of memory in the form of survey type cognitive maps, as well as a clear level of transmission of information from finger to mind.

Figure: 4.9: Results of the Control panel area surface design study ranking the three highest scores and the worst options.

Figure 4.10: The (A) vertical pill, (B) horizontal pill and (C) circular control panels placed in a package scenario to assess the most appropriate panel shape and form to conclude the design study for the control area.

4.1.5 - SHOW AND HIDE SURFACE ITERATIVE DESIGN AND REFINEMENT

The circular bowl shape with an acute edge proved to be the best shape for tactility and mapping after a thorough design study of over four hundred different shapes and forms. The next stage of this study needs to look at the design fundamentals of showing and hiding: the fundamentals of tactility.

The show and hide surface design study was desk based. It began with a short sketch study that ideated several conceptual options. Those that had potential can be seen in figure 4.11. These sketch options were then drawn in package form and assessed under a criterion. Once again, the principle knowledge from section 2.5 was codified into useful forms to make an appropriate TSAHI demonstrator. The following criteria based on this knowledge was used to as a checklist to filter the most appropriate design.

Good reach
Ease of reach by hand to the location of haptic exploration was judged in the following way. 100% was given to a design that had only a single location; a mid-mark of 50% for designs that had more than one location but minimal distance(all within the design envelope) and 0% for designs that had more than one location that spread beyond the design envelope.

Simple, salient, and low amplification
In this criterion the principles discussed in section 2.5 of 'Simplicity' and 'Salience' and 'Haptic amplification' (but flipped to reduce surface noise) were used as a guide to understand which design options would be appropriate for the tactile show and hide demonstrator. A 100% score was given to a design that had the potential to have a single, acute edge only, for examplethe circle chosen in section 4.1.4. 0% was given to designs that had too many surplus edges. The mid-point was regarded as an indication that the design had more than one edge.

Design envelope fit
The third and last criterion is the 'Hyperbole' principle discussed in section 2.4. This criteria was a very simple. If a concept design did not fit within the potential maximum space needed to fit a radius of the acute circle (150mm) and reach the restrictions of the ergonomic 5th %ile female and 95th %ile male (300mm), it was given 0%. If it had the potential to fit within the design envelope, the design option was given 100%.

Various design principles from section 2.4 were not appropriate at this stage. For example, the best attributes for touch such as hardness and texture were handled later in the design process. Clustering was mainly related to the use of the buttons and will be covered later in this chapter. Mind/hand calibration and the issue of mechanical movement are resolved later in the programming of software and robotics and in mapping.
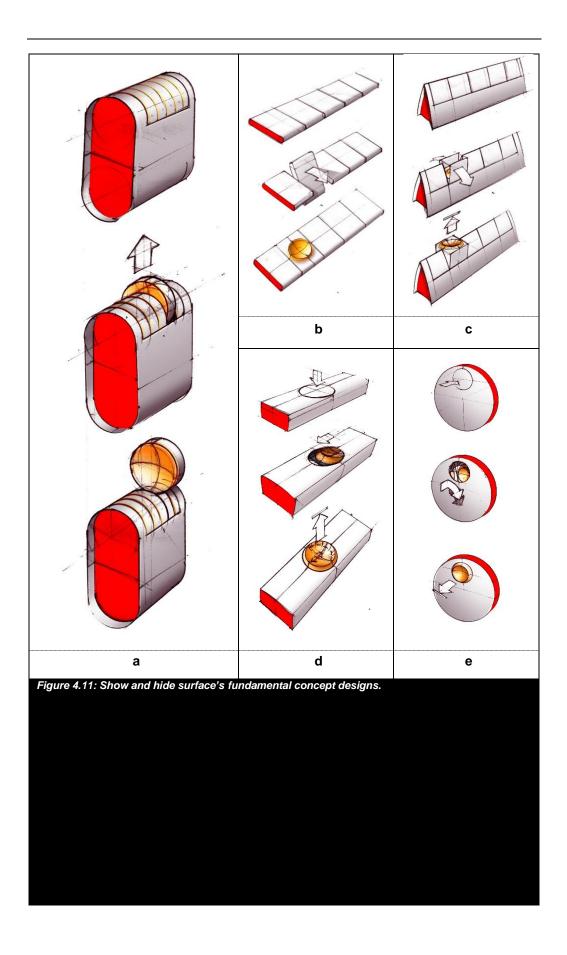
DESIGN RESULTS

The sketch eventually chosen for the final design was idea 'A' in figure 4.11. The design presented a circular acute edge of the control panel as cleanly as possible, with no other edges available to the driver from a seated position. One of the downfalls of the other options 'B', 'C', 'D', 'E' was that they were awkward to fit into the vehicle package adopted for this study (see figure 4.5). Design 'A' therefore was the only design that could fit into the design envelope without compromising it.

One area where design 'A' had a theoretical flaw was reach. To avoid the complex mechanical manipulation of the panels and to reduce the product packaging, the panels were stacked and simply moved up and down to reveal the desired panel. This creates a situation where they appear from different areas instead of from one single location, which had been the optimal solution. However, the location was within the design package so it was deemed as an acceptable distance. The design packaging of the switch components could also make the panels thinner, so the distance between each separate section was minimised.

Appendix 4.11 documents the design evaluation with the 5 options and how they fared against the criteria described in the previous section. The package studies of these can be seen in appendix 4.5.

To gain a level of intuitive verification of this chosen design and to decide if a second iteration of design options were necessary, 'quick and dirty' tests were conducted as briefly discussed in section 3.4 of the design methodology.

Figure 4.11: Show and hide surface's fundamental concept designs.

To quickly understand the implications of design 'A' for mechanical movement, the 2-D sketch work generated from the desk research activity was fabricated into a 3-D mock model.

'QUICK AND DIRTY' TEST

Four masters' students were asked to participate in these 'quick and dirty' user-tests. Two of the participants were female aged M=30.75 SD=6.7 and two were males aged M=26 SD=0.0.

In the user-tests the participants were asked to reach for the control areas presented to them on the 'A' design mock model made from the soft material that was chosen in the previous section. The tasks involved pointing at and pressing the low fidelity paper interface (Walker, Takayama, Landay 2002) of a control panel that simulated a typical in-car functional category, when manipulated and shown to the participant. Only one panel at a time was shown to them. The functional categories were CD player, telephone, climate and radio. The participant was asked to complete each operation three times and in a random order. In total, each participant was asked to reach and press a panel 48 times. Checkbox paper notes were taken to clarify if the participant completed the reaching task with the following: a 'glance' to the interface, 'no glance', or 'no glance with hand exploration'.

The test participants were asked to do this while engaging in a screen-based computer simulated driving environment. This was used to encourage the test subjects to access the visuo-spatial and kinaesthetic areas of the mind that are similar to the those used whilst driving on the road.

It is important to remember that the idea of a 'quick and dirty' test is to roughly simulate an environment or product to allow a designer to gain a quick and fluent idea of the design phase's progress without fully testing it as a finished item. It is less formal and has fewer constraints, providing rapid information at an acceptable level of accuracy. In some cases, a simple approximation can be used. The development of a 'dirty model' should be quick, often using glue or tape. Where heavier interaction is needed, stronger materials such as wood and foam are used (Bramston 2008: p87; Happian-Smith 2001: p 247). The 'dirty model' fabricated for this user-test can be seen in figure 4.12. The fabrication used ridged and bendable card and was reinforced with card and hot glue where necessary, to ensure that it was robust while being manipulated and that the movement of the control panels was accurate. The dimensions of the model, such as the diameter of the circular panel, were correct.

Figure 4.12: The experience prototype of the subordinate surface 'quick and dirty model' that was used with the participants and the test environment.

The driving was completed under 5 fundamental rules:

1 - The speed limit is 40 mph (maximum)

2 - Always drive on the road, in the left-hand lane

3 - Do not crash or collide with cars, trees, barriers, etc.

4 - At 'ALL TIMES', your 1st priority is to satisfy rule 1, 2 & 3

5 - When asked to complete a task, please do so without breaking rule 4

These fundamental rules aim to bring basic road rules to the forefront of the users' mind and replicate real driving responsibilities. These were the only instructions

disclosed, apart from reaching for areas of the subordinate control area. This should ensure more natural responses and results. Also, the participants were not told if they had made any errors in the tasks as this would influence the subsequent tests.

The amount of times a participant glanced away from the screen to look at the controls were recorded, as was any successful contact with the different parts they were instructed to touch. The participants were asked to comment freely about their experience following each test run to assess areas that might influence their behaviour.
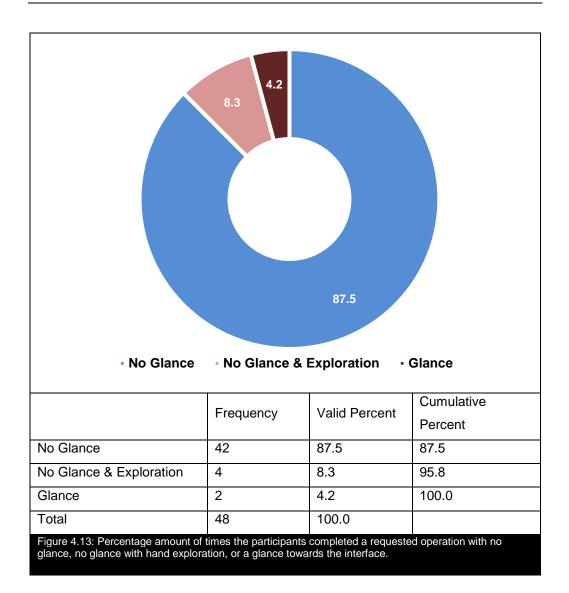
'QUICK AND DIRTY' TEST RESULTS
The users generally commented they found it "easy to reach areas" (Participant F1, appendix 4.8). One user commented that "it's the only thing to find … there's not much to it really" (Participant F2). This gave an indication that the principle concerned with salience had been somewhat successful.

It was particularly noticeable that there was little exploration of the subordinate area with the hand. The participants either placed their hands straight on the area or positioned their hand so that it directly faced the control area and then pushed it forward until it was found. There is no conclusive explanation for these actions. Further studies of the final prototype may provide more transparency to this phenomenon.

To understand how many times the participants glanced at the show and hide interface during the user-tests, a frequency analysis was conducted on the checkbox glance data, using IBM SPSS. The mean analysis revealed that 95.8% of the participant's glances were towards the road environment and away from the the interface. 8.3% of the participant's interactions were with hand explorations on the interface in conjunction with reach, instead of a straight point and press. Only 4.2% of the participant's glances were towards the interface to reach the show and hide interface control panel.

Although these figures appear encouraging it must be remembered that the sample size was small. Moreover, 'quick and dirty' tests are conducted to uncover any major problems and to highlight any necessary changes, gaining a rapid amount of information about the design to influence further iterations if needed. To fully and comprehensively understand the show and hide effects, a larger test group with highly accurate recording equipment was needed. This method and results of this testing are discussed later in the evaluation studies in chapters five and six.

	Frequency	Valid Percent	Cumulative Percent
No Glance	42	87.5	87.5
No Glance & Exploration	4	8.3	95.8
Glance	2	4.2	100.0
Total	48	100.0	

Figure 4.13: Percentage amount of times the participants completed a requested operation with no glance, no glance with hand exploration, or a glance towards the interface.

4.1.6 - BUTTON DESIGN STUDY (PT.1: HEIGHT)

A group of design issues fundamental to ensure that the demonstrator correctly related to the ideas of tactility/show and hide quickly came to light as the detailed design process began. Two fundamental questions were raised, the first being What size should they be? The second will be discussed in a later section.
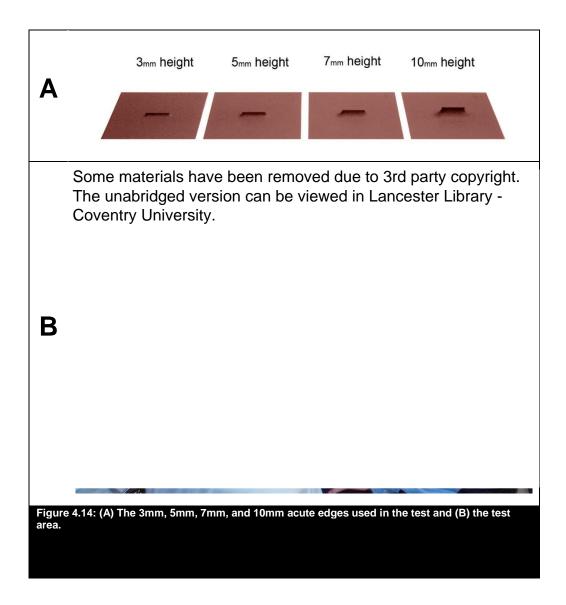
These questions proved problematic as they needed to be specified to ensure that a successful knowledge of tactility (section 2.5) could be successfully and robustly codified into a physical property.

Pheasant (1986) recommends that push buttons would work optimally at a size of 25mm, although, in general there are no recommendations on the optimum button height for tactile use. There is however a suggestion that raised edges for haptic

exploration should not be less than 1mm (Klatzky, Loomis, Lederman, Wake & Fujita 1993) as described in section 2.5.3. Tests therefore needed to be conducted to generate new knowledge that could be used to influence the design of the tactile demonstrators.

HEIGHT STUDY: 'QUICK AND DIRTY TESTS'
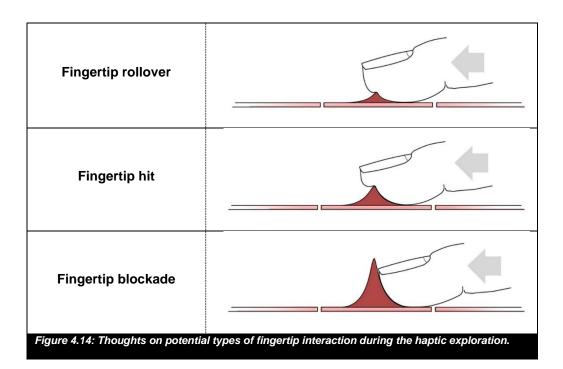
Six participants were used in this test, three males aged M=29.2 SD=5.5 and three females M=32 SD=5.5. Four different options were fabricated, as seen in figure 4.14b. Initially these fabricated edges were covered. As the subjects approached the test area, they were asked to look at the cross on the wall so their vision was not focused on the edges, as seen in figure 4.14a. The fabricated edges were then uncovered so the subject could interact with them. The participants were asked the simple question: 'Which edge gave the most sensation through the fingers?'

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

Figure 4.14: (A) The 3mm, 5mm, 7mm, and 10mm acute edges used in the test and (B) the test area.

HEIGHT STUDY 'QUICK AND DIRTY' RESULTS

Out of the 4 options, the 5mm high edge was preferred. Further comments from the users noted that apart from it feeling "the most edgy", the 5mm option felt most "at ease with the front of the fingers" and it "hit the tips quickly".

On reflection, it was informally observed in this test that the 10mm edge created a fingertip 'blockade' illustrated in figure 4.15. The edge was not readily available to the fingertips because it was higher than the 95%ile finger height. Similarly, the edge with a height of 5-7mm was just around half the depth of a 5th %ile female finger-tip at 13mm and just under half that of a 95th %ile male at 18mm (Niels et al. 1981). However, these were informal 'quick and dirty' observations. Further research is required to uncover the true mechanics of fingertip edge interaction, but this brief level of observation is insightful to the design process.

Fingertip rollover	
Fingertip hit	
Fingertip blockade	

Figure 4.14: Thoughts on potential types of fingertip interaction during the haptic exploration.
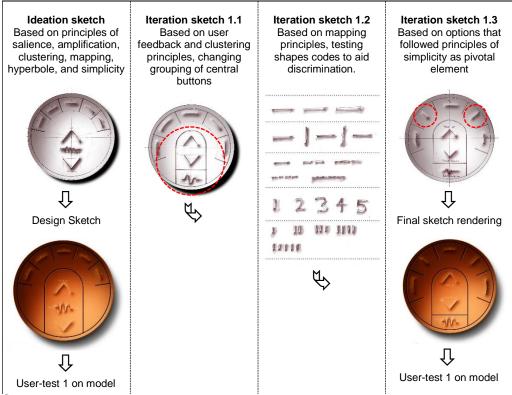
4.1.7 - BUTTON DESIGN STUDY (PT.2: SHAPE)

In addition to size, the second fundamental question raised in the design phase was: 'what shape should the buttons be?'

BUTTON DESIGN 'QUICK AND DIRTY' STUDY

The work in section 4.1.2 dictated that they buttons should be presented in clusters that logically group the functions together. Each design was fabricated in 3D and tested. Each designs used the principles created in the section 2.5. As mapped out in figure 3.1, test followed sketchwork on dirty models, and iterative sketchwork

commenced if the user-tests were not satisfactory. An example of the different iterative design options can bee seen in figure 4.15. The full iterative sketch and test process can be viewed in appendix 4.12.

Ideation sketch Based on principles of salience, amplification, clustering, mapping, hyperbole, and simplicity	**Iteration sketch 1.1** Based on user feedback and clustering principles, changing grouping of central buttons	**Iteration sketch 1.2** Based on mapping principles, testing shapes codes to aid discrimination.	**Iteration sketch 1.3** Based on options that followed principles of simplicity as pivotal element
⇩ Design Sketch	⇭		⇩ Final sketch rendering
⇩ User-test 1 on model		⇭	⇩ User-test 1 on model

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

Figure 4.15: An example of the iterative sketch design and user-test process for radio function of TSAHI

The criteria for the 'quick and dirty' models was that they should achieve a percentage of 90% or above for 'eyes on the road', a numeric value figure similar to that attained in the haptic studies of summerskill (2005a). The environment and the equipment used in the iterative design process was similar to that of the subordinate tests seen in **Figure 4.12**

Again, a range of test subjects from different demographic backgrounds took part. The same six participants from the Pt.1 Height tests (three males aged M=29.2 SD=5.5, and three females M=32 SD=5.5) were asked to perform a series of tasks on mock parts fabricated from the project's design sketch-work. The tasks involved typical in-car operations such as tuning a radio or forwarding a CD to another track. Appendix

4.10 show examples of the data sheets used and the instructions given to the participants. For the majority of the test, the subject was asked to conduct the tasks while using a screen-based computer simulated driving environment, again to encourage the participants to use the visuo-spatial and kinaesthetic resources they would normally use for driving, to make the control areas more realistic to compare closely with actual car interiors.

The driving was again completed under 5 fundamental rules - to reiterate:

1 - The speed limit is 40 mph (maximum)
2 - Always drive on the road, in the left-hand lane
3 - Do not crash or collide with cars, trees, barriers, etc.
4 - At 'ALL TIMES', your 1st priority is to satisfy rule 1, 2 & 3
5 - When asked to complete a task, please do so without breaking rule 4

Again, these rules aimed to bring to mind 'real world' driving responsibilities in order to gain more natural responses and results. Apart from the rules, the only instructions the participants received was to press and identify parts of the control area. Subjects were not given any feedback during the task so as not to influence the test results. Additionally, many car driver do not consult their interior car manuals before driving, therefore these rules about selective disclosure will expose whether the controls can be easily understood without intervention.

BUTTON DESIGN STUDY: 'QUICK AND DIRTY' RESULTS

Chooser User-tests

Respecting the dynamic environment of a car, it quickly became apparent that differentiating between the buttons while driving would be important. Over half of the symbols initially failed in the recognition tests this reason. After the 2nd design iteration that aimed to differentiate them, simplify them and improve them for tactile interaction however, most of them became recognisable while driving. Glances away from the road were good at this point with 92% of eye positioning being on the road. Despite this, on a few occasions the expectations of the users clashed with the designs. The CD symbol - that looked like a playback arrow - was mistaken for a hazard symbol. This did not enable mapping and confused the participants. To solve this, the shape was eventually changed to a circle to metaphorise the shape of a CD.

With the hazard problem resolved, the volume cluster was finalised for testing. The user test recognition of the CD button was good, but significantly, the volume buttons appeared to be recognisable to the extent that a user predicted their function without

assistance. At this point, with all the functions recognisable and the glance rates at an improved level of 95% 'eyes on the road', the design was frozen.

CD Player User-tests

The participants had little difficulty using the CD and quickly became familiar with the controls, so much so, that the total number of glances away from the road environment was only 10%, leaving 90% of eye contact on the road. One participant had slight problems locating the buttons accurately but seemed to quickly overcome this problem by imagining the buttons as compass points.

Radio User-test

The initial tests of the radio were not good, with the control area performing under par at 86% of eyes on the road. The pre-set buttons demanded too much visual attention. One user in particular reported problems with the middle pre-set buttons saying that they were "a blur". The bandwidth button was also slightly problematic in the first set of tests. While using the tuning buttons, the users kept colliding with the bandwidth as it was causing an obstruction. On a positive note, the 'Up' & 'Down' arrows worked well in the superordinate area.

Radio Design - Iteration 1

The idea that the pre-set buttons could be identical was seriously under question and amendments were needed to ensure theycould be could be used without vision. The buttons were consequently changed so that they could be more distinguishable. This iteration also saw a change to the locations of the tuning and bandwidth buttons. The tuning buttons were clustered together so the bandwidth button would not cause an obstruction when they were used.

Radio User-Test - Iteration 1

When asked for general comments, one participant noted that the presets were easy to find when they were spaced out and shaped differently. Another said the changes to presets nos. 2 and 4 broke up the buttons to help distinguish them. The bandwidth button was no longer a problem. As the design problems seemed to have been addressed, the user-test could finally claim 100% eye contact with the road environment - the best score of the whole study.

Climate Control User-test

The participants seemed to have no problems using the push buttons. There were however severe problems with the pictured symbol of a seated person. A test user

commented that "it was very difficult to use" and others had similar opinions, as far as commenting that it did not resemble the figure of a person.

Climate Control Design - Iteration 1
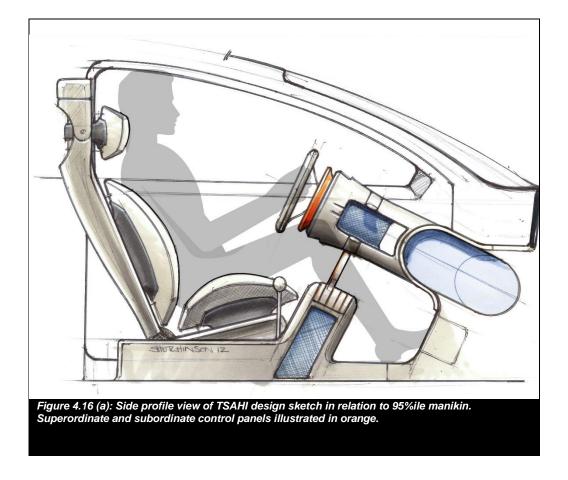
The second design iteration saw major changes to the figure which was designed to look more like a human so recognition and mapping would be better. The body was also split into 3 parts, as one user commented he or she "always has to feel the entire foot/body area to understand either".

Climate Control User-test - Iteration 1

When tested, an improvement was noted. Thus, the control area scored 92% 'eyes on the road'. At this point the design was frozen.

4.2 - THE RESULTING CONCEPT TSAHI DESIGN

The resulting TSAHI design from these documented design tasks was an automotive control system that is highly tactile to touch and shows the control clusters only when they are needed. The designs in the follow figures 4.16 (a), (b), (c), (d), and (e) illustrate the final concept sketch design.

Figure 4.16 (a): Side profile view of TSAHI design sketch in relation to 95%ile manikin. Superordinate and subordinate control panels illustrated in orange.

Acute edge surfacing
Only one panel would ever be shown at a any given time. When one is activated the others retract. This reduces the amount of choice, as discussed in the concept fundamentals, and increases the salience of the control panel in a search without vision because the acute edge of the panel is the only piece of amplified tactile information facing the driver.

Edgeless surfacing
The smooth surfaces of the end covers, side covers and streamlined control panel tops ensure that the surroundings consistently give very little in terms of tactile information; hence the acute edges is salient.

Hardwood
Helps to describe non-interactive areas when compared the soft control panels facias.

Sub-ordinate Control Console

Console control panels

Stationary Operation
Will only appear if the car is not moving

Climate

Radio

MP3

(b)

Radio control panel (c)

Presets Stations
Neutral acute edged forms are used to represent the pre-set station. There angled alternately angled at 90 degrees to help a driver distinguish one from another.

1mm Shut-line
1mm shut-lines are used, as they will not be easily sensed in a hapic search without vision. This reduces the amount cutaneous information a driver will receive and ensures the required edges are highly salient.

Tuning
Acute edges arrows represent the tuning functions.
Close clustering helps easy use. The switches have dual usage:
- Hold down/release for an automatic search
- Press/release for a manual search

FM/AM Bandwidth switch
Dreyfuss suggests that a wavelength symbol should be use for audio frequencies.

This suggestion influences the shape of the acute edged shape used for the FM/AM bandwidth switch. The shape is modified slightly so that it matches modern frequency symbols that are seen on consumer products. This similarity between the panel switch and everyday products should help users to recall memories of the switch and make mapping easy.

≈ Audio Frequency AC, 81

Figure 4.16 (B): Subordinate control console with show and hide control panels. Features of this design are edgeless smooth surfaces to lower haptic noise and make the single forward facing acute edge salient (section 2.5.1 and 2.5.2). The circular acute edge is closed to help create visual landmark (section 2.5.8). The tactile control panel and surrounding edgeless surfaces use opposing materials to help differentiate useful areas from redundant areas as suggested in section 2.5.5.

Figure 4.16 (C): Radio control panel uses shape coding and colour coding to help mapping (section 2.5.8) and buttons are widely spaced out to help make blind reach more efficient (section 2.5.3). Volume buttons are clustered together (section 2.5.6) as are pre-set buttons. All buttons are acute edges to help amplification (2.5.2)

Climate Control Panel (d)

Airflow direction
The shape code of a person in a seated position represents the different parts of the body that airflow can be directed towards.

1mm Shut-line
1mm shut-lines are used, as they will not be easily sensed in a hapic search without vision. This reduces the amount cutaneous information a driver will receive and ensures the required edges are highly salient.

Acute edged increase/decrease
Dreyfuss originally suggested Increase and decrease can be related to a specific application by using the following size variation.

This suggestion is considered but not directly applied, if the graphic of a fan and thermometer were to be used the detail on the small (decrease) switch would become unrecognisable by touch. The third ideal notes this. Instead simple arrows were used.

Temperature switch

MP3 Player Control Panel (e)

1mm Shut-line
1mm shut-lines are used, as they will not be easily sensed in a hapic search without vision. This reduces the amount cutaneous information a driver will receive and ensures the required edges are highly salient.

Play, Rewind & Forward
The acute edged switches, when possible, like all of the switches on all of the control panels, have been simplified without losing the meaning of the shape. In the case the arrows removing the rear of the triangles achieves this.

Audio Playback
All the CD player switches are derived from industry convention audio playback symbols. This is shape coding at it's best as the shapes are simple & widely known to ensure easy recognition and good mapping.

Figure 4.16 (D & E): Climate and MP3 control panels use shape coding and colour coding to help mapping (section 2.5.8) and buttons are widely spaced out to help make blind reach more efficient (section 2.5.3). In the climate control panel temperature, up/down are clustered, as are the air speed up/down and air direction head/body/feet buttons (section 2.5.6). All buttons are acute edges to help amplification (2.5.2)

Figure 4.16: (F): Superordinate chooser uses shape coding and colour coding to help mapping (section 2.5.8) and buttons are widely spaced out to help make blind reach more efficient (section 2.5.3). All buttons are acute edges to help amplification (2.5.2)

3

PART

SYSTEMATIC EVALUATION OF THE TSAHI DESIGN

CHAPTER 5
EVALUATION METHOD

5.1 - OVERVIEW

As mentioned in section 3.4.3, the method of testing was drawn together using the critical lens of Efficiency, Safety, and Satisfaction. Systematic rigour is crucial. This chapter closely assesses the methods used in the systematic evaluation of the TSAHI design in terms of standards, procedures, apparatus and measures.

5.2 - AIMS

This experiment aimed to compare the following conditions: Interfaces, TSAHI, Touchscreen (the problematic interface) and Tactile interfaces.

A number of tasks were completed:

1. Simulator driving.
2. MP3 use
3. Radio use
4. Climate control use

Driver behaviour was measured through:

1. *Visual Demand (Efficiency)*
    a. PEORT (Percentage 'Eyes Off Road' Time)
    b. Number of glances (global)
    c. Maximum glance duration
    d. Test duration

2. *Task performance (Safety)*
    a. Lane change task

3. *User Experience (Satisfaction)*
    a. Cognitive workload
    b. Tactile interaction
    c. System usability
    d. AttrakDiff
    e. Comparative questionnaire

The following research questions were addressed:

Q1: Did the new tactile/show-hide interface result in less visual distraction than the touchscreen whilst driving in a simulated environment?

Q2: Was the new tactile/show-hide interface more usable than the touchscreen whilst driving in a simulated environment?

From these questions, two experimental hypotheses were derived to explore the main sensorial design hypothesis: The TSAHI will result in less driver distraction than the Touchscreen (H1) and will be perceived as more usable (H2).

5.3 - ETHICAL APPROVAL

This study was approved by the Coventry University Applied Research Committee as a low risk project that has no links to external organisations that would require further ethical approval. For further information about the ethical procedure used to assess the project, see https://ethics.coventry.ac.uk/about/ethics-at-cu.aspx. The approved ethical documents can be seen in appendix 5.1

The project deployed an experimental design that included user-test participants. Each user-test participant was given a Participant Information Sheet and asked to sign a consent form confirming that he/she has read and understood the information sheet, that their participation was voluntary and that they agreed their actions and/or words could be video recorded or noted on paper to be used anonymously in the presentation of this research. If the participants had any questions, they would be answered. The participation information sheet and consent form can be seen in appendices 5.2 and 5.3

5.4 - STANDARDS: NHSTA AND ISO GUIDELINES

Before discussing the details of the experimental study, it is worth mentioning that there are rigid standards that govern the testing of in-car devices. Internationally, the major bodies involved are the National Highway Traffic Safety Administration (NHSTA) and the International Organisation for Standardisation (ISO).

Docket No. NHTSA-2010-0053 ('Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices') considers critical discussions with international organisations for car safety, major manufacturers and academia.

The final conclusions were reached following the discussions and guidelines proposed for the testing of in-car devices. To ensure an internationally reputable class of research was produced by this study, the guidelines suggested from Docket NHTSA were followed throughout the methodology for the experimental design.

In addition to the NHTSA guidelines, ISO 26022:2010 is also used intensely throughout the automotive ergonomics industry: 'Road vehicles -- Ergonomic aspects of transport information and control systems -- Simulated lane change test to assess in-vehicle secondary task demand'. Using this and the NHTSA standards for testing allowed the author to make comparisons with past research if necessary, as well as enabling researchers in the international community to make comparison to the results of this study.

5.5 - PARTICIPANTS

NHTSA Guidelines (2010-0053) recommend that tests use a 'mix of ages in each test participant sample' (pp 264). Six of each type are specified:

1) Participants 18 to 24 years old
2) Participants 25 to 39 years old
3) Participants 40 to 54 years old
4) Participants 55 to 64 years old and older

This mix of users strictly ensured that the results equally represented all age groups to a certain point. (2010-0053, p 214). No special focus or hypothesis was formed around age.

All of the drivers used in the tests had a valid driving licence at the time of testing to prove that they can indeed drive and must drive at least 3,000 miles per year (NHTSA 2010-0053 pp 210).

In total, twenty-four participants were recruited, six from each of the age groups. Initially, the pilot experiments were run with six participants. This refined the protocol and the experimental design, determined how long the final experiment would last and mapped the amount of time it took a user to learn and competently use the basic controls of the simulator including the steering wheels and pedals in conjunction with the driving software.

Although there was no hypothesis around age, several pilot user-tests were conducted

with elderly users in order to develop the testing method. These proved problematic as most of the 4 pilot participants suffered from simulator sickness, as noted by Porter (2011: p .94). This is a known problem in driving simulator tests. Kawano et al. found that a high proportion of their participants also suffered from simulation sickness when driving simulators. They concluded that this was associated with cognitive aging (Kawano et al. 2012). There are methods to test the elderly but this would require a completely different approach and consequently it would be very difficult to make comparisons in the study. The TSAHI hypothesis is mainly concerned with comparisons and not the outright performance of interfaces. For this reason, subjects over 65 were not included.

MALE AND FEMALE DRIVERS

The Institute of Advanced Motorists published research findings from Reading University highlighting that there are definite differences between male and female drivers (IAM 1998). These were noted as speed choice, following closeness, length of time driving without a break, competitiveness derived from the use of a car and accident types. Thus, an equal number of males and females were used to make a statistical comparison possible. This choice for gender balance echoed NHTSA regulations (NHTSA-2010-0053: pp 264) that specify:

'An equal balance of men and women in each of the age ranges 18 through 24 years old, 25 through 39 years old, 40 through 54 years old, and 55 years old and older.'

5.6 - RECRUITMENT

Participants were recruited with posters and emails throughout the Coventry University Environment and to local community groups such as the Coventry U3A (University of the Third Age). Where necessary, travel expenses and refreshments were given to all participants.

5.7 - CROSSOVER STUDY

Each participant allocated themselves a number by picking a numbered ball from one of six marked buckets. This was done for several reasons. Firstly, to increase the anonymity of the test subject, referring to them as a number in formal records and research presentations. Secondly, to randomise the data collected from the user-test, thus increasing the statistical accuracy of the results. Finally, splitting the numbered balls into six groups also enabled a 'crossover' style of study as seen in table 5.1.

	Condition 1 User Test	Condition 2 User Test	Condition 3 User Test	Condition 4 User Test
Crossover 1	Baseline	Tactile	Touchscreen	Tactile Show/Hide
Crossover 2	Baseline	Tactile	Tactile Show/Hide	Touchscreen
Crossover 3	Baseline	Tactile Show/Hide	Touchscreen	Tactile
Crossover 4	Baseline	Tactile Show/Hide	Tactile	Touchscreen
Crossover 5	Baseline	Tactile	Tactile Show/Hide	Touchscreen
Crossover 6	Baseline	Touchscreen	Tactile	Tactile Show/Hide

Table 5.1: The crossover method used to help randomise the test procedure illustrated as a chart.

5.8 - DATA COLLECTION

Demographic data was collected about the participants to inform the analysis and help categorise them in terms of gender, age and how often they drive. The participants were asked to clarify that they had a valid driving licence and how many miles a year they drive, to ensure they met the standard guidelines stated in NHTSA 2010-0053 pp 210. In addition to these questions, participants were also asked what portable electronic devices they use, to understand the types of product HMI they engaged with regularly. The form used to collect this personal information can be seen in appendix 5.3.

Various questionnaires (discussed later in section 5.12) were also completed by the participants, following test drives on the LCT. AV (Audio Video) data was collected with video recorders, microphones and an eye tracking headset. The AV equipment used is discussed in the following chapter, when further detail is given about the driving simulator environment.

All instructions, questions and other verbal communication from the researcher during the questionnaire were identical for each participant, to ensure consistency.

5.9 - DRIVING SIMULATOR

Figure 5.1 details the equipment used in the experiment. Features of the experiment set-up are governed by ISO and NHTSA regulations.

THE DRIVING SIMULATOR STEERING WHEEL

> 'an actual vehicle steering wheel mounted in a typical vehicle arrangement is necessary. Otherwise driver hand motions may not be realistic. For similar reasons, we think that force feedback should be present on the driving simulator's steering wheel'. (NHTSA 2010-0053: pp 203)

For this reason, the simulator was adapted so a real OMP 350mm steering wheel could be mounted onto the rig. NHTSA also recommend a simulator system with force feedback. The OMP steering wheel was mounted onto a Logitech G27 control unit. This unit had force feedback facilities to comply with NHTSA preferences. The features can be seen in figure 3.7.

DRIVING SIMULATOR PEDALS

'Gaming style pedal controls are adequate since current task acceptance tests do not use any metrics that will be affected by the movement of the driver's feet. However, we do think that pedal force feedback should be provided to assist the driver in maintaining a constant speed. Again, very simple but realistic pedal force feedback should be adequate.' (NHTSA 2010-0053: pp 203)

To comply with this guideline, the Logitech G27 steering unit was broken down and the accelerator, clutch, and brake push pedals were reverse mounted so they mimicked the position of a real car. This reverse mounting can be seen in figure 3.7. To further increase the level of realism, feedback was enhanced on the tactile feel of the pedals. The stock Logitech springs used in the G27 unit were replaced with Nixim progressive springs so the brake and clutch gradually felt harder to push. The brake pedal was also fitted with a rubber damper to simulate the 'bounce' felt at the end of a brake pedal push caused by hydraulic brakes used in real motor manufacturing.

DRIVING CABIN

'Open cabs, partial cabs, and/or non-production cabs are fine to use for this testing as long as the driving simulator has a seating and dashboard arrangement similar to that of an actual production vehicle so that realistic eye glance behaviour and control movements will occur'. (NHTSA 2010-0053: pp 265)

The cabin used in the experiment was a non-production conceptual open cabin. To comply with NHTSA regulations, the controls and seating arrangements were packaged using a conventional driving position so that a UK fifth percentile female and a UK ninety-fifth percentile male can use the primary and secondary controls with ease, as seen in figure 3.4. This shows the package drawing used to design the rig with the CAD model from the rig superimposed over it.

PARTICIPANT VIEW LOCATION

ISO 26022:2010 suggests that the 'The eye-to-display distance shall be no less than 60cm.' However, this conflicts with the NHTSA guidelines which require more distance from eye to display. NHTSA have recently changed their regulations on this issue, but the ISO standard is still short of the NHTSA guideline based on human focal abilities, which is a minimum of 2 meters. The viewing distance used in this study was 4 meters when considering fifth percentile females; a distance that is well within the minimum allocation and closer to the original 3.7 metre formerly recommended by NHTSA.

This distance also works well when considering other guidelines for vision from NHTSA, particularly the recommendation that:

'computer-generated imagery should be displayed in front of the simulated vehicle. The minimum recommended field-of-view should have a width of at least 30 degrees.' (p. 267)

The study's projector system used a 3-meter-wide screen. When the viewing angle is worked out from the 4-meter viewing distance to the screen, a 40 degree viewing angle is calculated - a figure, once again, well within the minimum NHTSA specification. These participant location dimensions are shown in figure 5.2.

These different forms of data were composited onto one AV monitor in a 4-way split screen so all recorded videos and the recorded eye tracking data from the Dikablis system (L in figure 5.1) could be synchronised using a single time code. The data from the AV monitor was used in the final analysis. A separate microphone was used to capture verbal protocols from the researcher and comments from the participants. These video preferences comply with sections 5.3.1, 5.3.2, and 5.3.3 of BSI ISO/TS 15007 2:2014.

DISPLAY EQUIPMENT

NHTSA 2010-0053 guidelines require that all 'computer generated image should be updated at least 30 times per second.' (pp 267) The visual display for TSAHI and Tactile interfaces (labelled G in figure 5.1) and the Hitachi ED-X42 overhead mounted LCD Projector (labelled B in figure 5.1) both update faster than 30 times per second.

AUDIO VISUAL RECORDING EQUIPMENT

Digital camcorders (C, D and E in figure 5.1) were used to capture the road scene ahead and the in-vehicle activities (D), as well as capturing video data of the participant's head (C) and hand movements around the different interface designs

during the experiment (E). This aided the understanding of hand movements in relation to eye-movements and the interface operation.

LANE CHANGE TEST

The Lane Change Test had two purposes. In addition to being a data collection tool (discussed later in section 5.11), it is also a standardised simulator format. The use and creation of the software interface is regulated through ISO.
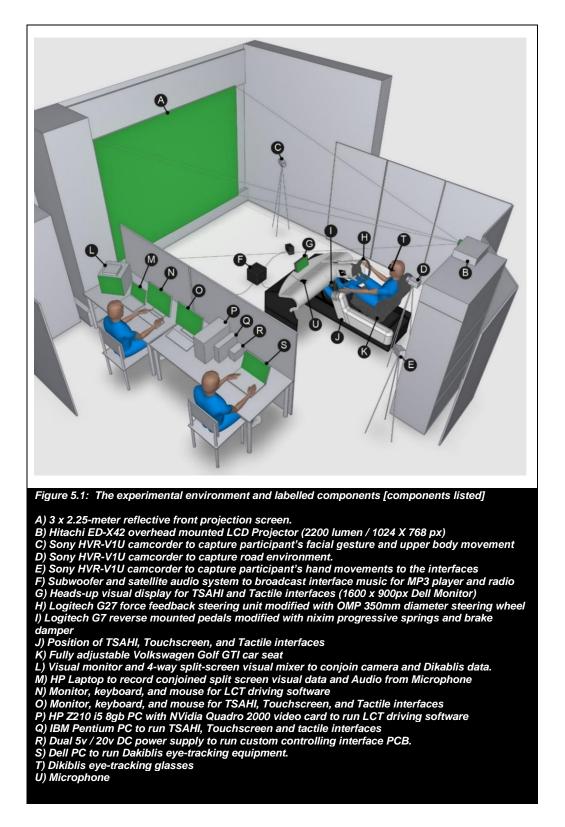
> 'The Lane Change Test (LCT), is a simple laboratory dynamic dual task method that quantitatively measures performance degradation in a primary driving task while a secondary task is being performed. The primary task in the LCT is a simulated driving task which resembles the visual, cognitive and motor demands of driving. In the LCT, a test participant is required to do a primary task consisting of driving at a constant, system-limited speed of 60 km/h along a simulated straight 3-lane road containing a series of lane changes defined by signs, displayed on a screen. Simulated vehicle position is controlled by means of a steering wheel. Participants are instructed in which of the lanes to drive by signs that appear at approximately regular intervals on both sides of the track. The LCT is performed by participants according to pre-test instructions contained in this Standard. The method may be implemented in a laboratory, in a driving simulator, in a mock-up or in a real vehicle.' (ISO 26022-2010: pp 3)
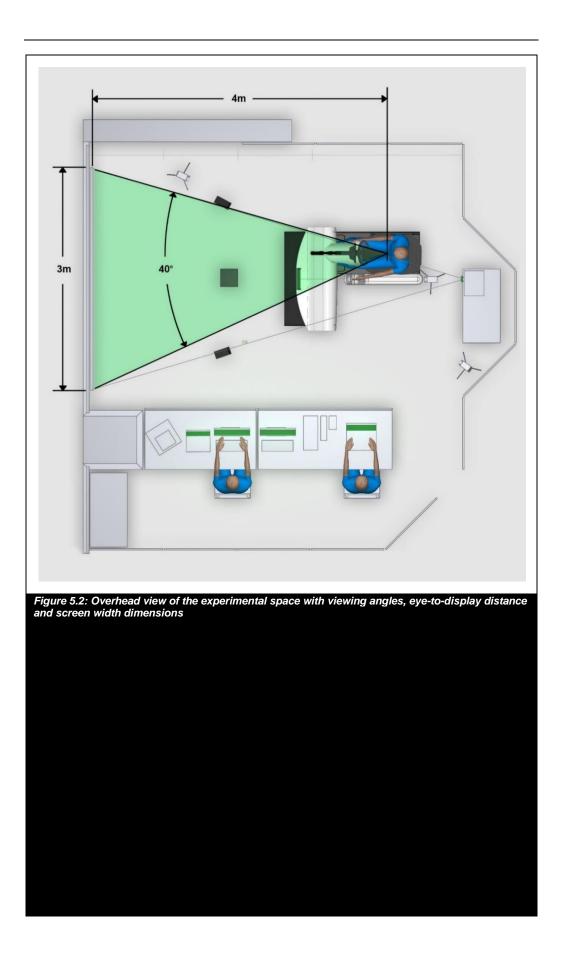
The simulator environment can be seen in figure 5.3. During the tests, all participants received identical instructions as follows:
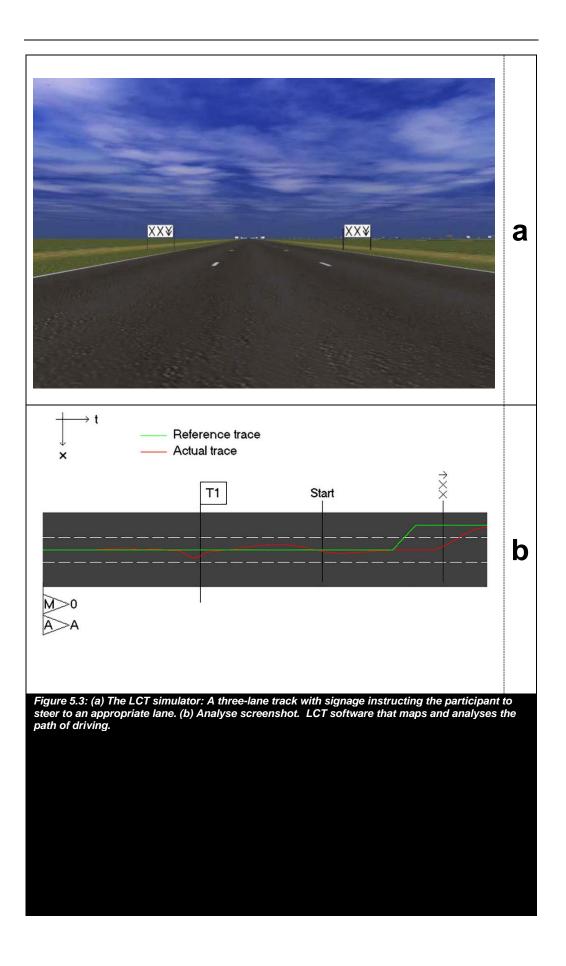
- Instructions that the drivers' primary responsibly is to drive safely at all times,
- Information on the general purpose of the test, in particular instructions on the lane change task,
- Training on the primary [driving simulator] task,
- Training on the secondary [using interface controls] tasks,
- Training on the dual task situations [driving and using interfaces],
- Instructions before the first baseline run,
- Instructions before the dual task testing and
- If required, instructions during the dual task testing.

These training instructions are requirements of NHTSA 2010-0053 (pp 220, 270) as well as ISO 26022 (Annex A). During this test, the participant was given instructions to

complete a variety of tasks. The precise details of these instructions will be discussed later.

Figure 5.1: The experimental environment and labelled components [components listed]

A) 3 x 2.25-meter reflective front projection screen.
B) Hitachi ED-X42 overhead mounted LCD Projector (2200 lumen / 1024 X 768 px)
C) Sony HVR-V1U camcorder to capture participant's facial gesture and upper body movement
D) Sony HVR-V1U camcorder to capture road environment.
E) Sony HVR-V1U camcorder to capture participant's hand movements to the interfaces
F) Subwoofer and satellite audio system to broadcast interface music for MP3 player and radio
G) Heads-up visual display for TSAHI and Tactile interfaces (1600 x 900px Dell Monitor)
H) Logitech G27 force feedback steering unit modified with OMP 350mm diameter steering wheel
I) Logitech G7 reverse mounted pedals modified with nixim progressive springs and brake damper
J) Position of TSAHI, Touchscreen, and Tactile interfaces
K) Fully adjustable Volkswagen Golf GTI car seat
L) Visual monitor and 4-way split-screen visual mixer to conjoin camera and Dikablis data.
M) HP Laptop to record conjoined split screen visual data and Audio from Microphone
N) Monitor, keyboard, and mouse for LCT driving software
O) Monitor, keyboard, and mouse for TSAHI, Touchscreen, and Tactile interfaces
P) HP Z210 i5 8gb PC with NVidia Quadro 2000 video card to run LCT driving software
Q) IBM Pentium PC to run TSAHI, Touchscreen and tactile interfaces
R) Dual 5v / 20v DC power supply to run custom controlling interface PCB.
S) Dell PC to run Dakiblis eye-tracking equipment.
T) Dikiblis eye-tracking glasses
U) Microphone

Figure 5.2: Overhead view of the experimental space with viewing angles, eye-to-display distance and screen width dimensions

Figure 5.3: (a) The LCT simulator: A three-lane track with signage instructing the participant to steer to an appropriate lane. (b) Analyse screenshot. LCT software that maps and analyses the path of driving.

5.10 - COMPARISON OF THREE DESIGNS

In the experimental design, three demonstrators were used to explore the TSAHI hypothesis. The term 'demonstrator' is used to describe the working physical mock-ups; the prototypes that were built to demonstrate three different theoretical models of interface design explored in the experiments.

WHY CUSTOM DEMONSTRATORS WERE USED

Three demonstrator conditions were used to broaden the investigation of the hypothesis: TSAHI, Touchscreen, and Tactile. By testing multiple demonstrator conditions, comparisons between the problematic interface (touchscreen) and the hypothesis could be made. Creating a third tactile interface allowed the theoretical ideals of tactility and showing/hiding to be analysed in isolation for further comparisons to the hypothesis conditions.

The collection of test-data from real cars was considered. However, road tests were rejected because of ethical implications and the lack of experimental control over the external environment of the car. Thus, a controlled room environment using a driving simulator was preferred.

, The potential use of a real dashboard interface was discussed with an ergonomist. However, it was concluded that a donor car interface from a real vehicle would not be appropriate in an exploratory experiment about interfaces. Also, different styles of graphics would not create a uniform set of conditions with the potential to cause confounding variables in the evaluation test results. The designed demonstrator interfaces used a uniform style of graphics and 3D form where possible.

Tsahi demonstrator

The demonstrator has been discussed in detail in chapter 4. In the test environment, this interface was mounted next to the driver in a similar position to the other interfaces with the superordinate chooser positioned behind the steering wheel. This can be seen in figures 5.5 and 5.6.

Tactile demonstrator

The interface is identical to the TSAHI interface with the exception of the show and hide element. None of the panels can be hidden and are always on display. To help decipher how effective is the show and hide, a tactile-only interface was also tested that used tactile controls identical to those used in the new design (Figure 5.7).

Touchscreen demonstrator

A touch screen as seen in figure 3.5 was used as a control in this experiment, because they are noted to cause large amounts of visual distraction (Burnett & Porter 2001; Green 1999). The touch-screen interface was mounted on the centre of the dashboard where these types of displays are typically placed to ensure good reach and visibility. Figure 5.8 shows the touchscreen interface.

The design of the touch screen was based on data from the case study to ensure a good model of an interactive screen was produced. This way, the quality of the design can be considered less of a factor in the comparative analysis of the three interfaces. For instance, the case study noted that the design of GUIs can be improved by making them less cluttered, using large graphics, using colour codes and making sentences short so that they can be viewed faster. The design also complied with NHTSA and JAMA guidelines, as discussed in section 3.6.

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

Figure 5.4: A screen shot of the 4-way split screen monitor from the pilot tests
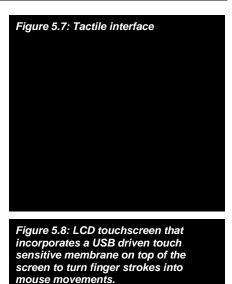
Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

Figure 5.5: TSAHI INTERFACE: A photographic overview of (a) the superordinate chooser that pushes (b) subordinate panels of Radio, MP3 and Climate up and down as desired, as well as (c) the visual display screen in the simulator environment.

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

Figure 5.6: Superordinate control panel.

Figure 5.7: Tactile interface

Figure 5.8: LCD touchscreen that incorporates a USB driven touch sensitive membrane on top of the screen to turn finger strokes into mouse movements.

5.11 - QUANTATIVE MEASURMENTS / PROCEDURES

The NHTSA and ISO standards discussed earlier are set for visual distraction tests and to ensure a robust, systematic procedure. The evaluation methodology uses both quantitative and qualitative research techniques; i.e. the empirical and objective method of Visual Demand analysis (VIS-D) and the more subjective methodology of extracting User eXperiences (UX).

The VIS-D study uses quantitative research methods, predominately deployed to observe eye positions. The LCT driving task observed relative driving performance. Both used a baseline (a familiarisation training period) and a dual task in the test method.

Familiarisation training period
To ensure errors were created only by the conditions presented to the participants and not by a lack of familiarity, the researcher introduced them to each participant, informing them of the function each button would control. The researcher then asked the participant to try out the controls and indicate when they felt comfortable and familiar with each condition demonstrator. This familiarisation period was timed and

recorded to understand more about the participants' learning abilities. This familiarisation served as an ideal training period, a requirement of NHTSA 2010-0053 as well as ISO 26022, as mentioned in section 5.4.

Baseline

All the test participants first conducted a baseline test on LCT - a driving task under recommendations from BS ISO 26022 - 2010. The baseline data recorded the level of visual distraction caused by the task of driving only. The participant was asked to drive the simulator along the road environment following arrows that indicated lane changes. There were no instructions to use any of the interfaces in the baseline test. Audio Visual and eye gaze data were collected for these tests.

Dual task

As in the baseline test, audio Visual and eye gaze data were collected. The dual task studies used the Dikablis eye tracking equipment to record spatial and time-based data. The participants were asked to complete a set of tasks that were instructed by the researcher, while operating the LCT driving simulator in blocks of no less than 2 minutes. The questions can be viewed in appendix 5.4. When the instructions were delivered to the participant, the researcher was not in view, to discourage interaction with the participant that might influence their visual interaction with the demonstrator conditions. This physical positioning of the participant and the researcher can be seen in figure 5.1.
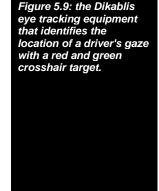
To measure the effect of these conditions on the participants, several measurements were used to make comparisons. Both subjective and objective measurements were used to gain a balanced exploration of the hypothesis.

EYE TRACKING (VIS-D)

The first of these were physiological objective numerical measurements of eye movement. These were taken from all participants while driving the LCT simulator to form objective data about each condition. A head-mounted eye-tracker system as suggested in section 5.2.1 of ISO/TS 15007-2:2014 (figure 5.9) was used to collect this data. This eye tracking system is regularly used by manufacturers such as BMW. The data was analysed in 'D-Lab', an analytical tool provided with the Dikablis eye tracker. The outputs from D-Lab can be used to produce graphs and numerical data. Particular outputs of interest from the eye tracker were as follows:

- Number of glance durations to all defined areas of interest (start time, duration, end time)
- Area of interest based glance metrics:
  - Total glance time to all defined areas of interest
  - Number of glances to all defined areas of interest
  - Mean glance duration to all defined areas of interest
  - Glance rates to all defined areas of interest
  - Maximum glance duration to all defined areas of interest
- Graphical data output:
  - HeatMaps (figure 5.10b)
- Glance charts (figure 5.10b)

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Figure 5.9: the Dikablis eye tracking equipment that identifies the location of a driver's gaze with a red and green crosshair target.

The Defined Areas Of Interest (AOI) were the road environment and the demonstrator interface components, as seen in figure 3.12. The following types of measurements were used to form the criteria for the analysis of the empirical data.

Total 'eyes off road' time (TEORT)
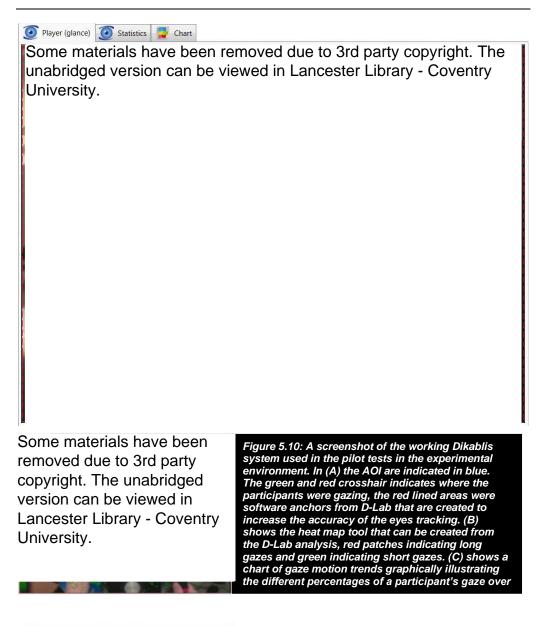
The amount of time that participants' eyes spend away from the driving environment is indicative of distraction. This was measured in various ways to explore the hypothesis. The entire eye glance data measurements were time based, as in BSI ISO/TS 15007-2:2014, when measuring TEORT and percentage of 'eyes off road' time (PEORT):

'Increasing TEORT and PEORT indicate that the subject may be distracted by TICS [Transport Information and Control Systems]. It can also be a sign for low primary task workload which may have the effect that the driver starts operating TICS in the car (which can in turn also lead to increased TEORT and PEORT).'

In addition, Rockwell (1988) noted that two second glances away from the road environment would lead to a lack of driving competence. Consequently, the implications of TEORT can be understood and the measurements placed in context. Rockwell's two second rule can be used as a benchmark figure to indicate excessive amounts of TEORT in the data analysis that will explore the hypothesis about levels of visual distraction in the various tested interfaces.

Glances to Transport Information and Control Systems (TICS)
Glance frequency was also measured to explore the hypothesis about levels of visual distraction in TSAHI. In a recent literature review, Young and Regan (2003) noted that the frequency of glances effects driving. Therefore, the following types of measurements were used to add more detail to the understandings of visual distraction. BSI ISO/TS 15007-2:2014 suggest the following:

- Number of glances - Dual Task (Driving/Interface): The number of glances is an indicator for how often a subject looks at a certain Area Of Interest (AOI). A high number of glances may indicate either the high importance of the area of interest or the visual intensity of the display, such that multiple glances are needed to extract information.

- Total glance time - Dual Task (Driving/Interface): Total glance time associated with an area of interest (e.g. an in-vehicle device) provides a measure of the visual demand noted. As visual demand increases, the total glance time should increase.

- Mean glance duration - Dual Task (Driving/Interface): The mean glance duration describes how long a subject has to look at a certain area of interest (e.g. a TICS display) to perceive information from it. Shorter mean glance durations are an indicator that information can be perceived quickly from an AOI and longer mean glance durations indicate the opposite.

- Maximum glance duration - Dual Task (Driving/Interface): Rockwell (1988) reminds us that "Drivers loath to go for more than 2 seconds without information from the road". Radio tuning was the standard task for this measurement. This is a standard requirement when indicating the magnitude of visual and mental demand that is caused by TICS.

Figure 5.10: A screenshot of the working Dikablis system used in the pilot tests in the experimental environment. In (A) the AOI are indicated in blue. The green and red crosshair indicates where the participants were gazing, the red lined areas were software anchors from D-Lab that are created to increase the accuracy of the eyes tracking. (B) shows the heat map tool that can be created from the D-Lab analysis, red patches indicating long gazes and green indicating short gazes. (C) shows a chart of gaze motion trends graphically illustrating the different percentages of a participant's gaze over

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LANE CHANGE TEST

The LCT simulator collects driving data via the steering wheel, in addition to providing a controlled environment and instructions for driving,. This data was used to analyse driving behaviour. The main measure of interest is the mean deviation (M.Dev)

distance that each participant strays from the perfect driving line while completing the tasks. The perfect driving line is referred to as the 'reference trace', and the participant's path of driving can be seen as a 'actual trace' in red in figure 5.3. The driving behaviour can be analysed using visually illustrated outputs as well as through numerical outputs.

5.12 - QUALITATIVE MEASUREMENTS AND PROCEDURES (UX)

A major part of the data collection was qualitative data. This was mainly a structured multiple choice format of well-known data gathering questionnaires and specific questions that asked the participant to openly compare the conditions. This gave the researcher a personal insight into their perceptions about the different control panels. Their comments were recorded in written preformatted sheets. All of the questionnaires were applicable to 4 different types of control panel: CD player, Radio, Climate and a Superordinate Chooser.

Multiple choice questionnaires with written criteria or the use of an incremental scale, open written comments and transcripts of the participants' comments were analysed for comparison with the quantitative data. 10% of the analysis was assessed by a second researcher to objectify the results and avoid the misinterpretation of data.

COGNITIVE WORKLOAD STUDY

A Raw NASA 'Task Load Index' (TLX) was used to measure how mentally demanding was each task in the experiment. The metrics of units collected with this questionnaire requested the participants to place a pen mark between any one of twenty-one points on gradated scale. The graphical format of this scale can be can be seen in a sample of the questionnaire in appendix 5.8. The researcher conducted a TLX questionnaire to collect data on the cognitive loads that were created by using the control panels as follows:

- Mental Demand; 'How mentally demanding was the task?'
- Physical Demand; 'How physically demanding was the task?'
- Temporal Demand; 'How hurried or rushed was the pace of the task?'
- Performance; 'How successful the participant thought they were in accomplishing the task?'
- Effort; 'How hard had they to work to accomplish their level of performance?'

- Frustration; 'How insecure, discouraged, irritated, stressed or annoyed was the participant?'

This TLX questionnaire was conducted after each block of simulator usage. The researcher asked the participants to manually record their answers for each of the questions on paper with a graphical scale. Formerly, Harbluk, Noy and Eizenman (2002) used the NASA TLX system to calculate the cognitive workload of drivers performing different tasks. Fairclough (1991) specifically talks about using the TLX to measure cognitive demands to accurately measure driver mental workload. As a result of their success, this study also used the TLX system. Recording workloads further informed the analysis regarding the participants' reactions to the various interfaces.

SYSTEM USABILITY SCALE

A system usability scale (SUS) questionnaire was used after each condition had been fully tested. This provided a 'quick and dirty' reliable tool for measuring usability. It was designed by John Brooke in 1986 and can be used on a wide variety of products. The options offered in the SUS are as follows:

- I think that I would like to use this system frequently.
- I found the system unnecessarily complex.
- I thought the system was easy to use.
- I think that I would need the support of a technical person to be able to use this system.
- I found the various functions in this system were well integrated.
- I thought there was too much inconsistency in this system.
- I would imagine that most people would learn to use this system very quickly.
- I found the system very cumbersome to use.
- I felt very confident using the system.
- I needed to learn a lot of things before I could get going with this system.

These options cover many aspects of system usability, such as complexity and the need for support or training thus having a high level of face validity for measuring usability (Brooke, 2015). In general SUS is an effective tool to understand more about acceptance of the interface and the experience and learning consequent in each condition, as these issues will ultimately determine how a participant uses the three interface conditions. To calculate the SUS score the researcher must:

'First sum the score contributions from each item. Each item's score contribution will range from 0 to 4. For items 1,3,5,7 and 9 the score contribution is the scale position minus 1. For items 2,4,6,8 and 10, the contribution is 5 minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall value of SU. SUS scores have a range of 0 to 100. Based on research, a SUS score above a 68 would be considered above average and anything below 68 is below average.' (Brooke 2016)

The SUS is widely used by manufacturer researchers such as BMW Group (Rümelin, Butz 2013) and academic institutions. Its use should ensure that the comparative analysis is coherent with current thinking about interfaces. A sample copy of this questionnaire can be seen in appendix 5.9.

ATTRAKDIFF

Attrackdiff was used in a similar fashion to SUS; following the tests of each condition. The data gleaned from the Attrakdiff questionnaire allowed the researcher to understand more about behavioural and emotional aspects of the user's perceptions of the interface in terms of attraction. This is important because if a user feels that they like an interface, they can perceive that it works better. Donald Norman makes the following case:

'Attractive things work better… When you wash and wax a car, it drives better, doesn't it? Or at least feels like it does.' (Norman 2004)

The objective and functional eye-tracking trials, the subjective TLX cognitive workload questionnaire, the good/bad usage experience questionnaire and the tactile and SUS questionnaires all take into account rational behaviours. However, as Norman suggests, emotional behaviours also affect usage. Bill Verplank, a pioneer of interaction design, views emotional behaviour as a critical aspect of human use. In the Interaction Design Sketchbook (2009) he splits human use into three categories: 'How you do' (operation using appropriate tools), 'How you feel' (pleasure or dislike) and 'How you know' (mapping). This cycle is illustrated in figure 5.11.

With respect to the emotional aspect of categories, 'How you feel' about an object can severely influence the choices to interact with it; a recent example being the sale of cars with leather seats. Vegan drivers for example will avoid leather seats (Autoblog 2015) because of their beliefs. This response is entirely emotional, based on the way they feel about the product. The notion of cruelty towards animal prevents them from engaging with the product. Therefore, engaging with the participants' emotional

responses to the conditions of the driving simulator tests was important, to determine any aspect that might affect usage.

The Attrackdiff questionnaire specifically analysed four different areas:

- Pragmatic Quality (PG): Clarity and usability of the interaction model.
- Attractiveness (ATT): General aesthetic quality.
- Hedonistic Quality of Identity (HQ-I): Resonation between self-perception of the user and the product.
- Hedonistic Quality of Stimulation (HQ-S): Potential for reaching individual goals perceived by the user.

The questionnaire used 28 questions to evaluate the behavioural and emotional consequences of usage. The full list of questions and the format can be seen in appendix 5.5.

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Figure 5.11: Bill Verplank illustrates the cycle of human use in a sketch that considers what we feel, know, and do.

CONDITION COMPARISON

A set of written multiple-choice questions was given to each participant, with the aim of understanding the comparative properties to enrich the data. This data was important as personal circumstances can change a participant's perspective on their experience. For this reason, part of the questioning was completely open with participants free to write whatever they wish. However, some questions were

structured in that ease of use, least distracting, and pleasure of use were formatted in a ranking system. 1 being the best, and 3 being the worst. A copy of the questionnaire format can be seen in appendix 5.6.

TACTILE INTERACTION

A written questionnaire about the tactile experience of the TSAHI and Tactile interface was completed by the participants. These questions were asked to allow the researcher to gain an insight into the participants' perceptions about the interface. The tactile principles used in the designs are detailed in section 2.4. These took the form of a 5-point scale with opposing answers. Participants were free to leave open comments if they felt the need to explain their choices. A sample copy of the questionnaire format can be seen in appendix 5.7.

5.13 - SUMMARY

This chapter has discussed the aims, tasks and measures used in the analysis of the data gleaned from the driving simulator tests. Standardised practices from ISO, JAMA, and NHTSA regulations as well as established best practice questionnaires such as the SUS, TLX, and Attrakdiff further contribute to underpin the experiment design. Overall, these elements validate the objective approach needed to rigorously examine the ideas of a Tactile Show and Hide Interface as mentioned in the discussion of mixed methods in section 3.4.

CHAPTER 6
RESULTS

The contextual review in Chapter 2 established that there was a problem with current interfaces and posed a related research question and hypothesis.

H1 *'TSAHI will result in less driver distraction than the Touchscreen'*
Driver distraction[7] was measured in terms of (a) driver behaviour in the form of eye tracking/movement; visual attention will be lower in the TSAHI in comparison to the touchscreen and (b), Performance in the Lane Change Test will result in less deviation from reference to the TSAHI condition in comparison to the touchscreen (as discussed in chapter 5).

H2 *'TSAHI will be perceived as more usable than the Touchscreen'*
Usability, measured in terms of driver understanding, will result in (a) low cognitive workload, (b) high scores on Attrakdiff, (c) high scores on the Systems Usability Scale and (d) high scores on Tactile Interaction questionnaire (as discussed in chapter 5).

6.1 - VISUAL DISTRACTION (VIS-D)

The AOIs (Areas Of Interest), described in section 5.11, were set-up as in Figure 5.10. Essential to the analysis was that the data was collected about the whole condition operated by the subjects. To ensure that this was the case, all the demonstrator components involved with the condition were grouped together in the analysis. For example in the TSAHI condition, the centre console panel that shows and hides the Visual Display Unit and the push button switches behind the steering wheel were grouped together, as this was the whole interactive condition being demonstrated. Separate AOI indicators were overlaid over each component in the Ergoneers D-lab software and the sum of the numeric data collected from these AOIs was used in the condition's analysis.

Regarding the sensitivity and levels of accuracy for the eye data capture sessions, although the Dikablis eye tracking equipment is very accurate (producing data outputs to several decimal points), there were systemic issues that sometimes caused a loss

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[7] *'Driver distraction is defined as the diversion of attention away from activities critical for safe driving towards a completing activity. (Young, Lee, Regan 2009')*

of data. D-lab and the Analyse software indicated that approximately >10% of eye movement was not recognisable from all the sessions. An informal random sample of 3 data videos was conducted and found this to be due to blinking, as the headset eyeball observation camera could not recognise the eye pupil when it was hidden under the eye lid. Informal conversations with researchers and users of the Dikablis eye tracking equipment indicated that this is a recognised systemic issue with eye tracking and that 90% recognition rate is normal.

As a prelude to the eye position analysis, it is useful to discuss a finding that applied to all the eye position data. The test data (table 6.1) shows that the level of high significance is caused by the low mean value of the baseline. The Tukey HSD post hoc tests showed that for the PEORT, there was a statistically high significance between all the conditions and the baseline, $p<0.001$. The participants were not asked to operate any interfaces during the baseline which explains this effect. Thus, in a comparative test to understand how a TSAHI compares to a touchscreen as described in the detailed hypothesis discussed at the begining of this chapter, this baseline value is of no interest, whereas the interface comparison is of interest.

6.1.1 - ONE-TAILED HYPOTHESIS

A oneway analysis of variance (ANOVA) was used to analyse the mean differences between the conditions in SPSS. This style of analysis was appropriate because the experiment used three or more experimental comparative groups - TSAHI, Tactile, Touchscreen, and Baseline - and each participant was used in each group (Field and Hole 2003).

As deviations in one direction are predicted in the experimental hypothesis[8], the significance testing for the analysis was one-tailed.

6.1.2 - MEAN GLANCE DURATION
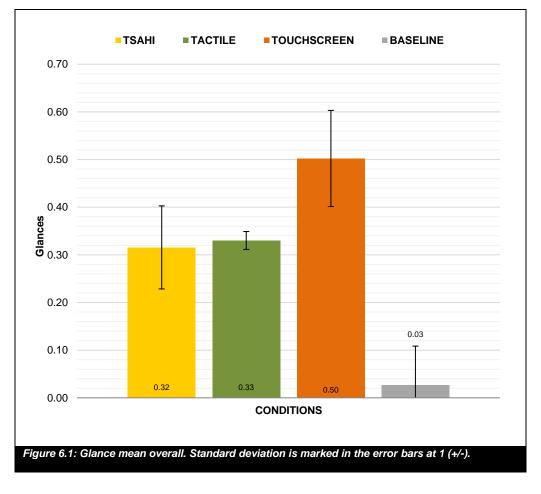
The data for the glance mean is summarised in table 5.1 and figure 5.1. Mean glances were highest in the touchscreen condition M=0.50, SD=0.19. The TSAHI condition M=0.31, SD=0.14 and tactile condition M=0.33, SD=0.12 were similar. The baseline condition M=0.02, SD=0.08 was the lowest value amongst the groups.

The Tukey HSD post hoc tests showed that for the glance mean, there is a significant difference between the touchscreen and the TSAHI conditions $p<0.001$; and the touchscreen and the tactile conditions $p<0.001$. There was no significant difference

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[8] The experimental hypothesis states 'less' visual distraction as an experimental hypothesis and not 'less or more'.

between the TSAHI and the tactile conditions p=0.492. The results summarised in figure 6.1 show an illustrated reference of this comparison. These results would suggest that part of the experimental hypothesis H_1 is highly supported. This indicates that information can be perceived faster from the TSAHI than from the touchscreen condition, when seen through the ideas of BSI ISO/TS 15007-2:2014. The post hoc mean descriptive and comparison data sheets can be viewed in appendices 6.1 and 6.2.

	(Seconds)	
Conditions	**Mean**	**SD**
TSAHI	0.31	0.12
Touchscreen condition	0.50	0.19
Tactile	0.33	0.12
Baseline	0.02	0.08

Table: 6.1 Mean glance results with standard deviation

Figure 6.1: Glance mean overall. Standard deviation is marked in the error bars at 1 (+/-).
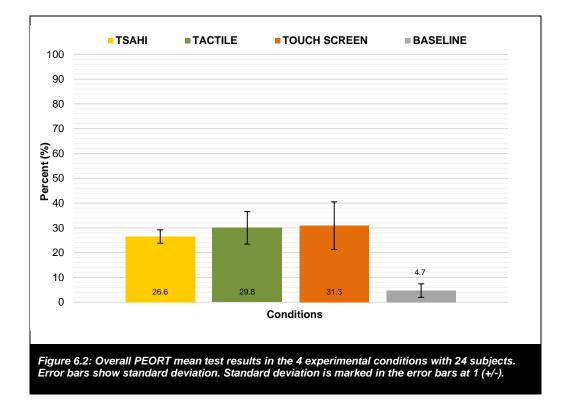
6.1.3 - PEORT (PERCENTAGE 'EYES OFF ROAD' TIME)

The results of the eye position study for PEORT are summarised in table 6.2 and figure 6.2. A full mean descriptive data sheet can be viewed in full in appendix 6.1.

The results show that overall, the TSAHI condition resulted in least 'eyes off road' time.

The one-way ANOVA tests showed that there was an effect of condition on percentage 'eyes off road' at the p<0.1 level [$F_{(3, 92)} = 129$, $p < 0.001$]. Tukey HSD post hoc tests show that when the different interface conditions are compared for PEORT, it can be seen that there is significant difference between the TSAHI and the touchscreen conditions p=0.016. However, there is no statistical difference between the TSAHI and the tactile conditions p=0.165 or between the tactile and touchscreen conditions p=0.779. These results would suggest that the experimental hypothesis H_1 is supported. Given that time looking away from the road is not a good thing, as this indicates low primary workload (BSI ISO/TS 15007, 2014), it can be seen that the TSAHI is the superior condition when compared to the touchscreen.

	(Glance Percentage)	
Conditions	**Mean**	**SD**
TSAHI	26.6	6.43
Touchscreen condition	31.0	5.2
Tactile	29.0	5.94
Baseline	4.0	3.24
Table 6.2: PEORT percentage results with standard deviation.		

Figure 6.2: Overall PEORT mean test results in the 4 experimental conditions with 24 subjects. Error bars show standard deviation. Standard deviation is marked in the error bars at 1 (+/-).
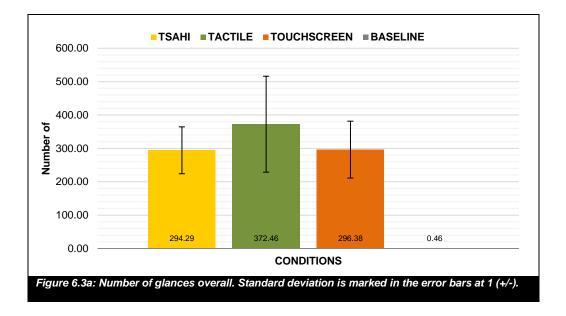
6.1.4 - NUMBER OF GLANCES

Overall, the TSAHI condition M=294.29, SD=125.06 resulted in the lowest number of glances when compared to the touchscreen and the tactile conditions. The tactile condition M=383.91, SD=184.35 created the most number of glances as well as having the highest standard deviation across the subjects. The touchscreen M=296.37, SD=120.53 came in just under the TSAHI condition in terms of the number of glances. The baseline number count for glances was M=0.45, SD=1.44. This data is summarised in table 6.3 and figure 6.3a. A full mean descriptive data sheet can be viewed in full in appendix 6.1
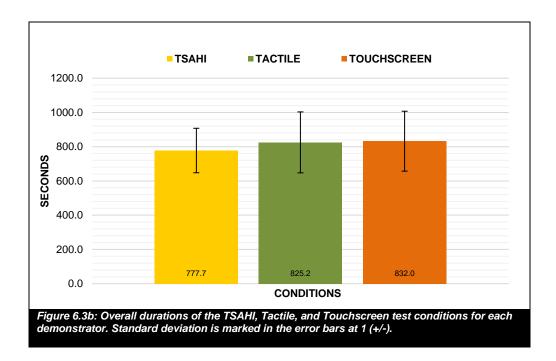
The Tukey HSD post hoc tests showed that there was no statistical difference between the TSAHI and tactile p=0.075, tactile and touchscreen p=0.085, and TSAHI and touchscreen p=1.00 conditions.

These results would suggest that part of the experimental hypothesis H_1 is statistically rejected by the null hypothesis H_0, supported in terms of the number of glances that a driver made toward the interface demonstrators in each condition.

Condition	(Glances No.)	
	Mean	SD
TSAHI	294.29	125.07
Tactile	383.92	184.36
Touchscreen	296.38	120.53
Baseline	0.46	1.44
Table 6.3: Results of the number glances with standard deviation at 1 (+/-)		

Figure 6.3a: Number of glances overall. Standard deviation is marked in the error bars at 1 (+/-).

It is useful to add a second dimension to the analysis to examine why this null hypothesis exists and assess the number of glances over a longer period of time, in particular over the duration of the test. Within the duration data (fig 6.3b) it can be noted that in the TSAHI condition, the subjects consistently completed the test faster in comparison to the other conditions and the touchscreen condition in particular. With this in mind one it could be argued that even though the number of glances towards the TSAHI were a similar total to the touchscreen demonstrator, the fact that the tasks were completed more quickly might suggest that the information was easier to process even though it would appear to possess a similar amount of intensity. The cross-over style of study moreover eliminated the possibility of learning (from tactile or touchscreen) to help increase the test speed of the TSAHI.

Figure 6.3b: Overall durations of the TSAHI, Tactile, and Touchscreen test conditions for each demonstrator. Standard deviation is marked in the error bars at 1 (+/-).

Finally, user comments were analysed, identifying words that related negatively to the word 'distraction' (this can be fully seen in Appendix 6.8). There were seven particular instances of negative 'distraction' in the comments, one of which was related to the TSAHI:

- *"Distracting* to use. Harder to operate. Slower response." (participant D2)

However, 6 of the instances from 5 different participants were negatively related to the touchscreen.

- "Felt a lot more *distracting* as there was a lot more buttons to get the end result. Would be best for a passenger to use instead of a driver." (participant A3)

- "Very *distracting* - made mistakes of not paying attention to the road." (participant B3)

- "*Distracting* and difficult to use. Had to keep looking to ensure I had selected appropriate item." (participant C4)

- "Easier once used to it but more *distracting* because you're looking directly at screen. Good position would help. More complicated and can become *distracting* when remembered." (participant D1)

- "It was very easy to use when NOT driving BUT *demanded* more of my attention than the other systems while driving. The reach to the far left of the controls was really a long way and *distracting*." (participant D5)

It should be remembered that in the tests, the participants were openly commenting and at no time were they specifically asked to comment on distraction. Therefore, the term 'distraction' was deemed significanat enough to mention, but it should also be remembered that each participant had an individual subjective perspective of the events while involved in the simulator tests.

6.1.5 - MAXIMUM GLANCE DURATION

As mentioned in the methodology discussion, the maximum glance duration measurement allows time periods spent looking away from the road to be observed in more depth. As the subjects were asked to either drive on the road environment or use the condition demonstrators without any other visual distraction, this analysis assumes that the when the subjects were not looking at the road, they were gazing at the demonstrators in order to operate them. This analysis will firstly present the overall results then look more closely to break down the tasks as NHTSA guidelines suggest (2010 p.95).

The overall maximum glance duration analysis for the experimental conditions revealed that in the TSAHI condition, the duration of glances were the lowest at 1.95 seconds (0.97 SD) as shown below in table 6.4 and figure 6.4(a). A full mean descriptive data sheet can be viewed in appendix 6.1.

Conditions	(Seconds)	
	Mean	SD
TSAHI	1.95	0.97
Touchscreen condition	2.46	0.84
Tactile	2.04	0.85
Baseline	0.04	0.13

Table 6.4: Overall maximum glance time mean descriptive results with standard deviation at 1 (+/-)
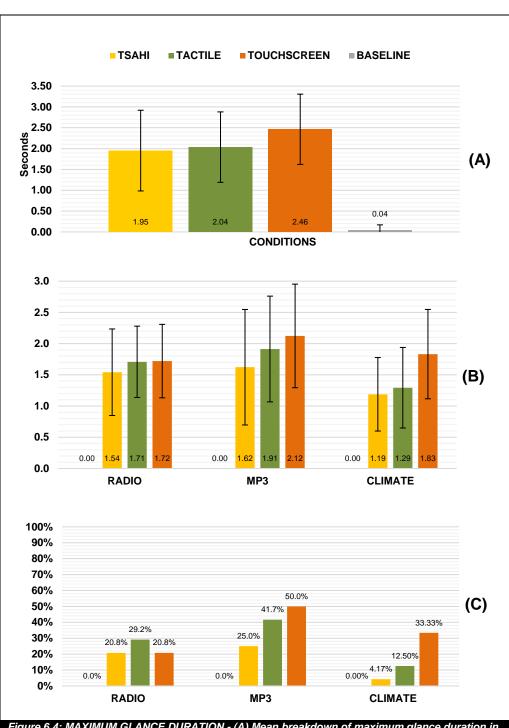
Figure 6.4: MAXIMUM GLANCE DURATION - (A) Mean breakdown of maximum glance duration in the 4 experimental conditions. Error bars show standard deviation. (B) Mean breakdown of maximum glance duration in the 4 experimental conditions broken down into Radio, MP3, and Climate task. (C) Percentage of glances 2 over seconds. Standard deviation is marked in the error bars at 1 (+/-).

The ANOVA tests showed a significant effect of the conditions on driver behaviour at the $p<0.05$ level [$F(3, 91) = 57.72$, $p<0.001$]. The Tukey HSD post hoc tests showed that overall, there was a significant difference between the touchscreen and TSAHI $p=0.109$. The difference between the tactile and the touchscreen $p=0.230$ and between the tactile and the TSAHI $p=0.491$ were not statistically significant. These results would suggest that the experimental hypothesis H_1 is supported in terms of the mean value of the overall maximum glance duration during the radio task in each condition.

MAXIMUM GLANCE DURATION TASK BIAS RESULTS

In terms of the Rockwell benchmark (1988) stating that a 'driver is loath to go for more than 2 seconds without information from the road', generally only the TSAHI condition satisfied this term. However, the Rockwell benchmark is conventionally calculated at 2 seconds using a task breakdown and usage of the radio.

RADIO TASK MAXIMUM GLANCE DURATION

Overall, the results varied when the convention of assessing the radio task was adhered to, but all of the conditions were below the recommended 2 second limit for a maximum glance as a mean value. In the radio analysis, the TSAHI condition M=1.54, SD=0.69 had the lowest mean maximum glances, the touchscreen condition M=1.72, SD=0. 58 were the highest, with the tactile condition M=1.708, SD=0.57 in between. The data is summarised in table 6.5 and figure 6.4 (B).

Task	Condition	(Seconds)	
		Mean	SD
RADIO	Baseline	0.00	0.00
	TSAHI	1.54	0.69
	Tactile	1.70	0.57
	Touchscreen	1.72	0.59

Table 6.5: Radio task maximum glance time results with standard deviation at 1 (+/-)

One issue that a mean comparison is unable to analyse is the maximum value of the glances, as it takes the average values. When a separate cross-tabulation of the data was conducted it was revealed that within the standard variation for each condition, overall none of the baseline participants were over the 2 second benchmark in the radio task. 20.8% of the participants in the TSAHI condition were over the 2 second Rockwell benchmark which was identical to the touchscreen condition. The highest percentage of participants over the benchmark in the radio task was 29.2% in the tactile condition.

The ANOVA tests showed that there was a highly significant effect of the conditions on driver behaviour at the p<0.05 level for the four conditions [F(3, 92) = 57.72, p<0.001]. When the interface conditions were compared, the post hoc Tukey test showed that there was no statistical significance between the TSAHI and the tactile conditions p=0.705, the TSAHI and the touchscreen conditions p=0.659 and between the tactile and the touchscreen conditions p=1.000. These results would suggest that the experimental hypothesis H_1 is statistically rejected and the null hypothesis H_0 is supported in terms of the maximum glance duration made toward the interface demonstrators during the radio task in each condition.

MP3 TASK MAXIMUM GLANCE DURATION

To look beyond the NHTSA recommended guidelines of using the radio as a task for analysis, it can be observed that the MP3 task saw results above the 2 second benchmark as a mean value for the touchscreen condition M=2.12, SD=0.83. The TSAHI condition M=1.62, SD=0.92 was recorded as having the lowest mean maximum glance duration and the tactile M=1.91, SD=0.85 was just under the benchmark. This data is summarised in table 6.6 and figure 6.4 (B).

Task	Condition	(Seconds)	
		Mean	SD
MP3	Baseline	0.00	0.00
	TSAHI	1.62	0.92
	Tactile	1.91	0.85
	Touchscreen	2.12	0.83
Table 6.6: MP3 task maximum glance time results with standard deviation at 1 (+/-)			

To add detail to this analysis, overall none of the baseline participants were over the 2 second benchmark in the MP3 task for each condition. In the TSAHI condition, 25% of the participants were over the benchmark, with 50% being the highest percentage in this task for the touchscreen condition. In the tactile condition the percentage was close to the highest at 41%.

The ANOVA tests showed that there was a highly significant effect of the conditions on driver behaviour at the p<0.1 level for the four conditions [F(3, 92) = 39.60, p<0.001]. In terms of statistical significance for the results of the MP3 task, the Tukey HSD post hoc tests shows that there was a measure extremely close to being of statistical significance between the TSAHI and touchscreen conditions p=0.1. There was no statistical significance between the TSAHI and the tactile conditions p=0.537

or between the tactile and touchscreen conditions p=0.767. These results would suggest that the experimental hypothesis H_1 is statistically rejected and the null hypothesis H_0 is supported in terms of the maximum glance duration made toward the interface demonstrators during the MP3 task in each condition.

CLIMATE TASK MAXIMUM GLANCE DURATION

The climate task reported the lowest figures of all the tasks among the three conditions. The TSAHI condition M=1.188, SD=0.59 being the lowest, the touchscreen condition M=1.83, SD=0.72 being the highest and the middle value being the tactile condition M=1.29, SD=0.64. The results are summarised in figure 6.4 (B) and table 6.7. A full mean descriptive data sheet can be viewed in full in appendix 6.1.

Overall, none of the baseline participants were over the 2 second benchmark in the climate task for each condition. Once again, in the TSAHI condition, the least number of participants, only 4.17%, exceeded the 2 second benchmark, the lowest percentage of all the tasks. Again, as in the radio and MP3 tasks the greatest number of participants exceeded the 2 second benchmark in the touchscreen condition, 33.33% to be specific. In the tactile condition [under a quarter of the 24 participants] 12.50% of participants exceeded the benchmark figure.

The ANOVA tests showed that there was a highly significant effect on driver behaviour for the four conditions [$F(3, 92) = 44.92$, $p<0.001$]. The Tukey HSD post hoc tests revealed that there was a high statistical significance between the TSAHI and the touchscreen conditions p=0.001 and a level of significance between the tactile and touchscreen conditions p=0.007. However, there was no statistical significance between the TSAHI and the tactile conditions p=0.917. A full post-hoc mean comparative data sheet can be viewed in full in appendix 6.2. These results would suggest that the experimental hypothesis H_1 is supported.
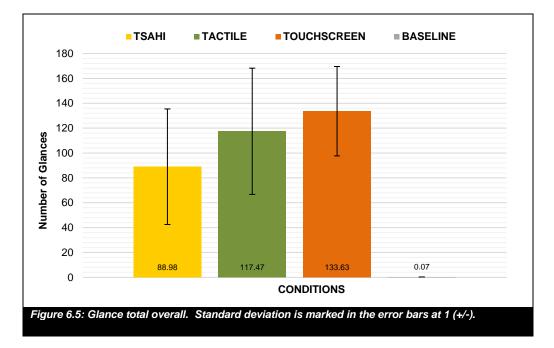
Throughout the maximum glance analysis, all the conditions at first sight appear to satisfy the Rockwell rule with the TSAHI condition suggesting that it promotes the lowest magnitude of driver distraction. However, a deeper analysis showed that the TSAHI excelled, showing an even smaller magnitude when controlling incremental scale interfaces and scrolling interfaces, such as an MP3 player, that had many options to sort through. The touchscreen and tactile conditions were more visually demanding, required more visual attention and hence showed a high magnitude of driver distraction.

		(Seconds)	
Task	Condition	Mean	SD
CLIMATE	Baseline	0.00	0.00
	TSAHI	1.19	0.59
	Tactile	1.29	0.64
	Touchscreen	1.83	0.72

Table 6.7: Climate task maximum glance time results with standard deviation at 1 (+/-)

6.1.6 - OVERALL TOTAL GLANCE TIME

Although the variance of the results was not insignificant, there were clear separations between the conditions, with the TSAHI (M=88.98s, SD=20.95) condition representing the lowest amount of time spent glancing at the interface components. This was a third less than the touchscreen (M=133.63s, SD=15.18), which represented the highest amount of time. These results are summarised in figure 6.5.

The Tukey HSD post hoc tests showed that for the glance total, there was a high statistical significance between the TASHI and the touchscreen conditions (p=0.001), the comparison between the TSAHI and the tactile conditions is also statistically significant (p=0.033), but there was no significance between the tactile and the touchscreen conditions (p=0.712). These results suggest that the experimental hypothesis H_1 is supported in terms of the total glances that a driver made toward the interface demonstrators in each condition. This indicates that TSAHI was less visually demanding in comparison to the touchscreen, according to BSI ISO/TS 15007-2:2014.

Figure 6.5: Glance total overall. Standard deviation is marked in the error bars at 1 (+/-).

6.2 - LCT (LANE CHANGE TEST) RESULTS

Unfortunately, due to data corruption, a full data set could not be used. Therefore, a sample of 10 male (SD=15.18) and 12 female (SD=15.17) was used.

Overall, comparative results of the 4 conditions in the LCT were very close, with the TSAHI condition M=1.61m, SD=0.24m, the tactile condition 1.60m, SD=0.34m, and the touchscreen condition 1.63m, SD=0.27m. The baseline was 1.38m SD=0.58m.

The ANOVA tests showed that there was a level of significance at p<0.1 for the four conditions [F(3, 84) = 3.87, p=0.012].

The Tukey HSD post hoc tests showed that for the LCT, there was a significant statistical mean difference between the baseline and the TSAHI condition (p:0.039), the baseline and the touchscreen (p:0.018) and the tactile condition (p=0.058). There was also no significant statistical mean difference between the TSAHI, tactile, and touchscreen in any way: Tactile and TSAHI - p:0.999, Touchscreen and TSAHI - p:0.992, Tactile and Touchscreen - p:972.

6.3 - USER EXPERIENCE (UX)
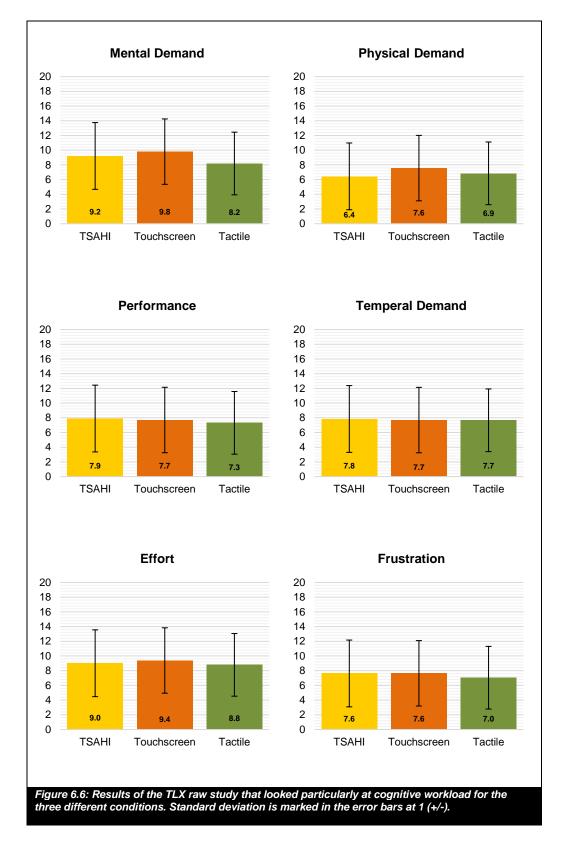
6.3.1 - RAW NASA TASK LOAD INDEX (TLX)

The aim of the raw TLX questionnaire was to understand the participants' cognitive workload during the experimental conditions.

The ANOVA comparison for the Task Load Index showed that there was no statistical significance between any of the groups in each of the categories at the p<0.1 level. The categories being:

- Mental demand [F(2, 69) = 0.819, p= 0.445]
- Physical demand [F(2, 69) = 0.506, p= 0.605]
- Temporal demand [F(2, 69) = 0.013, p= 0.988]
- Performance [F(2, 69) = 0.137, p= 0.872]
- Effort [F(2, 69) = 0.111, p= 0.895]
- Frustration [F(2, 69) = 0.158, p= 0.854]

Figure 6.7 and table 6.8 summarise the results for the TSAHI, tactile, and touchscreen conditions. The results of the one-way ANOVA analysis suggest that no significant

differences can been seen between any of the conditions. The full data sheets for the descriptive and comparative means can be viewed in appendices 6.6 and 6.7.

Figure 6.6: Results of the TLX raw study that looked particularly at cognitive workload for the three different conditions. Standard deviation is marked in the error bars at 1 (+/-).
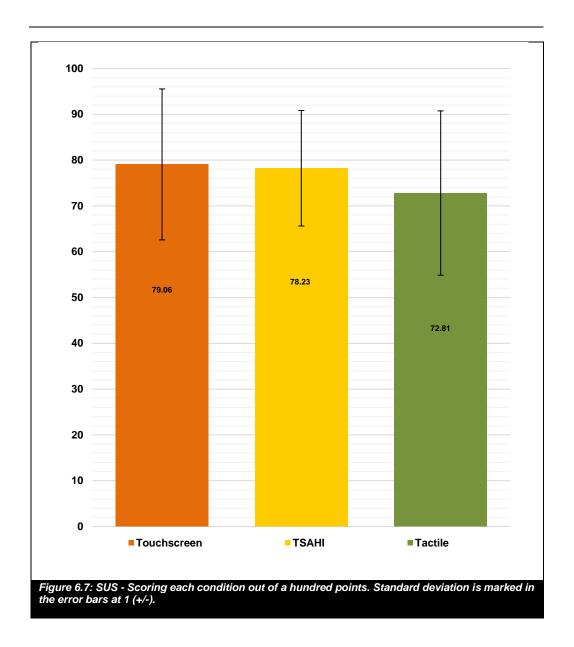
| | (Points) | | |
	Condition	Mean	SD
Mental Demand	TSAHI	9.217	4.542
	Touchscreen	9.804	4.449
	Tactile	8.192	4.261
Physical Demand	TSAHI	6.442	3.653
	Touchscreen	7.567	4.288
	Tactile	6.854	3.788
Temporal Demand	TSAHI	7.838	4.199
	Touchscreen	7.692	3.935
	Tactile	7.663	4.162
Performance	TSAHI	7.900	4.230
	Touchscreen	7.700	3.982
	Tactile	7.313	3.604
Effort	TSAHI	9.013	4.406
	Touchscreen	9.388	4.533
	Tactile	8.792	4.369
Frustration	TSAHI	7.625	4.285
	Touchscreen	7.646	4.175
	Tactile	7.046	4.144

Table 6.8: Descriptive mean results of the TLX Raw test with Standard Deviation at 1 (+/-).

6.3.2 - SYSTEM USABILITY SCALE (SUS)

The SUS (Systems Usability Scale) provided a reliable measuring tool for usability. In terms of interpreting the results, a score of 68 and above would be considered above average while anything below 68 is below average (Usability.gov 2016). When the data was analysed as a whole and the stratified sample described in section 5.5 was used, it was found that there were no conditions under the 68 threshold score that would deem any of the interfaces as below average The data is summarised in figure 6.8 and table 6.9.

The lowest was tactile, with a mean score of M=72.8 SD=17.9. The touchscreen was highest with a score of M=79.0 SD=16.5. The TSAHI scored m=77.2 SD=11.9. Although there was some variation, the ANOVA tests showed that there was no significant difference between any of the conditions [$F_{(2, 69)}$ = 1.005, p=0.371]. Based on this statistical evidence, the null hypothesis H_0 is supported.

| | (Points) | |
Condition	Mean	SD
TSAHI	77.19	11.96
Tactile	72.81	17.94
Touchscreen	79.06	16.48

Table 6.9: Descriptive mean results for the SUS study.

Figure 6.7: SUS - Scoring each condition out of a hundred points. Standard deviation is marked in the error bars at 1 (+/-).

6.3.3 - TACTILE INTERACTION

The Tactile interaction UX questionnaire was designed to relate directly to the design principles of the demonstrators that represented differing theoretical perspectives, thereby evaluating the design against criteria from the perspective of a potential end-user.
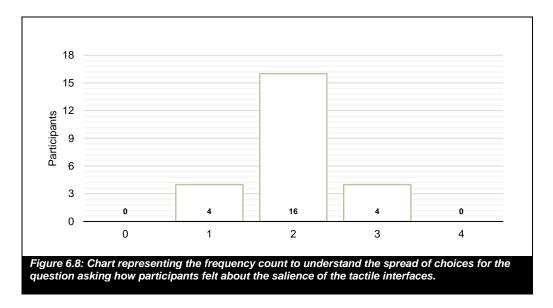
A 5-point scale was used for the questionnaire and participants were encouraging to mark 'x' where their experiences were most appropriately represented (See section 5.7). The points on the scale represent different factors that were questioned rather than an incremental scale. It will be made clear which factor is related to the numerical scale in each section of the UX Tactile Interaction analysis.

SALIENCE RESULTS

In the salience question, zero related to primarily visual use and the number four, to primarily tactile use. Number two was the mid-line representing a combination of both.

The mean results of the salience question M=2.0 SD=0.6 suggest that overall, participants felt that a combination of both touch and vision was needed.

The frequency count of the data for salience (as seen in figure 6.8), clarified that a majority of eighteen participants agreed with this. Only four of the participants used the interface primarily via tactility and identically, four others opted mainly for vision. What is evident however is that none felt they had used either touch or vision alone. Vision and touch therefore worked together to achieve the goal of interacting with the system.

Figure 6.8: Chart representing the frequency count to understand the spread of choices for the question asking how participants felt about the salience of the tactile interfaces.

Participants commented about the learning time needed for these interfaces before they could be recognised without vision:

- 'Once familiarised with the rough location via visuals, then the tactile part confirms the selection.' (B5 - appendix 7.2)
- 'I felt I usually needed to look at them to be sure. I learned the position of some of them.' (D5 - appendix 5.2)
- 'Would learn placement over time' (C2 - appendix 5.2)
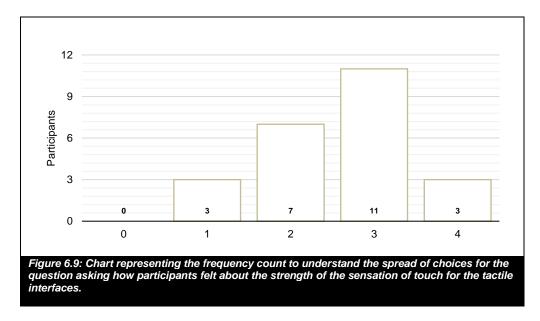
AMPLIFICATION RESULTS

The participants were asked about the strength of the sensation of touch while using the tactile interfaces. In figure 6.9, zero represented a weak sensation of tactility and

four represented a strong sensation through the fingers. Two represented a satisfactory level.

The results M=2.8 SD=0.9 indicate that the amplification was above satisfactory. The participants' spread of choice showed that a majority of eleven felt that the sensation through the finger tips was close to being strong. None thought it weak, but three participants felt that it was closer to being weak than satisfactory. The same number perceived a strong sensation. Seven participants thought it satisfactory. The participants commented that:

- 'Could feel them easily due to the pronounced shapes.' (A5 appendix 7.5)
- 'Good feedback to confirm the selection has been made.' (B5 - appendix 7.5)
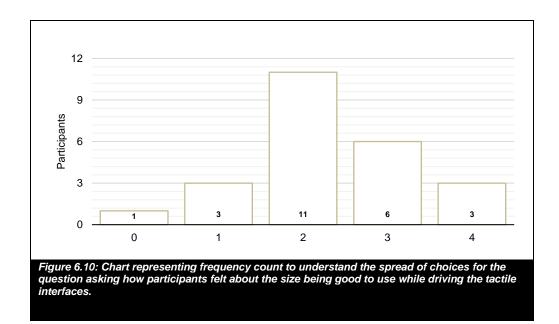
Figure 6.9: Chart representing the frequency count to understand the spread of choices for the question asking how participants felt about the strength of the sensation of touch for the tactile interfaces.

HYPERBOLE RESULTS

Users were asked if the size was good to use while driving. Zero suggests it was not good, four suggests that the size was perfect and the mid-point two suggests it was satisfactory.

The mean result of how well the hyperbole design ideas performed under usage were just above satisfactory M=2.3 SD=0.9. Interestingly, one participant in this section of the test felt that the tactile interface was not good to use while driving. Overall, comments from the comparison study eluded to this perspective suggesting that 'size wise they are too big' (Participant A1 - appendix 5.2).

However, the mean of this test suggests that the majority were satisfied with the size of the tactile interface. The spread of choice is presented in figure 6.10 where it can be seen that the majority of eleven of the participants felt this to be satisfactory. Nine users felt that that it was above satisfactory, with some perceiving it as perfect.

Figure 6.10: Chart representing frequency count to understand the spread of choices for the question asking how participants felt about the size being good to use while driving the tactile interfaces.
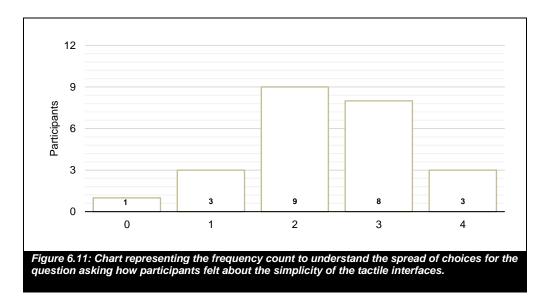
SIMPLICITY RESULTS

In this section the participants were asked to express how simple they perceived the interface. Zero suggests that it was very complex, four that it was simple and two, the mid ground, that it was just satisfactory.

Figure 6.11 summarises the results of the simplicity section of the questionnaire. At M=2.4 SD=1.0 the mean result suggests the design was above 'satisfactory'. When the frequency analysis was conducted, the general curve of favour leans towards being above satisfactory. A small group of four participants suggested that it was below satisfactory. Nine participants perceived that it was satisfactory and eleven that it was above satisfactory. This is supported by the participants' comments:

- 'Very intuitive and easy to use, not distracting, simple.' (Participant B3 - appendix 5.2)
- 'Very simple to use and very conventional.' (Participant A4 - appendix 5.2)
- 'Extremely simple. Buttons on the tactile were simple and easy to use. Looks quite old fashioned with simple amount of buttons' (Participant A3 - appendix 5.2)

These comments could suggest that conventionality or familiarity contributed towards the level of simplicity.

Figure 6.11: Chart representing the frequency count to understand the spread of choices for the question asking how participants felt about the simplicity of the tactile interfaces.
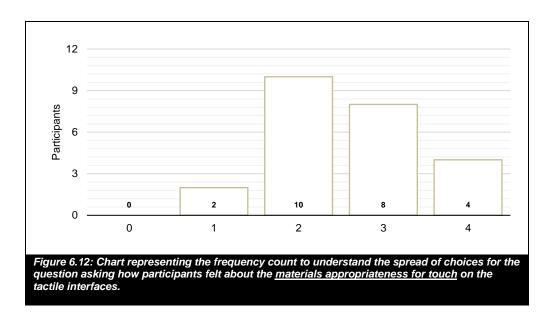
RESULTS FOR THE BEST ATTRIBUTE FOR TOUCH

This section asked the participants if the materials were appropriate for touch. Zero suggests that they did not perceive them as good, four that the materials were perfect for touch interaction and the mid-ground of two represents satisfactory.

The mean score for this section was M=2.6 SD=0.9, indicating that these design ideas were above satisfactory. As in the simplicity question, a general curve of favour leans towards being above satisfactory, but with higher values in favour of the material choices in terms of hardness, texture and temperature as laid out in the principles of knowledge from section 2.5.5. No participants felt that the materials were not good for use while driving (figure 6.12). two of the participants however felt they were close to inappropriate. One participant emphasised that they 'didn't really rely on touch.' Potentially, this question had no context for the participants other than their perceptions about the materials being unsatifactory. Half of the group (twelve participants) however thought it was above satisfactory, commenting that:

- 'Were practical and usable' (A4 - appendix 5.2)
- 'A nice click, but material could be better.' (A6 - appendix 5.2)
- 'Maybe different textures/raised borders for more definition' (B4 - appendix 5.2)
- 'OK on the whole' (C6 - appendix 5.2)

Despite the high scores however, , the participants felt that improvements could be made.

Figure 6.12: Chart representing the frequency count to understand the spread of choices for the question asking how participants felt about the <u>materials appropriateness for touch</u> on the tactile interfaces.
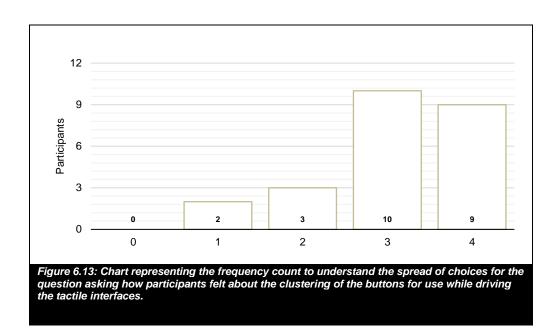
CLUSTERING RESULTS

Here, participants were asked if the buttons were logically clustered for use while driving. Zero indicates that they were completely random and un-ordered, four, that the buttons were perfectly clustered together while two indicated that they were satisfactory.

The results about clustering M=3.1 SD=0.9 yielded the highest score in all the test sections. Nineteen of the twenty-four participants were more than satisfied with the way the functions were clustered for use while driving. Comments included:

- 'Very logical' (participant A4 - appendix 5.2)
- 'Clear layout. Very functional as you would expect.' (B1 - appendix 5.2)
- 'Very methodically arranged, you wouldn't want to do it any other way!' (B5 - appendix 5.2)
- 'Well placed and simple to understand.' (C2 - appendix 5.2)

In fact, only two of the participants were less than satisfied with the clustering experience. None felt it was not fit for use while driving. Three participants felt it was satisfactory. The relative scores can be seen in figure 6.13.

Figure 6.13: Chart representing the frequency count to understand the spread of choices for the question asking how participants felt about the clustering of the buttons for use while driving the tactile interfaces.

MIND/HAND: 'SEE' RESULTS
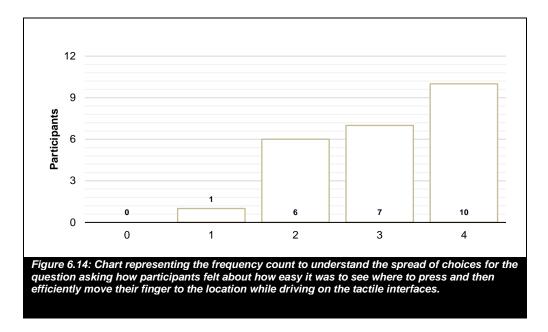
This section asked the participants if it were easy to see where to press and then efficiently move their finger to the chosen location while driving. Zero represents not at all, four, that it could easily be seen and two, that the user's experience was satisfactory.

The mean score to this question was M=2.8 SD=1.0. Seventeen of the twenty-four participants felt that they could more than satisfactorily see where to press and then efficiently move their fingers to the target. Only one participant declared the conditions for vision and target were below satisfactory. Six participants perceived them to be satisfactory. Although the mean test score was 2.8, figure 6.14 shows a definite upwards incline of the scores in favour of ease of vision and target. Various participants commented that:

- 'The colour and placement helped on tactile. Hiding others and being in one place helped with TSAHI.' (A3 - appendix 5.2)
- 'Decent size' (C2 - appendix 5.2),
- 'Large and minimal amount of buttons made everything simple.' (A6 - appendix 5.2)
- 'Clearly labelled and identified.' (B4 - appendix 5.2)

Clearly there seem to be links with the hyperbole principle (section 2.5.3). Clustering principles, as noted by Todorovic (2008) in section 2.5.6, contribute to the participants'

ability to make easy visual maps, then target their hands towards the goal. However, the operation of an interface is subjective and individual. On user commented: 'No, because seat / hand wheel / interface positioning didn't suit me.' Obviously for a small percentage, the style of the operation did not meet their expectations.

Figure 6.14: Chart representing the frequency count to understand the spread of choices for the question asking how participants felt about how easy it was to see where to press and then efficiently move their finger to the location while driving on the tactile interfaces.

MIND/HAND: 'REMEMBER' RESULTS

Here, the participants were asked if it was easy to remember where to press and then efficiently move their finger to the location while driving. Zero represents not at all, four that they could easily remember, whereas two represents 'satisfactory'.
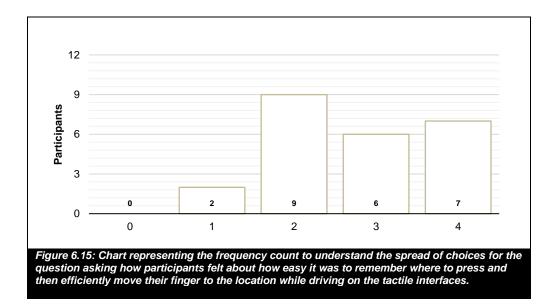
Figure 6.15 summarises the results for mind/hand co-ordination and remembering. The mean results were that M=2.8 SD=0.9 indicated a design that was above satisfactory. Like many of the other questions in this section concentrating on tactile interaction, there was a favourable lean towards the design being above satisfactory for thirteen of the twenty-four participants. Only one participant thought it below satisfactory and none felt they could not remember where to target and move hands. Nine participants felt it was satisfactory.

Although some difficulties were experienced in remembering the system, it was perceived that they could be overcome with practice:

- 'I feel with more time it would have gotten easier.' (A4 - appendix 5.2)
- 'It got easier throughout the trial.' (B4 - appendix 5.2)
- 'It's easier to do the more you use it.' (C6 - appendix 5.2)
- 'Easier on TSAHI' (C2 - appendix 5.2)

The last comment by participant C2 was particularly interesting. The participant felt that it was easier to remember mind/hand co-ordination routines on the TSAHI. This could possibly suggest that hiding unwanted functions and reducing the amount of information to be processed helped the utilisation of the brain's natural filtering system of taxonomies. This is discussed through Tversky & Hemenway (1984) and Rosch (1978) in the clustering principle (section 2.5.6). This potentially adds further evidence to the observations noted earlier in section 6.3.7. that there are links between the principles.

It was also noted that more participants found the TSAHI above average in terms of usability in the SUS study and in section 5.3.1. It was also noted that participants spent less time glancing towards the interfaces. In particular, the glance mean results (section 5.2.1.2) indicate that this information can be perceived faster from TSAHI than from the touchscreen condition. The total glance time (section 5.2.5.2) moreover indicated that TSAHI was less visually demanding in comparison to the touchscreen.

Figure 6.15: Chart representing the frequency count to understand the spread of choices for the question asking how participants felt about how easy it was to remember where to press and then efficiently move their finger to the location while driving on the tactile interfaces.

MIND/HAND: 'IMAGINE' RESULTS

In this section the participants were asked if they could imagine the shape of each button effectively while driving. Zero indicates they could not do this, four indicated that they could visualise them perfectly and two, that they were satisfactory.
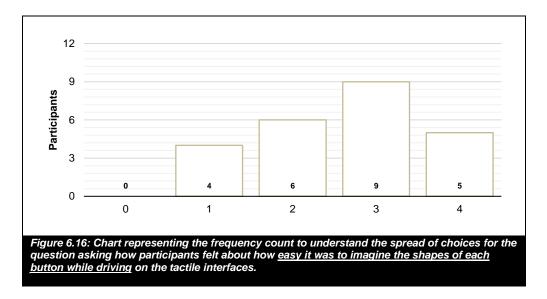
Figure 6.16 summarises the results of this section. The mean result M=2.6 SD=1.0 indicated that the design was above satisfactory. Once again the general spread of results leaned towards this conclusion as fourteen of the twenty-four participants expressed that they could visualise the shape of each button while driving. None felt

that they could not imagine them at all. Six participants thought they could do this satisfactorily. Comments include:

- 'Each button had easily memorable shapes.' (A3 - appendix 5.2)
- 'They are very memorable.' (A5 - appendix 5.2)
- 'Very logical grouping/shaping makes them easy to remember. Colour also works well'. (B5 - appendix 5.2)
-

It was interesting to note that one participant felt that they were 'beginning to [imagine the shapes while driving] but still checking during the exercise. Again, tactile [condition] was more difficult'. (C6 - appendix 5.2). This, although an isolated comment could provide some evidence to suggest that the show and hide system is superior to the tactile condition. Further conclusions will be drawn on this subject later.

Figure 6.16: Chart representing the frequency count to understand the spread of choices for the question asking how participants felt about how _easy it was to imagine the shapes of each button while driving_ on the tactile interfaces.

It was also interesting to note that the tactile interface buttons were 'familiar shapes although numbers on radio might be more intuitive.' (A6 - appendix 5.2), suggesting that the addition of graphics could aid the use of the buttons.

MAPPING: DISCRIMINATION RESULTS

In this section the participants were asked if they could easily discriminate between the different buttons while driving. Zero indicates not at all, four that it was perfectly easy and two, that they were satisfactory.

Figure 6.17 summarises the results of this section. The mean result was M=2.8 SD=0.9. One participant that felt that it was not easy to discriminate between different functions while driving. That user left no comment as to why, although in the condition

comparison study, it was apparent that this user found the static tactile interface problematic, commenting:

- 'This interface was the hardest to get used to, maybe because I was new to the test.' (C5 - appendix 5.1)
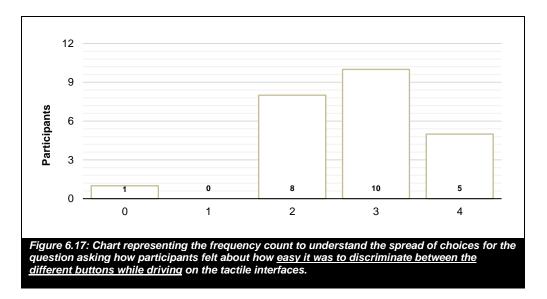
Fifteen out of the remaining twenty-four participants perceived the tactile interface was above satisfactory. One left a comment stating:

- 'No mistaking which buttons were which.' (B5 - appendix 5.2)

One of the issues indicated by the eight participants who statedthe discrimination between the buttons was 'satisfactory' was time needed to learn the different shapes:

- 'Easier with the TSAHI because it was always in the same place.' (C6 - appendix 5.2)
- 'I could discriminate but it required attention from driving.' (D5 - appendix 5.2)
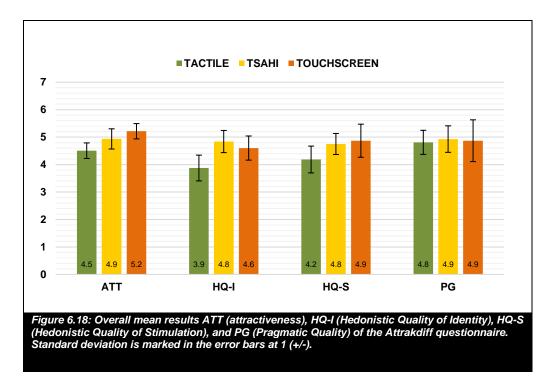
One of the early design issues of the buttons that caused several iterations of the sketch study was a lack of clarity between the shapes, as noted in section 4.1.7. One of the 'quick and dirty' user-testers had commented that the radio buttons 'were a blur' (Participant M3, Appendix 4.10) when they were in a uniform shape aligned to the edge of the circular panel. There seemed to be less of a problem with a larger test group and the redesign that followed this comment, excepting one user in these later tactile tests.

Figure 6.17: Chart representing the frequency count to understand the spread of choices for the question asking how participants felt about how *easy it was to discriminate between the different buttons while driving* on the tactile interfaces.

6.3.4 - ATTRAKDIFF

The Attrakdiff questionnaire aimed to understand how the participants felt about the different conditions. In brief, the Attrakdiff is a standardised questionnaire assessing emotional qualities, used by companies such as BMW and Jaguar. To be specific there are four emotional qualities: Pragmatic quality (PG) - Clarity of interaction model and usability, Attractiveness (ATT) - General aesthetic quality, Hedonistic Quality of Identity (HQ-I) - Resonation between self-perception of user and product and Hedonistic Quality of Stimulation (HQ-S) - Potential for reaching individual goals perceived by user.

The questionnaire answers range from 0-7 (7 being positive perception and 0 being negative), making 3.5 the midpoint or average point of the graph seen in figure 6.18. From this simple bar chart, it can instantly be observed that there are not many significant differences between the TSAHI and the touchscreen. User comments therefore been used in the analysis to enrich the research on emotional factors.

Figure 6.18: Overall mean results ATT (attractiveness), HQ-I (Hedonistic Quality of Identity), HQ-S (Hedonistic Quality of Stimulation), and PG (Pragmatic Quality) of the Attrakdiff questionnaire. Standard deviation is marked in the error bars at 1 (+/-).

ATTRACTIVENESS (ATT)

Overall the touchscreen values for this level were above average M=5.21 SD=028. These were the highest values where attractiveness was tested. The TSAHI values were M=4.93 SD=0.37 and the tactile values were M=4.51 SD=0.28. This comparison between the TSAHI and tactile values could suggest that the moving element of the interface played a role in increasing its overall attractiveness.

A final point in this area is that the touchscreen was negatively perceived in one section, as users suggested that they found it felt 'bad' rather than 'good' as in comparison to the TSAHI demonstrator. This can be seen in figure 6.19 which has a more detailed breakdown of the results from the Attrakdiff questionnaire.

However, it can be noted that several users quoted positively about their experiences with the touchscreen (appendix 4.1).

'Personally I like the touchscreen due to it looking/feeling more modern and technical', 'considered premium, sleek', 'very stylish.' (Participant B5, B6, C3).
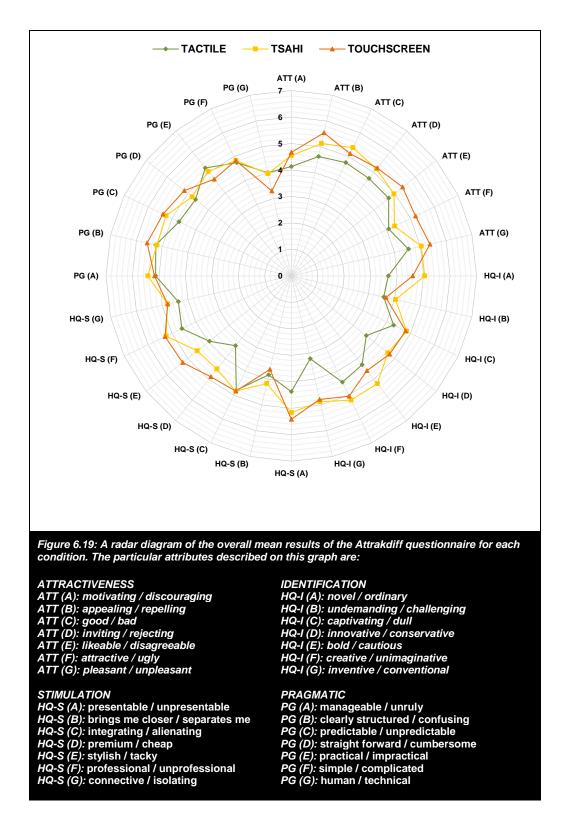
It is evident that aesthetics has an influence in how participants perceived the touchscreen. One user echoed the general findings:

'I personally like the touchscreen due to it looking/feeling more modern and technical, however I can see how some people would find hard to use due to not being able to recognise functions with your fingers.' (Participant A5 - appendix 5.1)

Potentially this could point out possible hedonic properties or cognitive ambivalence i.e. tension between desire and self-control (Miao 2011), in that the operator admires the touchscreen despite being visually distracted, which he or she is aware may not have a good outcome. That said, it is notable that the general support for the touchscreen indicates that participants seek to achieve be-goals described by Hassenzahl (2008), such as 'being competent' and 'being special'. These contribute directly to the core of positive experience. In this paper he argues that 'be-goals are the driver of experience. Lack of usability might impose a barrier to the fulfilment of active be-goals, but it is in itself not desired' (2008: p.2).

HEDONIC QUALITIES - IDENTIFICATION (HQ-I)

Overall, the TSAHI condition was identified as preferable according to the mean values of the Hedonistic Quality of Identity data, but only by a slim margin at M=4.84 SD=0.40, The touchscreen condition ranked below this with M=4.60 SD=0.44 and the tactile condition was M=3.88 SD=0.47. None fell below the mid-way mark.

The high level of satisfaction with the TSAHI and touchscreen conditions is evident as a mean average, in comparison to the tactile condition in the Hedonic qualities of identification.

Figure 6.19: A radar diagram of the overall mean results of the Attrakdiff questionnaire for each condition. The particular attributes described on this graph are:

ATTRACTIVENESS
ATT (A): motivating / discouraging
ATT (B): appealing / repelling
ATT (C): good / bad
ATT (D): inviting / rejecting
ATT (E): likeable / disagreeable
ATT (F): attractive / ugly
ATT (G): pleasant / unpleasant

STIMULATION
HQ-S (A): presentable / unpresentable
HQ-S (B): brings me closer / separates me
HQ-S (C): integrating / alienating
HQ-S (D): premium / cheap
HQ-S (E): stylish / tacky
HQ-S (F): professional / unprofessional
HQ-S (G): connective / isolating

IDENTIFICATION
HQ-I (A): novel / ordinary
HQ-I (B): undemanding / challenging
HQ-I (C): captivating / dull
HQ-I (D): innovative / conservative
HQ-I (E): bold / cautious
HQ-I (F): creative / unimaginative
HQ-I (G): inventive / conventional

PRAGMATIC
PG (A): manageable / unruly
PG (B): clearly structured / confusing
PG (C): predictable / unpredictable
PG (D): straight forward / cumbersome
PG (E): practical / impractical
PG (F): simple / complicated
PG (G): human / technical

To provide a more detailed breakdown of this section and provide context for the results, the TSAHI achieved higher scores in comparison to the touchscreen in several sections, namely novelty vs. ordinary, undemanding vs. challenging, and bold vs. cautious, the former of each category being positive. The results for the tactile condition however were disappointing in all sections. At a glance, the HQ-I bar chart with standard deviation bars (figure 6.19) indicates that the difference between the tactile and the TSAHI condition is significant, as the error bars at no point cross each other to show a correlation.

To enrich these results, comments from the open section of the condition questionnaire were observed. Terms that matched the Attrakdiff results such as 'Novel' or 'innovative' occurred several times:

'Novel, exciting, easier than tactile', 'Extremely novel, easy to reach, easy to figure out', 'I think this is quite a novel way of presenting the functions and automating where your hand goes to use the controls', 'Quirky!', 'Very neat and innovative. Like the tactile interface but more conceptual and unusual!' (Participant: A2, A3, B6, B5, A4 Appendix 5.1).

The 'be-goal' definition notes that human needs beyond the instrumental (such as a need for novelty), are relevant because they promise fulfilment of an underlying human need, to be stimulated, to perfect one's skills and knowledge and to grow (Hassenzahl 2008; Hassenzahl and Tractinsky 2006: p93). A level of importance should be attributed to these results with this perspective in mind.

The Tactile condition in HQ-I (G) was noted being as less than average in score in terms of inventiveness vs. conventionality.

HEDONIC QUALITIES - STIMULATION (HQ-S)
With respect to the stimulation section of Hedonic qualities, the touchscreen at M=4.87 SD=0.60, scored marginally higher than the TSAHI at M=4.75 SD=0.38. It is however evident from the standard deviation that there is a level of correlation between the two conditions that would render the difference insignificant. The Tactile condition at M=4.18 SD=0.49, scored lowest, as in the previous two sections.

Looking at the data in more detail, it is immediately apparent that figure 6.19 shows a spiking dip in favour of the touchscreen condition. This dip on the HQ-S (B) axis represents relatedness and is other-oriented (Hassenzahl 2008), in terms of whether the condition 'brings me closer' or 'separates me'. This could suggest that the

touchscreen system did not help the participatory group to feel a sense of closeness to others. However, there are no further details to suggest its context and further research is needed.

Another issue that can be seen from the detail in the data (figure 6.19) is a spiking dip in favour of the touchscreen condition. As above, this dip on the HQ-S (B) axis represents relatedness and is other-oriented (Hassenzahl 2008) in terms of whether the condition 'brings me closer' or 'separates me'. This could suggest that the touchscreen system did not help the participatory group feel a sense of closeness to others. Again, further research is necessary to determine the context.

Notwithstanding, the touchscreen condition fared comparably if slightly better in various cases to the TSAHI including 'unpresentable vs. presentable', 'cheap vs. premium' and 'stylish vs. tacky'.

PRAGMATIC (PG)

Overall, the mean results of the different interfaces in this category were similar across all three conditions with TSAHI at M=4.93 SD=0.48 proving to be very slightly superior, followed by the touchscreen at M=4.87 SD=0.76, then tactile, at M=4.81 SD=0.44. With such similar results, it is clear that there is a correlation in the difference between the conditions.

Scrutiny of the PG category reveals that overall, the results were mixed. However, the most noticeable detail was the sharp dip in score for the touchscreen in the PG (G) axis (figure 6.19) to below average. The PG (G) shows the 'human vs. technical' factor of the conditions, indicating that the participants perceived that the touchscreen condition was too technical as an operative feature.

An interesting observation when cross referencing data from other studies was that there may have been a conflict between the scoring method and modern consumer values. In the Attrakdiff questionnaire, 'technical' attributes are seen as negative in the pragmatism section, but several users alluded to it as being positive in their opinion. In section 6.3.4, 'cognitive ambivalence' about the subject was noted. It was also observed that participants were seduced by the modern 'technical' look and feel of the interface, but understood that it did not help them. There is an obvious area of ambiguity here and as concluded by other Attrakdiff studies, it is dangerous to draw any conclusions that pitch usability against hedonic qualities without further research to conclude this issue (Isleifsdottir and Larusdottir 2008).

6.4 - SUMMARY

The results of all the studies in relation to the hypothesis can be viewed in Table 6.10.

Evaluation criteria	Study	Study section	Hypothesis Result
Efficiency	Vis-D	Glance mean	H_1
		Percentage Eyes Off Road Time (PEORT)	
		Total Glance Time	
		Maximum Glance Duration	
		Glance Number	H_0
Safety	LCT	Lane Position	
Satisfaction	UX	TLX	
		SUS	
		Tactile Interaction	
		Attrakdiff	

Table 6.10: Table of results for visual demand (VIS-D), Lane Change Test (LCT), and User eXperience (UX).

VISUAL DEMAND (VIS-D)

To summarise, it can be concluded from the test results that there is a significant level of difference between the touchscreen and the TSAHI.

- Glance mean that indicates that information can be perceived quickly
- PEORT indicates that the driver is distracted by TICS (Transport Information and Control Systems) as well as low primary task (driving performance) workload,
- Total glance time that indicates increased visual demand
- Maximum glance duration: TSAHI the lowest levels of visual/mental demand.

This level of significance completely supports the experiment hypothesis H_1 suggesting that in terms of driver behaviour in the form of eye tracking/movement; visual attention will be lower in the TSAHI in comparison to the touchscreen.

- Glance Number: the visual importance of TSAHI was similar to the Touchscreen. However, users glanced at TSAHI were shorter periods of time.

LANE CHANGE TEST (LCT)

There was evidence to suggest that the TSAHI and touchscreen conditions had a significant effect on driving performance but there was no significant difference between each condition.

USER EXPERIENCE (UX)

TLX raw (Task Load indeX)

The results from the TLX raw were very mixed, hence inconclusive. All that can be attained from the data is that there was a general trend for the lower scores to be attributed to the physical demand category and the higher scores to be attributed to the Mental Demand and Effort categories. One participant (Participant D5 - Appendix 6.8) gave a detailed account of their feelings, emotions, efforts and workloads experienced between the conditions.

- Touchscreen: 'It's very difficult to use. AKA, mental workload. Tring to drive the car and reach and hand wobbles, emotionally upsetting - have to go back so many times.'
- Tactile: 'This seemed quite chunky to use, but actually felt easier while driving.'
- TSAHI: 'It's a two-step process, but it feels easier. Whilst you're driving, you don't need to remove eyes off the road. Can do it progressively. Felt like a harder workload.'

The participant commented that the workload was greater, but that the mental workload on the touchscreen was also very challenging. It was also mentioned that the touchscreen was '… more stressful' and that the Tactile and TSAHI conditions were 'easier' to use while driving.

Similar to the conclusion of the VIS-D - eye positions category of the various studies, it must be remembered that these results are subjective, hence it is unwise to draw conclusions from isolated instances because everyone has different abilities and skills. However, these observations provide further evidence to better understand the workloads of the conditions. Again, further research is required to understand the full effect of workload on the participants.

SUS (System Usabiliy Scale)

It can be concluded from the data analysis that although the difference between the conditions was not significant, the mean results did not drop below the 68 threshold. This confirms that the overall results in the VIS-D most probably were not caused by a condition being a 'bad' or 'below average' interface.

In addition, it can also be concluded that more participants perceived the TSAHI as above average. This helps to add clarity to the AVOVA means test, suggesting that more test participants felt the TSAHI to be superior.

Tactile Interaction

All the mean results of this questionnaire were above average. This is a good indicator that the design principles in general were effective. The user comments from the condition comparison questionnaire added valuable insights into why choices were made to enrich the results. It was noticeable that there were linkages between principles. For example, the hyperbole principle and the clustering principles (section 2.5) enhanced the participant's ability to perceive the aim and target areas on the control panels. These are dicssed in much more detail chapter.

Attrakdiff

There was a general trend for the touchscreen to feel more attractive. In terms of hedonic qualities there were mixed results. In the identity category, the TSAHI mostly led. On the other hand, the touchscreen was mostly perceived as more stimulating. The practically section gave a very mixed result. There was a general trend for the tactile to rank lowest in most of the categories, as can be seen in the smaller radius formed on the radar diagram of figure 6.19.

CHAPTER 7
GENERAL DISCUSSION

7.1 - LIMITATIONS OF THE STUDY

The fact that the tests were performed in a simulated environment is of great importance because it limits the generalisability of the results to real driving environments.

REAL AND SIMULATED DRIVING

In studies conducted by Hallvig et al. (2012) it was found that lateral movement differed in simulator vs. real driving studies because in real driving, there was more variability. For example, participants deviated to the left and reduced their speed more. In a recent study, Louveton et al. (2017) found that attention level metrics were significantly higher in a real-driving environment than in a simulation. Suggest that any issues in terms of attention and any consequential linkages to performance while using an interface may be under-pronounced in a simulator trial.

Having understood that there are differences between simulator activities and real world driving it should be considered that results from the TSAHI tests are relative and not absolute in relation to the real task of driving. Despite this, in terms of safety, efficiency and satisfaction a comparative picture about the different interfaces is clear.

RESOURCES

It should also be noted that as an independently funded PhD project, resources were limited but used where important. For instance the majority of the funding was used to develop a valid simulator environment that conformed to ISO and NHTSA standards and for the creation of the custom interface demonstrators.

In terms of the TSAHI design it should be remembered that a functional demonstrator of the ideas of a tactile show and hide interface was tested rather than a finished design. Conventionally, manufacturers invest high levels of funding to optimise the feel and touch of a single button to improve consumers' emotions about their brand. This was not the task with this thesis. Function and usability were the main foci of the demonstrator design. This is reflected in the results of the Attrakdiff study in section 6.3.4. The relative comparability of one set of demonstated ideas against another can however be claimed.

PARTICIPANTS

Other studies (such as the NHTSA 2002-808536 report that observed the naturalistic driving styles of 100 participants) can provide a level of generalisation. However, this is not the case for this thesis, although the study met the recommended twenty four participants of differering age ranges as specified in NHTSA 2010-0053. Consequently the results should be viewed as indicative.

Differences were noted between age categories. This is discussed later in this chapter. However, the study could have been improved with a larger sample of third age participants.

ONE OF MANY POTENTIAL SOLUTIONS

Another important issue to remember is that the results of this thesis are limited to one set of designs for evaluation. There are many different options that could elicit different results. In addition to this, only one main experimental study was conducted on the design. As a result, only relative rather than definitive conclusions can realistically be acrued from the studied comparision between the interfaces.

However, there are valuable advantages to the use of this study's approach. The VIS-D, LCT, and UX approach has relative benefits regarding speed and convenience, in addition to having the ability to test prototype ideas that could not easily be conducted in a conventional vehicle. Ultimately, this approach serves as an excellent first filter for conceptual new design options that are continuously produced in the creative environment of a design studio.

LITERATURE

The review of literature was appropriate locate the research, to form its context and provide insights into previous work (Blaxter et al., 2010). What was evident was that there was a good amount of objective data to support the argument that interactive screens are distracting. However, what wasn't readily avalible was a detailed level of knowledge about the problems from a User eXperience perspective. It was for this reason that a case study was needed. The 'self witnessing' method (James 2008) used to understand the UX was rich in content but subjective.

7.2 - DRIVER PERFORMANCE (LCT)

The Lane Change Test results (section 6.2) that indicated how many meters a driver deviated from their lane as a mean average were inconclusive. No level of significance could be found, as the results were similar for all the interfaces. Hence, no conclusive

evidence could be found to suggest any of the interfaces were superior with respect to safety and driving performance. At the beginning of this section if was discussed that Louveton et al. (2017) noted an under pronunciation of actions in simulator results. As there was no significant difference between the results in terms of mean lateral deviation it may be possible that a new method is needed to adiquately evaluate driver performance of the TSAHI. One that scrutinises road events and TSAHI interaction much more explicitly.

7.3 - BEST AESTHETICS FOR TSAHI (UX)

The demonstration of aesthetics was not a major consideration throughout the thesis because its focus was visual distraction. However, it was notable in the results of the Attrakdiff questionnaire that aesthetics had for various reasons influenced the participants' thoughts. The TSAHI performed badly in the Attractiveness (ATT) tests as in various sections of the Hedonic qualities relating to stimulus (HQ-S), specifically: 'unpresentable' vs. 'presentable', 'cheap' vs. 'premium', 'stylish' vs. 'tacky'. Potentially, further studies are required to understand the best aesthetic form for a TSAHI, as its efficiency in the VisD tests was significantly superior to the touchscreen in terms of visual distraction. Further studies should also help create a more positive experience for the end user.

7.4 - DESIGN PRINCIPLES (UX)

It is useful to review the impact of the design principles used to develop the TSAHI design. In the tactile interaction section of the results it was summarised that all the principle scored above average. In order to add some a critical perspective to how these performed in this section the design principles are reviewed against literature from chapter 2 and participants comments from the tactile interaction questionnaire in the UX study.

PRINCIPLE ONE: SALIENCE
The aim of the principles was to reduce the need for visual inspection. The majority of the participants felt that they needed to use both vision and touch to achieve a satisfactory level of interaction with the tactile designs. However, Purdy, Lederman & Klatzky (1999: p769) consider this as customary during the process of haptic recognition, noting that the last view a subject has of an object facilitates the pre-reach (the moment before the subject initiates reach as discussed in section 2.3.1 where knowledge in the field of haptic psychology is discussed). It is also notable that these glimpses at the interface help to form cognitive maps (Lederman, Klatzky, Collins and Wardell 1987; Rieser, Lockman and Pick 1980).

PRINCIPLE TWO: AMPLIFICATION

Enhancing somatosensory interaction aimed to increase the information that participants could gain from tactile interaction. It is indicated that this principle was above satisfatory as participants perceived the interaction as strong. The ideas of Klatzky and Lederman (1992) that underpinned this principle were a crucial element as participants disclosed: 'Could feel them easily due to the pronounced shapes', 'The raised area made it simple' (Participant A3, A5 - appendix 6.9). The idea that coarse information would be useful also proved pertinant with a participant commenting: 'Nice bold icons to aid identification' (Participant B4 - Appendx 6.9), when asked about the levels of aplification in the tactile interaction questionnaire.

The height test, that resulted in a 5mm acute edge being favoured, arguably had a certain level of success as the data shows that it was above satisfactory (M=2.8 score out of a possible 4.0). It would be of interest to understand how to increase this score to reach the upper limits of somatosensory sensation, and to assess whether stronger sensations are actually needed in such an experience as driving a motor vehicle.

Reflecting on the button height design study in chapter 4.0, it could be concluded that making the buttons lower than the 5mm specified from the 'quick and dirty' user-test may be detrimental to a tactile design. However, it had already been loosely concluded that increasing the height would effectively form a 'barricade' effect during an exploration procedure. Further research with a larger group and a greater variation of buttons would help gain an understanding of the optimal height.

PRINCIPLE THREE: 'HYPERBOLE'

One participant commented that the size of the interface was too large. Another perceived it to be less visually appealing because of its 'clunky' appearance (appendix 6.8 – participant C2 and A1). Although there were some positive comments, it could be argued that the negative responses were due to the participants' expectations. Further comments indicated: 'They are practical but could be better' and ' Less appealing to the eye, but lacking technical edge - which I'm now used to.' The issues experienced in the Attrakdiff study are evident here. It is possible that particular patterns and configurations that are more contemporary with current trends could have alleviated this particular issue. The work of minimalist designers such as Dieter Rams suggests that it is possible to create physical interfaces with spaced out controls (figure 7.1) that also have a sophisticated level of aesthetic appeal.

Futher research is needed to improve this design principle with a study that both investigates and offers guidance about the aesthetics of spacing.

PRINCIPLE FOUR: SIMPLICITY

Feedback indicates that the levels of simplicity were good for the design. There were however participants who felt that the tactile interfaces could have been simpler. Whether this is an aesthetic or a functional issue is not fully clear. There were a range of responses. Some participants commented that the 'raised area' made it simpler (participant A3 and B4, appendix 6.9). Another respondent (B5 participant, appendix 6.8) commented that the Tactile interface was overly complicated ('Too many buttons at once!') compared to the TSAHI interface ('The right buttons are where you need them'). Another perceived that the TSAHI was a more 'minimal design' (participant A6, appendix 6.8). From this comparison between the tactile and the TSAHI interface it is possible to argue that the effect of showing and hiding controls to minimise choice, as hypothsised, is highly effective through this principle. However, this is a conclusion from a very small sample. Further research with a larger samlple would give a much clearer picture of the effectiveness of simplicity in a TSAHI.

The principles in section 2.5 that were formulated for the study mention that subsequent repeated hand exploration would be required to follow contours, resulting in complication, low confidence and innacuracy (Klatzky and Lederman 1992). This was not the case during the tests however and reviews of the video data confirm this. It could therefore be presumed that this principle promted a level of simplicity that allowed accurate and confident identification of surfaces.

PRINCIPLE FIVE: BEST ATTRIBUTES FOR TOUCH

Some participants made negative comments about the touch and feel of the tactile interfaces: 'weird texture - feels too soft', 'Could have been nicer to touch', 'not premium', 'nice click, but material could be better', 'A softer touch would be preferable.' (Participant A1, A3, A4, A6, B6 appendix 6.9). Dispite the tactile interfaces scoring above average in the study, users clearly felt they could be improved, as indicated in the results in section 6.3.3. However, the availability of finance and resources limited the evaluation of this principle.

One participant comment that 'differing surface finishes would help.' This aligns with the principles of section 2.5, underpinned by Klatzky and Lederman (1992). The tactile panels had been formed from one main texture to indicate a useful area in general. Further guidance, for example written instructions could be required with respect to this principle i.e 'a detailed and explicit indication of usefulness is needed' in order to optimise a design for touch utilising textures and hardness.

PRINCIPLE SIX: CLUSTERING

The clustering principle worked well during the study to the extent that it yielded the highest score for tactile interaction. Many participants commented positively about the logical nature of the clustering. Presumably the ideas of Tversky and Hemenway (1984), Rosch (1978) and Niesser (1976) had been effective.

PRINCIPLE SEVEN: MIND / HAND CALIBRATION

This principle concentrated on the coordination between 'seeing', 'imagining', and 'remembering' as known factors in the use of object manipulation, as discussed in sections 2.5 and 2.3.2. The participants' comments were varied. For example, 'the colour and placement helped on tactile [interface]… Hiding others and being in one place helped with TSAHI.' When refering to how well the controls could be imagined, the same participant stated: 'each button had easily memorable shapes.' (Participant A3 - appendix 6.9). Another suggested that 'large and minimal amount of buttons made everything simple.' (A6) while another agreed 'Very logical grouping/shaping makes them easy to remember. Colour also works well.' (participant B5 – appendix 6.9).

Altnough the results were mixed, linkages are apparent between this principle of mind/hand calabaration and the others; in particular the observations concerning the prinicples of clustering, simplicity and amplification in this sample. It is indicated moreover that there are prerequisites to achieving the maximum benefits of the mind/hand calibration design principle. There was however no evidence in the results to indicate explicitly what the various factors of the prerequisite would be. It should be ascertained whether any factors can be omitted without causing a detrimental effect to the overall goodness of the principle. Additionally it would be useful to understand if all the factors have indeed been uncovered and whether there is any hierarchy of importance for the different factors that make good mind/hand calibration while using a TSAHI. Further research therefore is needed to explore the mechanism of this design principle.

On a different note, one participant directly commented that the 'tactile was more difficult' (Participant C6 - Appendix 6.9). This suggests that the TSAHI could be superior in mind/hand calibration, however as this is an isolated incident, further research with a larger group is needed to validate this claim.

PRINCIPLE EIGHT: MAPPING
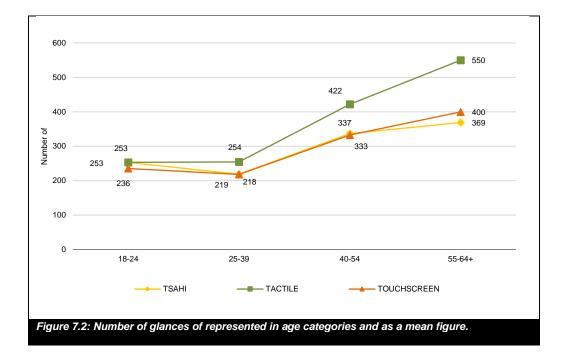
With respect to the mapping principle, participant A3 (Appendix 6.9) commented '[the]Button had easily memorable shapes.' Another commented that they 'could discriminate but it required attention from driving.' (D5 - Appendix 6.9). These comments suggest that the ideal of Green, Levison, Paelke and Serafin (1994) and Norman (2005) is effective in the experimental environment, while using the TSAHI. However, there was no evidence to support the ideas of Kovacs & Julesz (1993) suggesting that closed contours form landmarks more effectively than open contours. All of the of the interfaces were circular so no comparision could be made. Additional comparative research would furthert understanding in this area.

7.5 - Visual distraction and age (VIS-D)
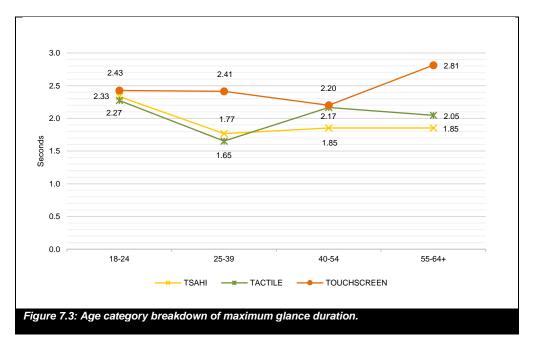
Age, as described by Kinnear and Stevens (2015) is associated with different levels of visual distraction.

Observations showed that from the age of 18-24 the results for the number of glances rose continuously as the participants' age increased from 25-34, through 35-54 to 55-64. The tactile condition more than doubled the number of glances during this the observations, as did the touchscreen and the TSAHI conditions (seen in figure 7.2)

For a comparative discussion, Kinnear and Stevens (2015) pointed out that young drivers were more likely than older drivers to look away from the road for longer periods of time. A breakdown of maximum glance durations (figure 7.3) for the age categories shows that this is dependent on the type of interface used. In the 18-24 age category, glances over Rockwell's (1998) two second limit were observed for all conditions. But at the more advanced age scale, the longer glances were mainly towards the touchscreen condition and saw the duration dropping below 2 seconds in the TSAHI condition. The overall conclusions of the VIS-D study indicate that maximum glance duration correlates with the visual and mental demand. Hence is could be suggested that for younger drivers, the visual/mental demand levels of distraction are more or less similar for all the interfaces. But for the older drivers however, the magnitude of visual/mental demand is considerably less for the TSAHI condition, suggesting it is an interface that is more appropriate for older drivers to

combat distraction. This suggests that older drivers stand to gain the most in terms of alleviating driver distraction through using a TSAHI design.

Figure 7.2: Number of glances of represented in age categories and as a mean figure.

Figure 7.3: Age category breakdown of maximum glance duration.

4
PART

CONCLUSIONS AND CONTRIBUTION

CHAPTER EIGHT
CONTRIBUTION TO KNOWLEDGE AND SUGGESTIONS FOR FURTHER WORK

8.1 - DESIGN DEVELOPMENT & EVALUATION

The aim of this design research was to explore the effects that automotive interactive screens have on visual attention, with an emphasis on searching for a solution to the problems evidenced:

- To understand the reasons for driver distraction when using interactive displays
- To specify the requirements of a Tactile, Show And Hide Interface design and hypothesise where and how such an interface may reduce driver distraction in the use of automotive secondary controls
- To produce a demonstrator of a Tactile, Show And Hide Interface design
- To evaluate and gain an in-depth understanding of the extent to which the demonstrator reduces a driver's visual distraction

In Chapter 2 the contextual review and a case study demonstrated that numerous opinions have identified that there is a problem with the use of in-car interactive screen interfaces while driving. These problems have been noted to cause fatalities and injuries. It was concluded that a new approach to screen usage and information design was needed. In section 2.3 a hypothesis was posed:

H1: 'TSAHI will result in less driver distraction than the touchscreen'
H2: 'TSAHI will be perceived as more usable than the touchscreen'

Following this, the contextual review examined existing theories and practices in tactile displays. This exposed gaps in the field of automotive design for tactile auto interior design, especially in the field of show and hide auto interior design, making this a very fertile field in which to conduct research and increase the opportunity to create new knowledge. Following the contextual review the research was grouped under three headlining factors: Safety, Efficiency, and Satisfaction to help focus the consequent discussions and create a critical lens (Section 2.4).

A radical mixed methodology approach was taken for the design research (section 3.4) and completed to explore the hypothesis. A design development study was deployed, followed by an experimental design (in line with NHTSA , ISO and JAMA specifications) to systematically evaluate the conditions. A TSAHI prototype demonstrator design used the principles created by the author in section 2.4 to ensure it rigorously embodied ideas of tactility and object manipulation. The TSAHI was designed and produced to manifest tangible and testable ideas. A comparative touchscreen interface was also developed to JAMA standards (section 3.6). Measurements and procedures for the evaluation of the TSAHI demonstrator were defined in chapter 5. Qualitative User eXperience (UX) standardised questionnaires, the objective Lane Change Test (LCT) and VISual Distraction (VIS-D) eye tracking observations (sections 5.11 and 5.12) were used to explore the hypothesis under the critical lens of Satisfaction (UX), Safety (LCT), and Efficiency (VIS-D). These measurements of human behaviour were taken in a custom built simulated driving environment that was prepared to NHTSA and ISO guidelines and standards (discussed in section 5.9) against a demonstrator model of a touchscreen - the problematic interface (section 3.6).

The mesurements of the TSAHI and touchscreen demonstrators showed for the most part, that the experimental H1 hypothesis stating that a *'TSAHI will result in less driver distraction than the touchscreen'* was supported in terms of the objective data observed in the VISual-Demand. There were mixed results in the LCT and subjective User eXperience data hence H2 of the hypothesis that states *'TSAHI will be perceived as more usable than the Touchscreen'* was not conclusively supported.

8.1.1 - VIS-D CONCLUSION (EFFICIENCY)

Firstly, when the TSAHI and Touchscreen eye-tracking data was compared, the 'Glance mean' was significantly different, in favour of the TSAHI (section 6.1.2). This indicated that information can be perceived faster with the TSAHI (section 5.11).

Secondly, percentage 'Eyes Off Road Time' was significantly different in favour of the TSAHI, showing that the participants spent less time looking at the road than in the touchscreen condition (section 6.1.3). This indicated that the driver was more distracted by the touchscreen (discussed in section 5.11).

Thirdly, 'total Glance time' was again significantly different in favour of the TSAHI (section 6.1.4). This measure indicated that there was an increase in visual demand for the touchscreen (section 5.11).

Lastly, the 'maximum glance duration' was also significantly different to that of the Touchscreen in favour of the TSAHI. Maximum glance durations were shorter than the Touchscreen glances (section 6.1.5), indicating a lighter visual and mental demand in comparision to the touchscreen condition (section 5.11).

There was however a measure that at first sight denotes support for the null H_0 hypothesis. This was the 'glance number' measure. The ANOVA tests showed that there was not much difference between the touchscreen and the TSAHI conditions. The figures were very similar, but once observed with the perspective that the 'overall duration' of the test (section 6.1.4) was significantly lower for the TSAHI. The results suggested that the participants took shorter glances while operating the TSAHI. This correlated with the results of the 'maximum glance duration'. This could have been caused by the information from the TSAHI being processed faster.

Being able to perceive information about an interface and lowering visual demand so attention can be given to the road thus spending less time looking away from the road environment, are attributes that are considered a lessening of distraction according to the definition of 'driver distraction': 'the diversion of attention away from activities critical for safe driving towards a competing activity' (section 2.1) (Young, Lee and Regan 2009).

Viewing the evidence through the critical lens developed throughout the thesis, it could be deemed that the results from the VISual Demand studies suggest that the TSAHI is an 'efficient' design that has the capability and potential to lessen driver distraction.

8.1.2 - LCT CONCLUSION (SAFETY)

It is only possible to suggest that the different interfaces had similar results during the lane change test. Further research that looked into the driving events in more depth, using a different method of evaluation with the Lane Change Test may uncover differences in the TSAHI's effect on safety in comparison to touchscreens

8.1.3 - UX CONCLUSION (SATISFACTION)

The User eXperience results were mixed. The Raw NASA TLX results (section 6.3.1) were inconclusive. However, an observation could be made that as a general trend, the mental demand results tended to be higher and the physical demand results were lower.

The SUS showed similarities between the TSAHI and the touchscreen conditions (section 6.3.2). Further analysis indicated that when the benchmark was considered, more participants found the TSAHI to be above average, in comparison to the touchscreen.

The Attrakdiff results (section 6.3.4) were mixed, suggesting that there was a high level of satisfaction in the Hedonic qualities of identification, as it satisfied 'be-goals' that are neccasary to to perfect one's skills and knowledge. Although the TSAHI fared less well in terms of attractiveness and stimulation qualities, it proved slightly more satisfying than the other interfaces in terms of pragmatism factors.

8.2 - METHODOLOGY AND PRACTICE

The design methodology used throughout this study is an extension of the practice that is taught throughout universities and practiced in automotive studios. Unfortunately, the lack of detailed academic documentation about studio processes makes it difficult to make a direct comparison. Literature such as 'How to Design Cars Like a Pro' by Lewin (2010) describe the process of drawing and the creation of models. The process of tried and tested iterative studio methods are also well documented, as noted in section 3.4. However, the process of in-house testing to the extent achieved in this thesis is not a normal occurrence, as testing is conventionally the responsibility of relevant ergonomics departments, companies or consultants. The positive results of this study suggest that there may be be an advantage in having in-house standardised Vis-D testing facilities that would allow designers to engage with rapid testing and development on an accurate scale, with results and design decisions that are evidence based. Admittedly it is a longer and more expensive process, but it is superior. It should be noted that a lack of formal training for practitioners may however be a barrier to achieve this.

8.3 - IMPLICATIONS ON FUTURE DESIGNS

This study was an exploration of theoretical ideas about TSAHI. It is important that one does not become deluded or convinced that it serves as a pre-production prototype for manufacture. It was created as a tool that would allow the researcher to extract knowledge about theoretical ideas as stated in section 3.4.

The research conducted serves as proof of concept. However, from a wider perspective there are other implications. In section 2.3.2 showing and hiding devices were discussed mainly in a theatrical perspective as this, to date, has been the focus

of this function. The Nissan IDS was exemplified as a vision of the future that proposes movable interior panels, controls and seating in an autonomous vehicle. But many other Original Equipment Manufacturers, (OEMs), are planning autonomous vehicles like this. The Volkswagen's I.D Buzz, Mercedes' F 015 (2015), Chrysler's Portal (2017), Volvo's concept 26 (2015), EVE's NIO are further examples. Global automotive interior suppliers and tier 1 companies also envisage concepts such as Yanfeng's XiM18, Faurecia's morphing instrument panel and Continental's Cockpit Vision. Suggesting that:

"technologies use integrated electronics, mechatronics, smart surfaces and new materials for a life on board experience including an adaptable interior" (Faurcia 2017),

"During automated driving, for example, certain controls and displays will remain hidden. They will become visible and accessible when requested" (Continental 2017).

Without a doubt, the transformable interiors that show and hide functions are an important factor of future automated vehicles up to level 3 and parts of level 4 of the SAE J3016 taxonomy and definitions seen in figure 8.1.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)
Human driver monitors the driving environment						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	System	Human driver	Human driver	Some driving modes
Automated driving system ("system") monitors the driving environment						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	System	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	System	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	All driving modes

Figure 8.1: SAE J3016 (2014) summary of international levels of driving automation for on-road vehicles.

This study shows that hideaway interfaces can not only create comfortable vehicle interiors but also interiors that are efficient to use, supporting screens and reducing any distractions.

8.4 - CONTRIBUTIONS TO KNOWLEDGE

The results of this thesis build on work completed by researchers in the field of automotive interface design for visual distraction, with an additional level of interest in terms of understanding how a show and hide interface can decrease levels of visual distraction. The field of show and hide interfaces is relatively new, as during the literature review, no relevant studies could be found, therefore this knowledge is in itself a pioneering study.

The contributions to knowledge are as follows:
- A set of core studies and interviews with expert practitioners
- Formalisation of design principles and focus on a tactile, show and hide approach (novel in the automotive context) aimed towards automotive manufacturers, educative establishments and designers in a studio environment to help bridge the gap between design and ergonomics and to direct the future of automotive design.
- The documented development of a very low-cost driving simulator that complied with ISO, JAMA, and NHTSA regulations with the implimention of the standardised lane change task. The simulator also has an added advantage in that it can be used in any design studie because of the accurate but simplified nature of the build.
- A rationale for a radical mixed methods approach to evaluation giving practitioners an alternative to the usual incremental methods.
- A worked example of the Tactile Show and Hide Interface - taking readers through the design concept and development.
- An explicit experimental format following ISO best practice that can be replicated by practitioners.
- A critical review of a successful approach to tackling the design of interfaces that aim to lower visual demand.
- Recommendations for further work regarding the design of interfaces that lower driver demand.

8.5 - FUTURE WORK

CONTEXT OF AGE

It was discovered that the TSAHI was more favourable for different age groups. It was concluded that it was more appropriate for older age groups compared to the touchscreen. With a larger participatory group a clearer picture could be built around the effect of age on TSAHI usage.

It should be noted that although the quota of participants requirement were met in the evaluation, several participants from the older age groups dropped out leaving the researcher to find new participants to replace them. Park et al (2006) and Brooks, et al (2010) also note sickness and drop-outs for older drivers and suggest older participants had a greater likelihood of simulator sickness than younger participants. Several of the participants who dropped out from this study disclosed that they couldn't continue due to headaches, and nausea. There are guidelines for conducting simulator studied on older participants. Domeyer, Cassavaugh, and Backs (2013) recommend adaption to overcome simulator sickness.

AESTHETICS OF THE TSAHI

Further studies need to be conducted to understand the best aesthetic form for a TSAHI. Further studies would also help create a more positive experience for the end user.

DESIGN PRINCIPLES

The best presentation format for the principles needs to be investigated. In their current format the prinicples are only guidelines. Bruseberg and McDonagh-Philp (2000) noted that 'most designers regretted that they lacked information but found that traditionally long-winded research is often seen as "too difficult to interpret"'. For the principles to have potential within the design community the format needs to be changed. Bruseberg and McDonagh-Philp comment that visual stumuli would be more effective. Further research needs to be completed on the best way to present these principles to students and professionals in the design industry.

Many of the participants' comments indicate that the design principles were appropriate in the tactile interaction questionnaire, however the discussions in section 7 indicate that they need to be optimised and refined. It is evident that the level of guidance in the principles, human expectations and aesthetics are all crucial factors that must be considered to attain their best results for use. The following areas were identified as useful start points for refinement:

Amplification principle

Understand what the optimium height of a tactile edge is would add further precision to the principle.

Hyperbole principle

The participants felt the aesthetics of the tactile controls had low appeal. This affected the UX scores. Further research in aesthetic for spacing the controls would add further guidance to the hyperbole principle.

Simplicity principle

It was commented that the effect of showing and hiding controls minimises choice. This was the aim of the orginal hypothesis. Further research into this effect with a larger participant group would help provide an understanding of how to best achieve this with simplicity.

Best attribute for touch principle

Further research needs to be completed to detail the most effective surface finishes that should be used for a TSAHI.

Mind/hand calibration principle

The results were above average for this principle. With further analysis it was established that there were linkages between the principles and the prerequites necessary to create optimal mind/hand calibration on the TSAHI interface. Further research is needed to understand the mechanisms of linkages, understand what principles can be missed out without causing a detrimental effect, whether all of the factors have been uncovered and finally any order of hiarachy among the principles.

Similar to the simplicity principle it was suggested that because the mind/hand calibration was good in the TSAHI, this made it superiour to a tactile only interface. Further research with a larger group would validate this claim.

Mapping principle

The work of Kovacs and Julesz (1993) suggested that landmarks are created by closed contours. A comparative experiment with open contours would help build knowledge of how well this idea would work in detail with a TSAHI.

CONTEXT OF MANUFACTURING

The TSAHI design was created as a tool that would allow the researcher to extract knowledge about theoretical ideas as stated in section 3.4. This was a primary aim of the thesis, indicated in section 1.2. The discussion about limitations of the study in section 7.1 point out that manufacturers traditional invest a high amounts of resource to gain clarity in terms of user experience. A detailed assessment of the TSAHI design in relation to a manufactured interface, possibly with increase resources, would be a useful next step. This would help to clarify feasibility and further define understanding of a TSAHI.

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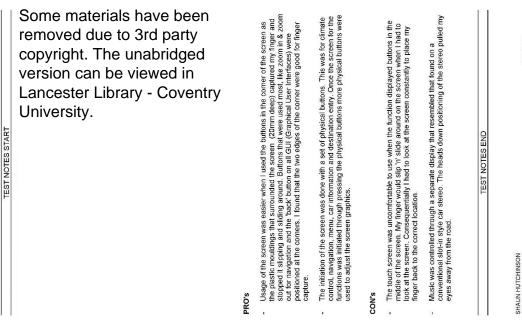
APPENDIX 1

APPENDIX 1.1 - TEST-DRIVES

TEST NOTES START
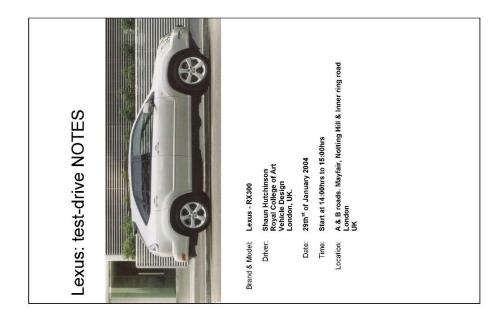
PRO's

- The Dual screen option meant that I had a choice if was to access information, with a standard speed check glance at the display between the speedometer and tachometer or at the main screen. I felt that the surrounding effect worked very well.

- CD, Radio, Telephone were usable without the main screen after pressing the function button. I could see the relevant information through the display between the speedometer and tachometer. I didn't need to use the MMI knob. I could also use the steering wheel controls.

- Climate control controlled by displaying information in an analogue fashion with graphics. The main screen was also used, a very simple 'cut-in' screen on the main display showed a knob with numbers. Overall the experience of using the air conditioning was good, un-confusing and simple.

CON's

- The MMI could use some BMW style electromagnets to give haptic information about the number of function used with the knob. Also to tell the driver when they had reached the start and end of a menu (knob stops turning at the end and start of the knob turning). I found myself twirling the knob for a good while before I realised that the main screen menu wasn't moving in the scroll option.

- Could feel around the buttons but I felt that I would bump into the rotary controller, hence all of my actions were completed with high caution and consequentially found that I need to look at the button to gain rough map of where the functions where.

- I had to look at the screen to use; the setup functions, car dynamics, computer manual & navigation (navigation could be used without the screen but only after setting it up initially through the main screen). Swerving on the motorway occurred as a result.

Audi: test-drive NOTES

Brand & Model: **Audi A8 - TDI 4.0 litre Quattro**

Driver: **Shaun Hutchinson**
Royal College of Art
Vehicle Design
London, UK.

Date: **31st of January 2004**

Time: **Start at 11:30hrs to 13:30hrs**

Location: **Wimbledon A & B roads in London City.**

APPENDIX 1.1 - TEST-DRIVES

TEST NOTES START

PRO's

- The haptics of the iDrive knob helped the usage of the screen as the knob would put up some resistance when it reached the end of the scroll menu so that I didn't sit there twiddling the knob forever. Consequentially, I felt that I could give the road more viewing time as I could feel what was happening.

- Conventional physical knobs were used to adjust the climate control after I had initiated the function using a nudge from the iDrive knob and had twisted it to select the where I was going to adjust (Foot-well, Centre, Window, etc). It was kind of a relief to get back to controls I could feel. A combination of this type of thing with the rest of the functions could maybe make the usage of the other functions easier.

CON's

- So many words in the screen. In the time that I had with the car I didn't get to use the CD properly as I was trying to make the climate control work through the screen (The sales person had to adjust it in the end). For example the temperature I eventually adjusted was in small text at the bottom of the screen mixed amongst other information.

- I spent a long time looking at the screen. Characteristically, of this class of car, it near enough drove itself. This meant that I didn't have to concentrate on the task of driving (gearing up and down, etc.) and could concentrate on the task of using the screen. This is probably a dangerous attribute, as one's awareness of the outside world in relation to the car would lower in such and instance. If the same system was in a car that didn't near enough drive itself I don't think that I would have been able to use the screen so well.

- Tracking through the functions and menus was hard work and complex. I felt lost at times. The only thing that I could do when this happened was nudge the knob to take me back to the beginning. When this happened I felt that all my hard work was lost and that I had to track through the mass of words to get back to the area again. (The Audi A8 did much better I always knew where I was in the Audi A8 as the high use of simple, big graphics meant that I could recognise the functional areas well.)

SHAUN HUTCHINSON

PAGE 2

BMW: test-drive NOTES

Brand & Model:	BMW 7 Series Saloon 730d
Driver:	Shaun Hutchinson Royal College of Art Vehicle Design London, UK.
Date:	10st of February 2004
Time:	Start at 15:30hrs to 16:15hrs
Location:	Golders Green A & B roads, North Circular in London City.

SHAUN HUTCHINSON

PAGE 1

APPENDIX 1.1 - TEST-DRIVES

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

PRO's

- Usage of the screen was easier when I used the buttons in the corner of the screen as the plastic mouldings that surrounded the screen (20mm deep) captured my finger and stopped it slipping and sliding around. Buttons that were used most, like zoom in & zoom out for navigation and the 'back' button on all GUI (Graphical User Interfaces) were positioned at the corners. I found that the two edges of the corner were good for finger capture.

- The initiation of the screen was done with a set of physical buttons. This was for climate control, navigation, menu, car information and destination entry. Once the screen for the functions was initiated through pressing the physical buttons more physical buttons were used to adjust the screen graphics.

CON's

- The touch screen was uncomfortable to use when the function displayed buttons in the middle of the screen. My finger would slip 'n' slide around on the screen when I had to look at the screen. Consequentially I had to look at the screen constantly to place my finger back to the correct location.

- Music was controlled through a separate display that resembled that found on a conventional slot-in style car stereo. The heads down positioning of the stereo pulled my eyes away from the road.

SHAUN HUTCHINSON

PAGE 2

Lexus: test-drive NOTES

Brand & Model: **Lexus - RX300**

Driver: **Shaun Hutchinson**
Royal College of Art
Vehicle Design
London, UK.

Date: **29thst of January 2004**

Time: **Start at 14:00hrs to 15:00hrs**

Location: **A & B roads. Mayfair, Notting Hill & inner ring road**
London
UK

SHAUN HUTCHINSON

PAGE 1

Mercedes: test-drive NOTES

Brand & Model: **Mercedes-Benz, S-Class 320 CDI Saloon**

Driver: **Shaun Hutchinson**
Royal College of Art
Vehicle Design
London, UK.

Date: **26th of February 2004**

Time: **Start at 14:00hrs to 15:00hrs**

Location: **North Circular, A40 in London City, UK.**

TEST NOTES START

PRO's

- Buttons activated the screen of desired function so haptic recognition can be used. To get to a function from another simply press and the function cuts in over the last one.

- My last commands are always remembered by the computer so that if I cut into another function, when I go back to the old function things looked familiar.

- The climate control was not controlled by the screen. The button that controlled the climate control were very good actually. The buttons afforded the functions in the climate control sub-system in a verbally metaphoric way (Push the button down and the temperature went down and visa-versa).

CON's

- In certain cases the buttons were too close to each other and too similar. This meant that I had to spend time looking at the button to locate and press the button as I could have easily pressed another if I didn't look.

- The screen was in a head down position. Using the screen pulled my eyes away from the road as I had o look down a lot. A lot of the functions were controlled by singular buttons (e.g. The radio function used the numeric keypad).

- The screen used a lot of words. Although they large sized words - making them better than the BMW 7-Series screens – The use of words made operation of the screen long winded. This meant that my eyes were off the road while I had to read the text. I think the S-Class screens were not as successful as the Audi A8's that used big graphics.

APPENDIX 1.1 - TEST-DRIVES

Nissan: test-drive NOTES

Title:	**Nissan Primera Test Drive**
Brand & Model:	**Nissan Primera SE**
Driver 01:	**Shaun Hutchinson** **Royal College of Art** **Vehicle Design** **London, UK.**
Driver 02:	**Jussi Timonen** **Royal College of Art** **Vehicle Design** **London, UK.**
Date:	**5th of june 2003**
Time:	**Shaun: 8 hours in total in day & night conditions** **Jussi: 4 hours in total in day conditions**
Location:	**A & B roads, M25 in London City.**

TEST NOTES START

PRO's

- The screen graphics were simple and easy to see. I thought this was good and it made them easy to understand. All the main functions that were active were on the one screen in the model I used. I.E.: Air conditioning, radio, CD. This made it slightly hard to work out where thing were. Even so the simple colour co-ordination (Yellow for radio, Green for air conditioning, etc.) compensated for this I think.

- The cut-in screen for the reverse parking function was good. It appeared and disappeared on a need to know basis (when you put the car in reverse gear).

- Over the 8 hour I got to know the controls quite well. 6 hour or so I knew where the button and dials were and felt that I could the interface with confidence. Reach times to a function reduces. I attribute this to the fact that I could rely on Haptic (sensation of position and movement and touch) knowledge instead of visual knowledge of the control area.

CON's

- Although I got a good sense of Haptics to control the functions I still had to look at the screen to ensure that I was making completing correct steps (pulling my eyes away from the road).

- The screen interface reset itself when it wasn't used after a certain amount of time (about 30 sec.) I found this very annoying and it force me to start again if I had to pull my attention away from the screen to go around a busy round about for example.

- In general my subject - Jussi Timonen - reported that using the screen reduced his reaction time by half and that he felt a loss of control (incidentally later Jussi nearly crashed while using the screen). After performing the task of tuning the radio Jussi self-witnessed that it needed "maybe 75% of my attention". When asked if he looked at the screen more than the road he replied yes.

- I found that by the end of the 8 hours I was accustomed to the basic controls but found that, especially on motorways, my ability to steer the car in a straight line lowered when I used the interactive screen. I fell out of my lane several times because of this.

APPENDIX 1.1 - TEST-DRIVES

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Alpine: test-drive NOTES

Brand & Model:	**Alpine Touchpulse** ™
Tester:	**Shaun Hutchinson** **Royal College of Art** **Vehicle Design** **London, UK.**
Date:	**10ˢᵗ of February 2004**
Time:	—
Location:	**Willesden green B roads.**

TEST NOTES START

PRO's

- The screen clicks when you press a particular button. I found this good as I knew when I had pressed a button.

- The screen also makes a clicking sound to enhance the feeling of pressing a button.

- The buttons areas were large, as seen above, when you eventually got to them.

CON's

- Getting to certain areas was a nightmare. Some many words and graphics everywhere. When I first got into the car I had no idea of how to use it. The sales person had to do most of it. It was so complex that I just couldn't imagine where half the functions were.

- The screen makes a clicking pulse every time you touch the screen, where ever you touch it. If made a bigger clicking noise/pulse when you actually pressed something, but it was still bloody well confusing.

- Primarily it is still a screen interface tweeked a bit to make it a bit more touch worthy. As a result I still looked at it a lot. Using it without vision was v-hard.

TEST NOTES END

APPENDIX 1.2 - HUTCHINSON, TIMONEN (2003)

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APPENDIX 2

APPENDIX 2.1 - ASSMANN, BANGLE, KÜNZNER (2003)

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APPENDIX 2.1 - ASSMANN, BANGLE, KÜNZNER (2003)

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APPENDIX 2.6 - MELVILLE (2005)

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APPENDIX 2.8 - SUMMERSKILL (2005)

From: "Steve Summerskill" <S.J.Summerskill2@lboro.ac.uk>
Subject: **RE: BIONIC contact (from: shaun hutchinson)**
Date: 10 October 2005 11:53:11 BST
To: "'Shaun Hutchinson'" <shaun.hutchinson@alumni.rca.ac.uk>

Hey Shaun,

One of the aims of the simulator trial was to evaluate the tactile coding of the design. In order to familiarise the users the first part of the SIM trial didn't use the simulator. Instead, participants were asked to perform a series of tasks such as "turn on the cd player and select track 6. They then pushed the control that they thought was appropriate. If they made a mistake they were corrected. The next part of the simulator trial required the user to follow a white van at a safe distance in the simulator, and again they were given tasks to perform. At this point (half an hour in) they were asked to do the same again but with a piece of cardboard hiding the interface, still allowing the hand to reach and explore all controls. We got an accuracy rate of around 80-85%. In other words, after half an hour and with no vision, the users could find 80% of the controls using the tactile coding. Video of the mistakes made in the no vision condition helped to refine the tactile coding. Obviously we were not trying to predict IF users would use the controls non visually, we just trying to improve the tactile coding at that stage in the design process.

Hope that helps.

Best regards,

Steve Summerskill
Design Ergonomics Group
Department of Design and Technology
Loughborough University
Leics LE11 3TU
UK
Tel: +44 (0)1509 228313
Fax: +44 (0)1509 222668

-----Original Message-----
From: Shaun Hutchinson [mailto:shaun.hutchinson@alumni.rca.ac.uk]
Sent: 06 October 2005 17:58
To: Steve Summerskill
Subject: RE: BIONIC contact (from: shaun hutchinson)

hi steve

I have finally finised the paper you gave to me. Nice...

I have a request, i hope that you can help me. In the paper it said that you completed sim tests without visual restriction (no poncho). Could you possiblly some further transparency on this area. My tests are performed without visual restriction (freewill approach). I really need to find out if i'm upto the old loughbourough standard. If i'm not need to redo my work to ensure i have a good ergonomic standard.

BEST WISHES,

SHAUN HUTCHINSON (rca)

(P.S.: If you see Dr. Gary Burnett can you please thank him for his help with the handrighting experiments, Thanks)

-----Original Message-----
From: Steve Summerskill [mailto:S.J.Summerskill2@lboro.ac.uk]
Sent: Wed 07/09/2005 16:25
To: Shaun Hutchinson
Subject: RE: BIONIC contact (from: shaun hutchinson)

Dear Shaun,

Here is the link

http://ewic.bcs.org/conferences/2005/accessible/session4/paper2.htm

Steve Summerskill
Design Ergonomics Group
Department of Design and Technology
Loughborough University
Leics LE11 3TU
UK
Tel: +44 (0)1509 228313
Fax: +44 (0)1509 222668

-----Original Message-----
From: Shaun Hutchinson [mailto:shaun.hutchinson@rca.ac.uk]
Sent: 11 May 2005 19:11
To: Steve Summerskill
Subject: RE: BIONIC contact (from: shaun hutchinson)

Hi Steve

As promised I have attached a flyer to this mail. I agree, it's good to
talk about this stuff. I'm based in Birmingham at the moment (i've taken
some time off to care for my mother) so I don't see much of the RCA
studio's myself. Even so, I could pop over to Loughbourough and we could
talk. Suggest a date and i'll check my diary.

Best regards,

shaun

[p.s.: send my best to sam porter, she used to guide me through the
world of ergonomics when i was at coventry university you know:-)

-----Original Message-----
From: Steve Summerskill [mailto:S.J.Summerskill2@lboro.ac.uk]
Sent: Mon 5/9/2005 12:19
To: Shaun Hutchinson
Subject: BIONIC contact

Hey Shaun,

It's really interesting to have someone to talk about this stuff. I
would like to meet up and have a talk over our material. Maybe just a
visit is in order as I have not been to the RCA before. I can happily
talk about BIONIC using the presentations I have so if you think there
might be interest from your colleagues I am happy to talk to a group.
Let me know what you think. Looking forward very much to seeing the
flyer!

Sam Porter passes on her regards (her husband Mark was the BIONIC
supervisor)

Cheers,

Steve Summerskill
Design Ergonomics Group
Department of Design and Technology
Loughborough University
Leics LE11 3TU
UK
Tel: +44 (0)1509 228313
Fax: +44 (0)1509 222668

APPENDIX 2.9 - AUDIT OF SCREEN USE IN 2004

	With in-screen controls *(optional)*	With in-screen controls *(standard)*	With physical controls *(optional)*	With physical controls *(standard)*
Aston Martin	x	x	DB7 & Vanquish (Nav)	x
Audi	x	x	(Nav)	A8 (Multi)
Bentley	x	x	x	GT Continental (Multi)
BMW	x	x	3 Series (Nav)	1, 5, 6 & 7 Series (Multi)
Citroen	x	x	C2, C3, C5, C8, Xsara, Saxo, (Nav)	x
Chrysler	x	x	Voyager (Multi)	x
Daewoo	x	x	Matiz, Kalos, Toccoma, Nubria (Nav)	x
Daihatsu	x	x	x	x
Fiat	x	x	Stello, Punto, Ulyssee (Multi)	x
Ford	Mondeo (Multi)	x	Focus, Galaxy, Mondeo, C-max (Multi)	x
Ferrari	x	x	x	x
Honda	x	Accord (Multi)	Civic & CVR (Multi)	x
Hyundai	x	x	x	x
Isuzu	x	x	x	x
Jaguar	X-Type, S-Type, SJ (Multi)	x	XK8 (Multi)	x
Jeep	x	x	Cheriokie (Nav)	x
Kia	x	x	Rio, Carrens, Magentis, Sedona, Serento (Multi)	x
Lamborghini	x	x	Marcielago (Nav)	x
Lancia	continental sales only	continental sales only	continental sales only	continental sales only
Land Rover	x	x	Discovery (Nav) & Range Rover (Multi)	x
Lexus	GS, IS Range (Nav) & RX300 (Multi)	LS430 & SC430 (Nav)	x	RX300 (Multi)
Lotus	x	x	x	x
Maserati	x	x	4200	x
Mazda	RX8	x	Mazda 6 (Multi)	x
Mercedes	x	x	A, C, E, CL, CLK, SL, SLK & ML - Classes (Multi)	S - Class
Mini	x	x	Cooper, Cooper S, One , One D (Nav)	x
Mitsubishi	x	x	Showgun, Crisma	x
Nissan	x	x	Primera, Almera, X-Trail (Multi)	x
Porsche	x	x	Boxster, Carrera, Cayenne (Multi)	x
Peugeot	x	x	307, 607, 807	x
Renault	x	x	Clio, Megane in 6-types, Laguna, Espace (Multi)	x
Rolls Royce	x	x	Phantom (Multi)	x
Rover	x	x	75	x
Saab	93 (Nav)	x	93 - Linear, Arch, Vector, Aero (Multi)	x
SEAT	x	x	Leon, Alhambra, Toledo (Multi)	x
Skoda	x	x	Superb, Fabia, Octavia (Multi)	x
Smart	x	x	x	x
Subaru	x	x	Legacy (Multi) - to be released in 2004	x
Suzuki	x	x	x	x
Toyota	x	x	Yaris, Corolla, Avensis, Rav4, MR2, Celica, Land Cruiser, Amazon, Previa, Camry (Multi)	x
Vauxhall	x	x	Astra, Vetra, Signum, Omega, Zafira	x
Volkswagon	x	x	Golf, Sharon, Toureg, Phaton, Passat, Bora (Nav)	x
Volvo	x	x	S40, V50, V70, S60,S80,XC90, XC70 (Multi)	x

Forty-three European manufacturers and the type of screen that is used in the vehicle interior in 2004

APPENDIX 3

APPENDIX 3 - GUI SCREEN PILOT RESPONSES.

Pros	Cons
• USB/MP3 is straight forward. No need to look at the list and select through it. • Response time is good. • Nice clear layout – easily understood the format. • Representation of fan speeds are really good.	• Would prefer to have the albums as a list or something like that not only scrolling through a cascade. • May wish to consider the buttons changing colour as I press them so I have a feedback of the response. Hold down on button for incremental tasks like volume. It would be good to see all parameters at a glance, like home screens.

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Photo: Durable touch screen used in pilot runs and eventually in the final touchscreen demonstrator.

APPENDIX 4

APPENDIX 4.1 - CONTROL TYPE REVIEW - BODY STORMING

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APPENDIX 4.1 - CONTROL TYPE REVIEW - BODY STORMING

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APPENDIX 4.1 - CONTROL TYPE REVIEW - BODY STORMING

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APPENDIX: 4.2 - CONTROL TYPE REVIEW – NOTES

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

1.0(a) press buttons:
Closed clustering with flat form

- Location: Can be located everywhere

- Actions of usage: Single. Making physical co-ordination simple.

- Speed of use according to Pheasent (1986): Very Good

- Touch: Reactive with touch 'clicks'

- Reach: Bad. The lack of gaps between the buttons mean that a driver can't use the sense of touch discriminate one button from another. Klatzky, Loomis, Lederman, Wake & Fujita (1993) noted that the success rate of small detail approx 1mm has a low success rate of haptic recognition of 31%. This attribute was very noticable in the Lexus test vehicle seen left, making the use highly visual. The lack of gaps between the buttons also means that this option does not acheive 'blind reach' as specified by pheasent, 1986.

1.0(b) press buttons
Closed clustering with 3D form

- Location: Can be located everywhere

- Actions of usage: Single. Making physical co-ordination simple.

- Speed of use according to Pheasent (1986): Very Good
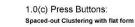
- Touch: Reactive with touch 'clicks'

- Reach: Bad. In tests of the mercedes (as seen in left hand photo) i found that the 3d forms helped general location of the interaction area. The lack of gaps between the buttons mean that a driver can't use the sense of touch discriminate one button from another. Klatzky, Loomis, Lederman, Wake & Fujita (1993) noted that the success rate of small detail approx 1mm has a low success rate of haptic recognition of 31%. The lack of gaps between the buttons also means that this option does not acheive 'blind reach' as specified by pheasent, 1986.

1.0(b) Press Buttons:
Closed clustering with 3D form (cont'd)

Further sketch development showed that there are a variety of configurations for this option.

○ Work completed by Lederman & Klatzky notes that noted that coarse detail or information extracted by touch during the participant's initial brief contact is used to guide hypotheses about the object's identity, which, in turn, guides subsequent Exploratory Procedures' (EP) for obtaining more precise information about desired properties (Lederman & Klatzky 1997: p.1705). The raised sides of this option is a coarse contrast to it's flat surrounding. out of the option how I beleive this would be most successful fo haptic recognition.

Footnote

[1] When a person aims to identify an object using the hands, on f rst contact they extract information using stereotypical hand movements. These 'hand movements are called exploratory procedures, 'EP' when abbreviated. The EP acts like a perceptual gateway to an objects properties. (Klatzky, Lederman & Reed, 1987. Klatzky & Lederman 1995)

1.0(c) Press Buttons:
Spaced-out Clustering with flat form

- Location: Can't fit the blind reach (100mm spaces between buttons) version on steering wheel and the side door is a cramped for space but a normal (seperations of 50mm Pheasent 1986, p.236, table 17.2) one would. The steering wheel sketch below details this.

- Actions of usage: Single, (Press)

- Speed of use according to Pheasent (1986): Very good

- Touch: Reactive with 'clicks' and/or friction.

- Reach: Good
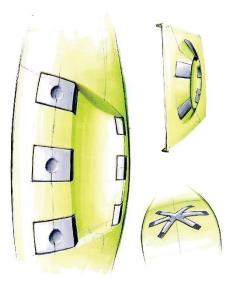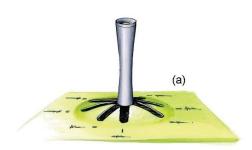
1.0(d) press buttons:
spaced-out clustering with 3D form

- Location: Can't fit the blind reach (100mm spaces between buttons) version on steering wheel and the side door is a cramped for space but a normal (seperations of 50mm Pheasent 1986, p.236, table 17.2) one would.

- Actions of usage: Single, (Press)

- Speed of use according to Pheasent (1986): Very good

- Touch: Reactive with 'clicks' and/or friction.

- Reach: Good

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(a)

(b)

2.0 Joystick:
eight-point compass
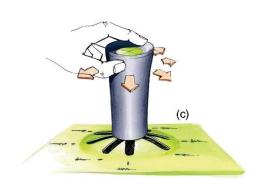
(a) - Long, slim handle
(b) - Short, slim handle
(c) - Long, wide handle
(d) - Short, wide handle

- Location: The long handles (a & c) make positioning of this control in an interior hard. they can obscure primary parts of the driving environment. An example being: a long joystick on a cieling would obscure the rear veiw mirror. If it was on the steering wheel it would obscure the turning. The side doors were feasable but the long joystick could catch on clothes easily. The short handles were better, but still had problems with slight obscuration of operation when they were placed on the steering wheel.

- Actions of usage: **Dual, (grasp, move)**

- Speed of use according to Pheasent (1986): **Good**

- Touch: **Reactive with 'clicks' and/or friction.**

- Reach: **Good.** Initially very good as the start point is always in the same position. Reach to a function becomes harder if the joystick travel is small.

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(c)

(d)

A small travel joystick can be seen in the photo of the nissan test vehicle seen on this page. If the travel is extended, the location of the control is less flexible as the area of usage becomes bigger.

(a)

(b)

(c)

(d)

2.1 Joystick:
Slide Switches

(a) - Long, slim handle
(b) - Short, slim handle
(c) - Long, wide handle
(d) - Short, wide handle

- Location: Like the 8 point compass, the long handles (a &c) make positioning of this control in an interior hard. They can obscure primary parts of the driving environment. An example being: a long joystick on a cieling would obscure the rear veiw mirror. If it was on the steering wheel it would obscure the turning. The side doors were feasable but the long joystick could catch on clothes easily. The short handles were better, but still had problems with slight obscuration of operation when they were placed on the steering wheel.
- Actions of usage: **Dual, (grasp, move)**

- Speed of use according to Pheasent (1986): **Good**

- Touch: **Reactive with 'clicks' and/or friction.**

- Reach: **Good.** Initially very good as the start point is always in the same position. Reach to a function becomes harder if the joystick travel is small.

2.2 Joystick:
Off-set notches

(a) - Long, slim handle
(b) - Short, slim handle
(c) - Long, wide handle
(d) - Short, wide handle

- Location: Like the 8 point compass, the long handles (a &c) make positioning of this control in an interior hard. They can obscure primary parts of the driving environment. An example being: a long joystick on a cieling would obscure the rear veiw mirror. If it was on the steering wheel it would obscure the turning. The side doors were feasable but the long joystick could catch on clothes easily. The short handles were better, but still had problems with slight obscuration of operation when they were placed on the steering wheel.

- Actions of usage: **Dual, (grasp, move)**

- Speed of use according to Pheasent (1986): **Good**

- Touch: **Reactive with 'clicks' and/or friction.**

- Reach: **Good.** Initially very good as the start point is always in the same position. Reach to a function becomes harder if the joystick travel is small.

(a)
(b)
(c)
(d)

(a) bad
(b) good
(c) bad
(d) okay

3.0 Rotary switchs

- Small, medium & large
- Continuous & incrimental rotation

Small rotary slide swithes (a) are hard to use as the handle is to close to the pivot, thus the user has a small amount of leverage. Big rotary slide swithes - that have bigger leverage - are a better option for usage.

AIR
CD
RADIO
TEL

3.0(a) Rotary switch:
Small to medium size, continuous rotation

- Location: **Can** *physically* **be placed everywhere. But there** problems when the hand - not the control - started to obscure the mirror in a body-stroring test. The medium sized rotary switch would also obscured the use of the steering wheel.
- Actions of usage: **Triple, (grasp, turn, press)**

- Speed of use according to Pheasent (1986): **Fair**
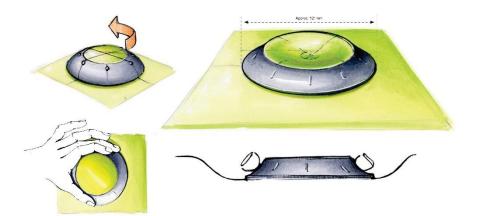
- Touch: **Reactive with 'clicks' and/or friction.**

- Reach: **Good.** As the knob gets smaller the distance between the functions gets smaller. and there for reach effectiveness will decrease.

3.0(b) Rotary switch: Large size, continuous rotation

- Location: **Can't be placed everywhere, obstructs air bag when placed on the steering wheel and will just about fit on a side door in a horizintal position. Hand would cause mirror obstruction if placed on the ceiling.**

- Actions of usage: **Triple, (grasp, turn, press)**
- Speed of use according to Pheasent (1986): **Fair**
- Touch: **Reactive with 'clicks' and/or friction.**
- Reach: **Good.**

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

3.0(c) Rotary switch:
Small to meduim size, incrimental rotation
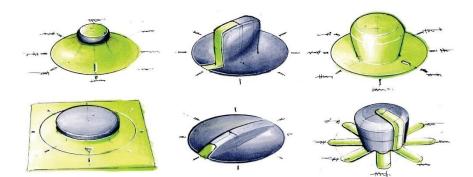
- Location: **Can be placed in most positions.**
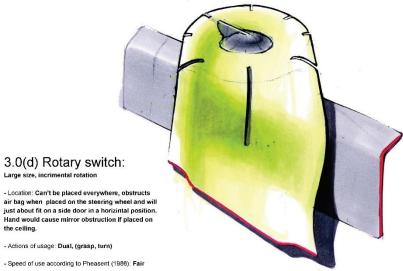
- Actions of usage: **Triple, (grasp, turn, press)**

- Speed of use according to Pheasent (1986): **Fair**

- Touch: **Reactive with 'clicks' and/or friction.**

- Reach: **Good.**

3.0(d) Rotary switch:
Large size, incrimental rotation

- Location: **Can't be placed everywhere, obstructs air bag when placed on the steering wheel and will just about fit on a side door in a horizintal position. Hand would cause mirror obstruction if placed on the ceiling.**

- Actions of usage: **Dual, (grasp, turn)**

- Speed of use according to Pheasent (1986): **Fair**
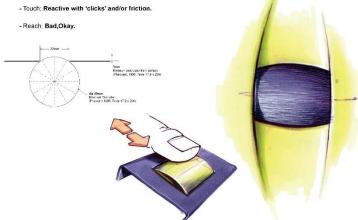
- Touch: **Reactive with 'clicks' and/or friction.**

- Reach: **Good.**

4.0 Thumb wheel: Large size, incrimental rotation

- Location: **Can be place everywhere**
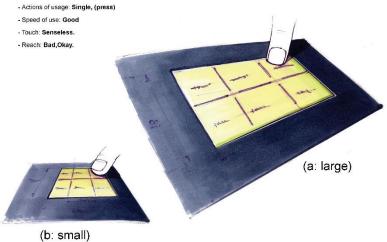
- Actions of usage: **Triple, (press, turn, press)**

- Speed of use according to Pheasent (1986): **Poor**

- Touch: **Reactive with 'clicks' and/or friction.**

- Reach: **Bad,Okay.**

5.0 (a & b) Flat touch button panel:

LCD & membrane
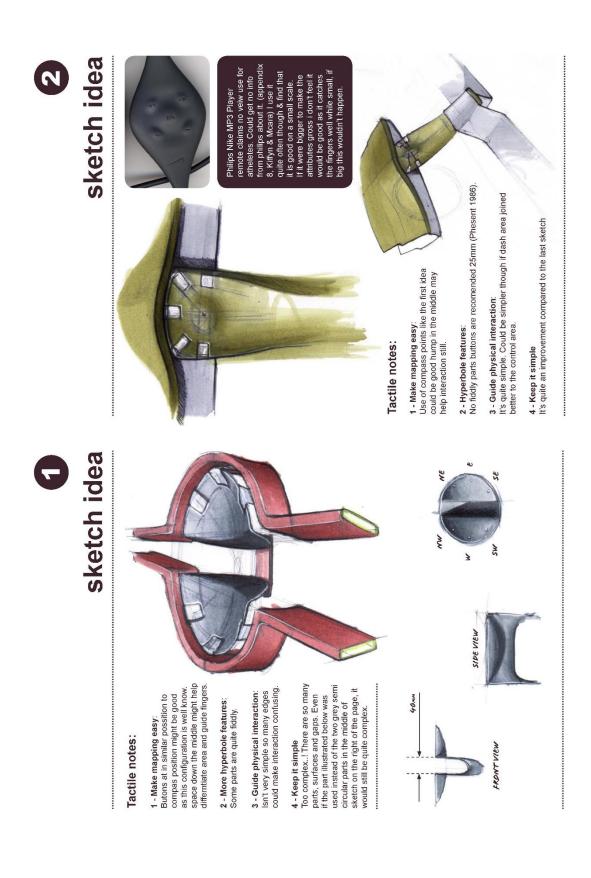
- Location: **The large panel would'nt fit on the steering wheel due to air bag obstruction**
- Actions of usage: **Single, (press)**
- Speed of use: **Good**
- Touch: **Senseless.**
- Reach: **Bad,Okay.**

(a: large)

(b: small)

APPENDIX 4.3 - CONTROL TYPE REVIEW – TABLE

Page 1 — Easy operation in Position / Actions of use / Speed of operation (Pheasent 1986)

	Item	Description	Scores from this page
LEXUS	1.0(a)	**Push Buttons** — Closed cluster with flat form	280
MERC	1.0(b)	Closed cluster with 3D form	280
	1.0(c)	Spaced-out with flat-form	240
AUDI, NISSAN	1.0(d)	Spaced-out with 3D form	240
	2.0(a)	**Joystick** — 8 point compass: Long, Slim handle	181
	2.0(b)	8 point compass: Short, Slim handle	201
	2.0(c)	8 point compass: Long, Wide handle	181
BMW	2.0(d)	8 point compass: Short, Wide handle	201
	2.1(a)	**Slide Switch** — Straight: Long, Slim handle	181
	2.1(b)	Straight: Short, Slim handle	201
	2.1(c)	Straight: Long, Wide handle	181
	2.1(d)	Straight: Short, Wide handle	201
	2.2(a)	Off-set notches: Long, Slim handle	181
	2.2(b)	Off-set notches: Short, Slim handle	201
	2.2(c)	Off-set notches: Long, Wide handle	181
	2.2(d)	Off-set notches: Short, Wide handle	201
	3.0(a)	**Rotary** — Small to medium with continuous rotation	183
	3.0(b)	Large with continuous rotation	143
	3.0(c)	Small to medium with incremental rotation	216
	3.0(d)	Large with incremental rotation	176
AUDI	4.0(a)	**Thumb wheel** — Thumbwheel	150
	5.0(a)	**Flat panel** — Large (width of an average hand)	235
	5.0(b)	Small (smaller that an average hand)	255

* Some thumb wheels double up as press buttons so that a driver can 'look-in' on a function that is on screen. The Audi A8 test car had this option to select the super-ordinate functions as well as the buttons.

† Flat panel displays - interactive LCD or Membrane (as found on microwave ovens) - were not assessed by Pheasent 1986, so my judgement is marked. Presume that vision is allowed.

Page 1

Page 2 — Touch / Reach (distance between functions) / Final scores

	Item	Description	Final scores
LEXUS	1.0(a)	**Push Buttons** — Closed cluster with flat form	360
MERC	1.0(b)	Closed cluster with 3D form	380 [3]
	1.0(c)	Spaced-out with flat-form	420 [2]
AUDI, NISSAN	1.0(d)	Spaced-out with 3D form	440 [1]
	2.0(a)	**Joystick** — 8 point compass: Long, Slim handle	321
	2.0(b)	8 point compass: Short, Slim handle	341
	2.0(c)	8 point compass: Long, Wide handle	321
BMW	2.0(d)	8 point compass: Short, Wide handle	341
	2.1(a)	**Slide Switch** — Straight: Long, Slim handle	281
	2.1(b)	Straight: Short, Slim handle	301
	2.1(c)	Straight: Long, Wide handle	281
	2.1(d)	Straight: Short, Wide handle	301
	2.2(a)	Off-set notches: Long, Slim handle	281
	2.2(b)	Off-set notches: Short, Slim handle	301
	2.2(c)	Off-set notches: Long, Wide handle	281
	2.2(d)	Off-set notches: Short, Wide handle	301
	3.0(a)	**Rotary** — Small to medium with continuous rotation	263
	3.0(b)	Large with continuous rotation	263
	3.0(c)	Small to medium with incremental rotation	316
	3.0(d)	Large with incremental rotation	316
AUDI	4.0(a)	**Thumb wheel** — Thumbwheel	258
	5.0(a)	**Flat panel** — Large (width of an average hand)	375
	5.0(b)	Small (smaller that an average hand)	315

** No gaps or many, many to choose from.

*** Approx 50mm apart.

**** Little choice or gaps greater than 100mm (Pheasent ,1986 discribes that the ideal separation distance between functions as 100mm – 150mm for blind operation).

Page 2

② sketch idea

Philips Nike MP3 Player remote claims no velw use for atheletes. Could get no info from philips about it. (appendix 8, Kiffyn & Mcara) I use it quite often though & find that it is good on a small scale. If it were bigger to make the attributes gross i don't feel it would be good as it catches the fingers well while small, if big this wouldn't happen.

Tactile notes:

1 - Make mapping easy:
Use of compass points like the first idea could be good hump in the middle may help interaction still.

2 - Hyperbole features:
No fiddly parts buttons are recomended 25mm (Phesent 1986).

3 - Guide physical interaction:
It's quite simple. Could be simpler though if dash area joined better to the control area.

4 - Keep it simple
It's quite an improvement compared to the last sketch

① sketch idea

Tactile notes:

1 - Make mapping easy:
Butons at in similar possition to compas position might be good as this configuration is well know. space down the middle might help differntiate area and guide fingers.

2 - More hyperbole features:
Some parts are quite fiddly.

3 - Guide physical interaction:
Isn't very simple so many edges could make interaction confusing.

4 - Keep it simple
Too complex...! There are so many parts, surfaces and gaps. Even if the part illustrated below was used instead of the two grey semi circular parts in the middle of sketch on the right of the page, it would still be quite complex.

40mm

SIDE VIEW

FRONT VIEW

NE

E

SE

NW

W

SW

sketch idea ④

The following sketches are variations of super-ordinate area seen on the sketch seen left

Tactile notes:

1 - Make mapping easy:
Uses compass points like the others, to make it easy to remember.

2 - Hyperbole features:
No fiddly parts, buttons are recomended 25mm (phesent 1986).

3 - Guide physical interaction:
Channel to interaction area could help guide.

4 - Keep it simple
Not bad, amount of edges makes it a bit complex though.

sketch idea ③

Tactile notes:

1 - Make mapping easy:
Uses compass points like the others, to make it easy to remember.

2 - Hyperbole features:
'C' looks to be the most fiddly with holes and knoteches. I thin 'A' is the most successful here. buttons are OK as a recomended 25mm width (Phesent 1986).

3 - Guide physical interaction:
'C' is the only idea that totally has a gutter catch or keep fingers from falling off the edge. 'B' has it only on the controll area and 'A' only in a little area in the centre. I think 'C' could be the most successful.

4 - Keep it simple
'A' is quite simple the convaced hump in the middle is the only thing that stops it being very simple. The same applies for 'B'. 'C' is too complex with all the holes and knotches. Removing the dash completely would make things even more simple, this does make it completely future focussed, manufacturers don't make cars with out dashboards at the moment as there area lot of components to be housed. this idea could make the project less versatile/valuable.

sketch idea 4

D

Tactile notes:

1 - Make mapping easy:
This option doesn't use compass points like the others.

2 - Hyperbole features:
The dots in the buttons are a bit fiddly, but the buttons are recomended 25mm (Phesent 1986).

3 - Guide physical interaction:
Channel to interaction area could help guide.

4 - Keep it simple
Not bad, the 'v' sectioned channel makes it a bit complex.

sketch idea 4

E

Tactile notes:

1 - Make mapping easy:
This option doesn't use compass points like the others. by the rubber part at the top could possibly indicate a datum point to orientate the driver useing it with no vision. good landmark maybe

2 - Hyperbole features:
Dots on buttons are a bit tiny, its has more surfaces than the others so it's bound to have small parts here and there. Buttons are recomended 25mm (Phesent 1986) though.

3 - Guide physical interaction:
Channel and inside edges could help guide hands to the interaction area.

4 - Keep it simple
Bit complex really, load of stuff going on here - diferent surfaces and parts.

sketch idea 4

B

Tactile notes:

1 - Make mapping easy:
Uses compass points like the others, to make it easy to remember.

2 - Hyperbole features:
No fiddly stuff except the lil hump in the middle. Buttons are recomended 25mm (phesent 1986).

3 - Guide physical interaction:
A channel to aid guidence to the interaction area.

4 - Keep it simple
Not so bad, lil hump in the middle and high amount of edges makes it a bit conplex though.

sketch idea 4

C

Tactile notes:

1 - Make mapping easy:
Uses compass points like the others, to make it easy to remember.

2 - Hyperbole features:
Buttons are recomended 25mm (Phesent 1986). The amount of different surfaces just makes areas small.

3 - Guide physical interaction:
Lots of channels to help guide interaction.

4 - Keep it simple
Most complex looking so far. The star formation in general is a bit extravagent in comparison to the other.

final sketch idea **5**

- bottleneck channel
- push buttons
- the bowl
- bottleneck channel

Best of the best tactile notes:

1 - Make mapping easy:
Use of compass points has been continuously used as i see no problem with it, why fix what ain't broke.

2 - Hyperbole features:
No fiddly parts buttons are recomended 25mm (phesent 1986). Humps, knotches and other such things have been vetoed.

3 - Guide physical interaction:
Channel to interaction area could help guide and bottle neck could help to catch fingers that don't aim totally accurately.

4 - Keep it simple
Out of all the shapes the circle has proven to be good for simplicity. In it's purest form the circular bowl has only one single edge and only one surface. Can you get much simpler...

sketch idea **4**

D

Tactile notes*:

1 - Make mapping easy:
Uses compass points like the others, to make it easy to remember.

2 - Hyperbole features:
Dots on the buttons area bit fiddly but buttons are recomended 25mm (phesent 1986).

3 - Guide physical interaction:
Channel to interaction area could help guide.

4 - Keep it simple
Bit complex.

E

Tactile notes*:

1 - Make mapping easy:
Uses compass points like the others, to make it easy to remember.

2 - Hyperbole features:
No fiddly parts buttons are recomended 25mm (phesent 1986).

3 - Guide physical interaction:
Channel to interaction area could help guide.

4 - Keep it simple
Bit complex. The circle shape is quite good though could be quite good if the hole was removed.

APPENDIX 4.5 - DESIGN STUDY - PACKAGE STUDY

APPENDIX: 4.5 - DESIGN STUDY - PACKAGE STUDY

Design Envolope: 150mm width
This measurment takes into account the sub-ordinate surfaces are next to seats that move. The actual (200) is reduced by 25mm each side to ensure parts don't rub and move each other.

Design Envolope: 300mm length between max reach and noramal grip of the 95% male.

95th & 5th%ile Bonnet line.
Parts of the interior that cross this line obstruct vision/reach

Visior cut off line: 15 degrees

Vision cut off line: 15 degrees

1 - max reach
2 - extended grip
3 - normal grip

- 5th %ile Female
- 95th %ile Male
- Physical Volume of the manipulable control panel
- Movement envolope of the control panel volume

B - curved

B - straight

d

Design Envolope: 300mm length between max reach and noramal grip of the 95% male.

Design Envolope: 150mm width
This measurment takes into account the sub ordinate surfaces are next toseats that move. The actual envolope (200mm) is reduced by 25mm each side to ensure parts don't rub and move each other.

95th & 5th%ile Bonnet line.
Parts of the interior that cross this line obstruct resolution

Vision cut off line: 15 degrees
Vision cut off line: 15 degrees

1 - max reach
2 - extended grip
3 - normal grip

■ - 5th %ile Female
■ - 95th %ile Male
■ - Physical Volume of the manipulable control panel
■ - Movement envolope of the control panel volume

c

Design Envolope: 300mm length between max reach and noramal grip of the 95% male.

Design Envolope: 150mm width
This measurment takes into account the sub ordinate surfaces are next toseats that move. The actual envolope (200mm) is reduced by 25mm each side to ensure parts don't rub and move each other.

95th & 5th%ile Bonnet line.
Parts of the interior that cross this line obstruct resolution

Vision cut off line: 15 degrees
Vision cut off line: 15 degrees

1 - max reach
2 - extended grip
3 - normal grip

■ - 5th %ile Female
■ - 95th %ile Male
■ - Physical Volume of the manipulable control panel
■ - Movement envolope of the control panel volume

Design Envolope: 300mm length between max reach and normal grip of the 95% male.

Design Envolope: 150mm width. This measurment takes into account the sub ordinate surfaces are next to seats that move. The actual (200) is reduced by 25mm each side to ensure parts don't rub and move each other.

95th & 5th %ile Bonnet line. Parts of the interior that cross this line obstruct observation.

Vision cut off line: 15 degrees

Vision cut off line: 15 degrees

1 - max reach
2 - extended grip
3 - normal grip

- 5th %ile Female
- 95th %ile Male
- Physical Volume of the manipulable control panel
- Movement envolope of the control panel volume

E

034 idea number

3D form on: parallel lines

1 - *How much of the suface joining is acutely edged?*

none | less then half | half | more than half | all

[bad]   [good]

2 - *How many surfaces[1] (curved or flat) does the design have?*

1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 & above

[good]   [bad]

3 - *Are the contours closed or open?*

closed contours | open contours

[good]   [bad]

Note:[1] This is assuming that a surface is a flat or curved continuous area.

---

021 idea number

3D form on: 6 - pointed star shape

1 - *How much of the suface joining is acutely edged?*

none | less then half | half | more than half | all

[bad]   [good]

2 - *How many surfaces[1] (curved or flat) does the design have?*

1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 & above

[good]   [bad]

3 - *Are the contours closed or open?*

closed contours | open contours

[good]   [bad]

Note:[1] This is assuming that a surface is a flat or curved continuous area.

APPENDIX: 4.7 - DESIGN STUDY - PANEL SHAPE PACKAGE STUDY

horizonal pill control panel option

circle control panel option

1 - max reach
2 - extended grip
3 - normal grip

■ - 5th %ile Female
■ - 95th %ile Male

50mm clearance to ensure a driver steer with hands bumping into objects.

Design Envolope: 200mm width. This dimention could be larger but there needs to be 50mm between the steering wheel and part for good hand clearance.

Design Envolope: 300mm length between max reach and normal grip of the 95% male.

95th & 5th%ile Bonnet line.
Parts of the bonnet but cross this line obstruct next vision.

Vision cut off line: 15 degrees

Vision cut off line: 15 degrees

vertical pill control panel option

APPENDIX 4.8 - DESIGN STUDY: SUBORDINATE AREA QUESTIONNAIRE DATA

Participant	Comments
M1	- "I liked it" - "I think, really, radio was the best, easy to reach" - "In a real car I think it would be easier" - "After a while I was thinking less and less about it" - "Once you find the first button [super], you know things are fine because it's easy to find"
M2	- "Easy to reach for areas" - "waited for an appropriate time to reach" (waited for a straight line, etc.) - "you know that this [super-ordinate area] relates to this [sub-ordinate area], it's quite easy!"
F1	Really easy…
F2	- "It's the only thing to find" - "Cool, good" - "There's not much to it really"

Personal details

Sample Form

Name: _____

Occupation: _____

Age:	16 - 21	22 - 30	31 - 40	41 - 50	51 - 60	64+
Tick applicable	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

Acute edge height test

Question 1 - Which one gave the most sensational through the fingers?

3mm	5mm	7mm	10mm

Question 2 - Any general comments; good points and bad points.

APPENDIX - 4.10: DESIGN STUDY - BUTTON SHAPE QUICK AND DIRTY QUESTIONNAIRE

Personal Details

Name: *M1*

Occupation: ████████████

Age:

Tick applicable choice

[ ] 16 - 21
[✓] 22 - 30
[ ] 31 - 40
[ ] 41 - 50
[ ] 51 - 60
[ ] 64+

Do you hold a driving licence:

Tick applicable choice

[✓] Yes
[ ] No

How often do you drive?

Tick applicable choice

[✓] daily (moped)
[ ] couple of days a week
[ ] weekly
[✓] monthly (car)
[ ] yearly
[ ] never

APPENDIX - 4.10: DESIGN STUDY - BUTTON SHAPE QUICK AND DIRTY QUESTIONNAIRE

Name: M1

Super-ordinate control questions

Question 1 - Identify all of the buttons visually to ensure you understand their functions? (Words are shielded and completed once in random order)

	CD Player	Navigation	Telephone	Climate	Radio
Success	✗ 'hazard'	✗	✓	✓	✓

Question 2 - Press a button while driving? (Words un-shielded and completed twice in random order)

	CD Player		Navigation		Telephone		Climate		Radio	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
No Glance	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
No Glance & Exploration										
With Glance										

Question 3 - Any general comments; good points and bad points.

- "No problem"
- "I know where they are"
- "nicely spaced, not all crammed together"

Name: M1

Sub-ordinate control questions: *RADIO*

Question 4 - Identify all of the buttons visually to ensure you understand their functions? (Words are shielded and completed once in random order)

	Bandwidth	Tuning-up	Tuning-down	Presets
Success	✓	✓	✓	✓

Question 5 - Press a button while driving? (Words un-shielded and completed in order)

Task	Pressed	Mistake	No Glance	With Glance	Driving
Tune up	✓		✓		
Tune Down		✓	✓		
Preset 1	✓		✓		
Preset 5	✓		✓		
Bandwidth	✓		✓		
Tune up	✓		✓		
Tune down	✓		✓		
Preset 4	✓		✓		
Bandwidth	✓		✓		
Preset 3	✓		✓		
Tune up	✓		✓		
Tune down	✓		✓		
Bandwidth	✓		✓		
Preset 2	✓		✓		

Question 6 - Any general comments; good points and bad points.

- The most difficult was the Tune-Up arrow the Bandwidth squiggle and the Tune-Down arrow, but you hit the Bandwidth squiggle, you know it's the wrong one because of the shape
- "Very easy to use indeed, maybe more more easy top find because of the size. Much better than fiddling about with tiny ones"
- "Arrows were easy to find"

APPENDIX 4.10 - DESIGN STUDY: BUTTON SHAPE QUICK AND DIRTY QUESTIONNAIRE

Name: M1

Sub-ordinate control questions (MP3 PLAYER)

Question 7 - Identify all of the buttons visually to ensure you understand their functions? *(Words are shielded and completed once in random order)*

	Play	Forward	Rewind	Stop	Pause
Success	✓	✓	✓	✓	✓

Question 8 - Press a button while driving?
(Words un-shielded and completed in order)

Task	Pressed	Mistake	No Glance	With Glance	Driving
Play	✓		✓		
Forward	✓		✓		
Play	✓		✓		
Stop	✓		✓		
Rewind	✓		✓		
Play	✓		✓		
Pause	✓		✓		
Forward	✓		✓		
Forward x3	✓		✓		

Question 9 - Any general comments; good points and bad points.

- "Really easy to use!, because of the east, north, west and south placement of the buttons make it easy."
- "Can't press another by mistake (spacing)."
- "You know from the edge [circular] where things are. Edge is a good guide."
- "The radio buttons could do with being spaced out like this. It would be more comfortable / easy."
- "Like the way they grow out of the surface."
- "Even easier to use than the radio."

Name: M1

Sub-ordinate control questions CLIMATE

Question 10 - Identify all of the buttons visually to ensure you understand their functions? *(Words are shielded and completed once in random order)*

	Flow to head	Flow to head	Flow to head
Success	✗ Seat Reclining option	✗ Seat Reclining option	✗ Seat Reclining option

	Flow Up	Flow Down	Temp Up	Temp Down
Success	✓	✓	✓	✓
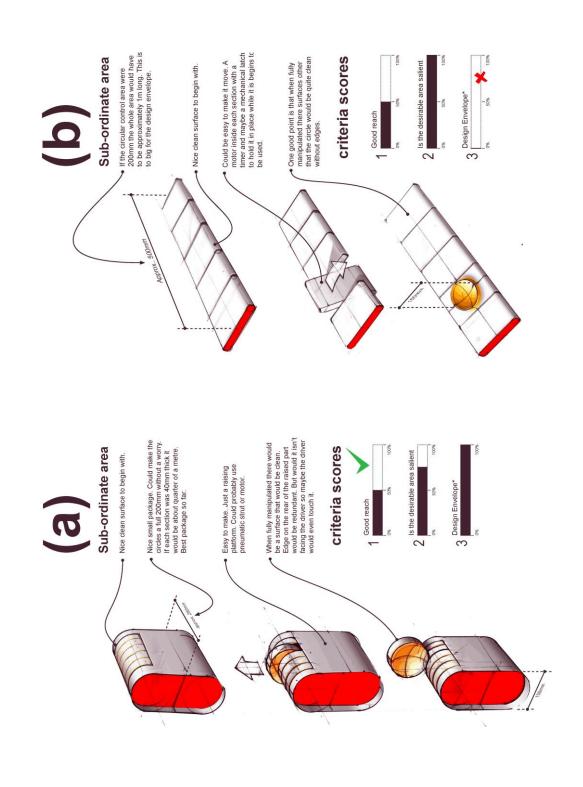
Question 11 - Press a button while driving? *(Words un-shielded and completed in order)*

Task	Pressed	Mistake	No Glance	With Glance	Driving
Temp Up	✓		✓		
Head & Body on	✓		✓		
Flow Up x2	✓		✓		
Temp Down	✓		✓		
Head off	✓		✓		
Feet on	✓		✓		
Temp Down		✓			
Flow Down	✓		✓		
Flow Up x3	✓		✓		
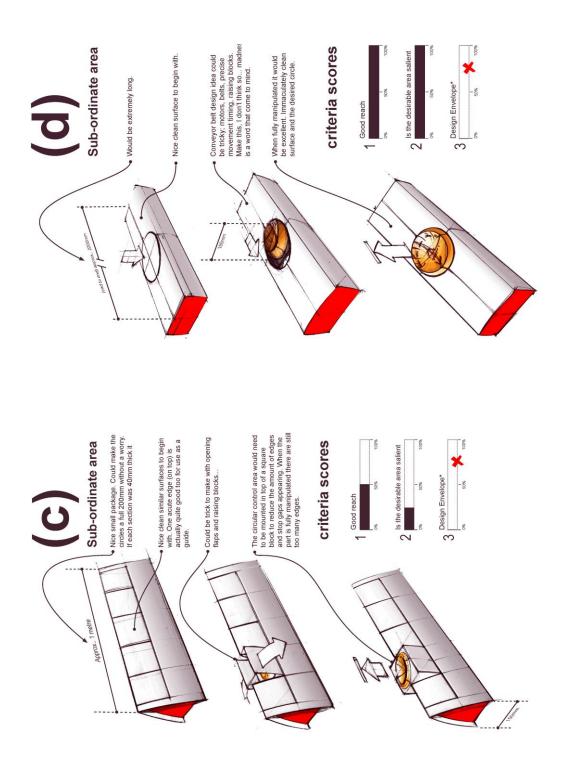
Question 12 - Any general comments; good points and bad points.

- "More difficult than the last one (CD)."
- "The body was difficult to find, there was less to catch your finger."
- "May touch top of leg and accidentally press body form feet."
- "Needs to look more like a body and needs a nose, humanise it."

(b)

Sub-ordinate area

If the circular control area were 200mm the whole area would have to be approximately 1m long. This is to big for the design envelope.

Nice clean surface to begin with.

Could be easy to make it move. A motor inside each section with a timer and maybe a mechanical latch to hold it in place while it is begins to be used.

One good point is that when fully manipulated there surfaces other that the circle would be quite clean without edges.

Approx. 500mm

criteria scores

1 Good reach   0% 50% 100%

2 Is the desirable area salient   0% 50% 100%

3 Design Envelope* ✗ 0% 50% 100%

(a)

Sub-ordinate area

Nice clean surface to begin with.

Nice small package. Could make the circles a full 200mm without a worry. If each section was 40mm thick it would be about quarter of a metre. Best package so far.

Easy to make. Just a raising platform. Could probably use pneumatic strut or motor.

When fully manipulated there would be a surface that would be clean. Edge on the rear of the raised part would be redundant. But would it isn't facing the driver so maybe the driver would even touch it.

Approx. 250mm

criteria scores

1 Good reach   0% 50% 100%

2 Is the desirable area salient   0% 50% 100%

3 Design Envelope*   0% 50% 100%

(d)

Sub-ordinate area

Would be extremely long.

Nice clean surface to begin with.

Conveyor belt design idea could be tricky: motors, belts, precise movement timing, raising blocks. Make this, I don't think so... madness is a word that come to mind.

When fully manipulated it would be excellent. Immaculately clean surface and the desired circle.

(end to end approx. 2000mm)

150mm

criteria scores

1 Good reach
0% 50% 100%

2 Is the desirable area salient
0% 50% 100%

3 Design Envelope* ✖
0% 50% 100%

(c)

Sub-ordinate area

Nice small package. Could make the circles a full 200mm without a worry. If each section was 40mm thick it

Nice clean similar surfaces to begin with. One acute edge (on top) is actually quite good too for use as a guide.

Could be trick to make with opening flaps and raising blocks...

The circular control area would need to be mounted in top of a square block to reduce the amount of edges and stop gaps appearing. When the part is fully manipulated there are still too many edges.

Approx.. 1 metre

150mm

criteria scores

1 Good reach
0% 50% 100%

2 Is the desirable area salient
0% 50% 100%

3 Design Envelope* ✖
0% 50% 100%

(e)

Sub-ordinate area

Nice clean surface to begin with.

To big to fit in the car if the circles were to facer the driver, which is what they need to do.

Like the conveyor belt design idea (d) complex to make.

When fully manipulated it would be excellent. Immaculately clean surface and the desired circle.

criteria scores

1 Good reach

2 Is the desirable area salient

3 Design Envelope*

APPENDIX 4.12 (A) - DESIGN STUDY: TACTILE SURFACE SKETCH STUDY

APPENDIX 4.12 (B) - DESIGN STUDY: TACTILE SURFACE SKETCH STUDY

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

APPENDIX 4.12 (C) - DESIGN STUDY: TACTILE SURFACE SKETCH STUDY

APPENDIX 4.12 (E) - DESIGN STUDY: TACTILE SURFACE SKETCH STUDY

APPENDIX 4.12 (E) - DESIGN STUDY: TACTILE SURFACE SKETCH STUDY

APPENDIX 4.12 (F) - DESIGN STUDY: TACTILE SURFACE SKETCH STUDY

APPENDIX 4.12 (G) - DESIGN STUDY: TACTILE SURFACE SKETCH STUDY

APPENDIX 4.12 (H) - DESIGN STUDY: TACTILE SURFACE SKETCH STUDY

APPENDIX 4.12 (I) - DESIGN STUDY: TACTILE SURFACE SKETCH STUDY

APPENDIX 4.12 (J) - DESIGN STUDY: TACTILE SURFACE SKETCH STUDY

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APPENDIX 4.12 (K) - DESIGN STUDY: TACTILE SURFACE SKETCH STUDY

Some materials have been removed due to 3rd party copyright. The unabridged version can be viewed in Lancester Library - Coventry University.

APPENDIX 4.12 (L) - DESIGN STUDY: TACTILE SURFACE SKETCH STUDY

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APPENDIX 4.12 (N) - DESIGN STUDY - TACTILE SURFACE SKETCH STUDY

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APPENDIX 4.12 (O) - DESIGN STUDY: TACTILE SURFACE SKETCH STUDY

APPENDIX 4.12 (P) - DESIGN STUDY: TACTILE SURFACE SKETCH STUDY

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APPENDIX 5

APPENDIX 5.1 - ETHICAL APPROVAL

REGISTRY RESEARCH UNIT
ETHICS REVIEW FEEDBACK FORM
(Review feedback should be completed within 10 working days)

Name of applicant: SHAUN HUTCHINSON..................... **Faculty/School/Department:** CSAD..................

Research project title: TACTILE SHOW AND HIDE INTERFACE & VISUAL DISTRACTION

Comments by the reviewer

1. Evaluation of the ethics of the proposal:
The main ethical issues have been adequately addressed and risks have been minimised.
2. Evaluation of the participant information sheet and consent form:
These are comprehensive, clear and fit for purpose.

3. Recommendation:
(Please indicate as appropriate and advise on any conditions. If there any conditions, the applicant will be required to resubmit his/her application and this will be sent to the same reviewer).

X	Approved - no conditions attached
	Approved with minor conditions (no need to resubmit)
	Conditional upon the following – please use additional sheets if necessary (please re-submit application)
	Rejected for the following reason(s) – please use other side if necessary
	Further advice/notes - please use other side if necessary

Name of reviewer: Martin Woolley ....

Signature: ....

Some materials have been

Date: 30.06.2010 ....

UX / VIS Questionnaire
User Experience / Visual Distraction

INFORMATION SHEET (for user-tests)

Thank you for attending the user-tests today. Please take the time to read the information contained in this sheet. If you have any queries do not hesitate to ask.

What is the purpose of the study?
The purpose of this study is to gain a new understanding about visual distraction and driver experiences. Specifically, this research explores people's experiences with a range of vehicle interfaces.

Why have I been chosen?
You have been chosen for two particular reasons. Firstly, because you have personal attributes that help to make a fair and balanced analysis of the new interface design. I.E: you are male or female, a particular age or you are either left or right handed. Secondly, because you represent a massive portion of the global population who can drive a motor car.

What are the possible disadvantages and risks of taking part?
There are no risks to taking part, but you will be asked to provide approx 3 hours of your time with comfort breaks factored into this timescale.

What are the possible benefits of taking part?
There are no direct benefits of taking part. However, the new understanding gained from these tests will benefits future drivers who would maintain safety.

What if something goes wrong?
If you have any concerns or queries about this study, feel free to contact the researcher who will answer your questions. Contact details to do this are provided at the end of this form.

CONTROL TYPE: **TSAHI** / **TACTILE** / **TOUCHSCREEN** **(pg. 1)** NUMBER:_____

UX / VIS Questionnaire
User Experience / Visual Distraction

What will happen if I don't want to take part in or carry on with this study?
You are free to withdraw from the research study at anytime and there will be no repercussions as a result of your withdrawal.

What are the procedures for recording data?
All your actions will be recorded using audio/video recording equipment. Your eye movements will be recording using eye tracking equipment. Your experiences will be made on paper through a questionnaire.

Will my input be kept confidential?
All information will be kept strictly confidential. The processing of the information will also be in accordance to the Data protection Act, 1998. All information will be anonymised and access to this information will be restricted to the research team only.

What will happen to the results of the research study?
The information and data we gain from this study will be used to inform our project team about specific details of interface use. You will not be identified in any results, report or publication. You will receive direct feedback on the results of the study when the project has been completed if you request it.

Who reviewed the study?
The study was given ethical approval by the Coventry University Research Ethics Committee.
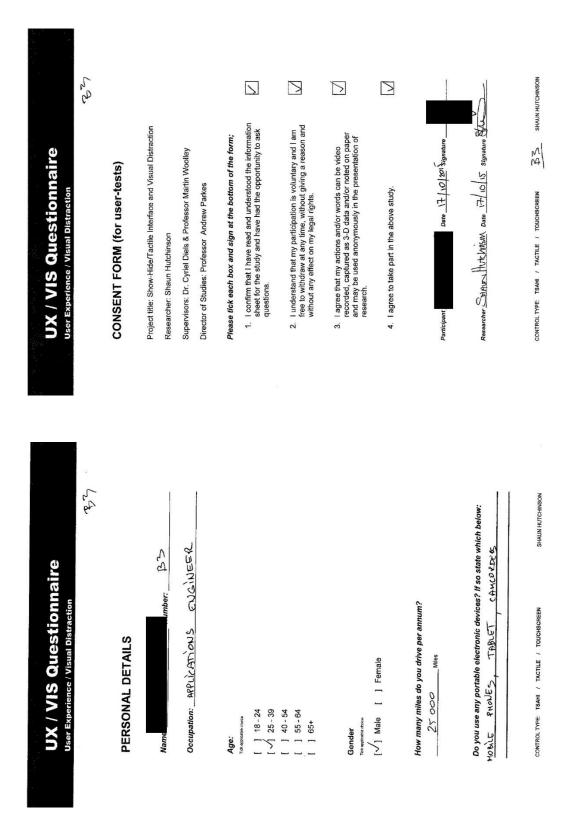
Who do I contact for further information?
If you need any more information, contact:

Shaun Hutchinson BA Hons, MA (RCA)
Coventry School of Art & Design
Maurice Foss Building
Room 208
Coventry University
CV1 5FB

Tel: **07803 136 048**
Email: s.hutchinson@coventry.ac.uk

CONTROL TYPE: **TSAHI** / **TACTILE** / **TOUCHSCREEN** **(pg. 2)** NUMBER:_____

APPENDIX 5.3 - PERSONAL INFORMATION COLLECTION SHEET AND CONSENT FORM

UX / VIS Questionnaire
User Experience / Visual Distraction

B3

CONSENT FORM (for user-tests)

Project title: Show-Hide/Tactile Interface and Visual Distraction

Researcher: Shaun Hutchinson

Supervisors: Dr. Cyriel Diels & Professor Martin Woolley

Director of Studies: Professor Andrew Parkes

Please tick each box and sign at the bottom of the form;

1. I confirm that I have read and understood the information sheet for the study and have had the opportunity to ask questions. [✓]

2. I understand that my participation is voluntary and I am free to withdraw at any time, without giving a reason and without any effect on my legal rights. [✓]

3. I agree that my actions and/or words can be video recorded, captured as 3-D data and/or noted on paper and may be used anonymously in the presentation of research. [✓]

4. I agree to take part in the above study. [✓]

Participant ███████████ Date 17/10/2015 Signature

Researcher Shaun Hutchinson Date 17/10/15 Signature

CONTROL TYPE: TSAHI / TACTILE / TOUCHSCREEN   SHAUN HUTCHINSON

UX / VIS Questionnaire
User Experience / Visual Distraction

B3

PERSONAL DETAILS

Name ██████ Number: B3

Occupation: APPLICATIONS ENGINEER

Age:
Tick applicable choice

[ ] 18 - 24
[✓] 25 - 39
[ ] 40 - 54
[ ] 55 - 64
[ ] 65+

Gender
Tick applicable choice

[✓] Male   [ ] Female

How many miles do you drive per annum?

25 000 _____ Miles

Do you use any portable electronic devices? If so state which below:

MOBILE PHONES, TABLET, CAMCORDERS

CONTROL TYPE: TSAHI / TACTILE / TOUCHSCREEN   SHAUN HUTCHINSON

APPENDIX 5.4 - QUESTIONNAIRE – VD: TASK INSTRUCTIONS

VD - MP3 QUESTIONS (Condition 1)

MP3 instructions
Operate interface while driving

Task	Success
Go to **MP3** menu	
Play **Sergio Mendes** album	
Forward to Track Forteen - El Menina	
Rewind to Track Nine - Samba de Bencao	
Rewind to Track Seven - Surfboard	
Rewind to Track Four - The Frog	
Increase volume to **Seven**	
Decrease volume to Three	
Go back to MP3 menu	
Play Foo Fighters album	
Forward to Track Ten - Burn Away	
Rewind to Track Five - Disenchanted Lullaby	
Go back to MP3 menu	
Play Studio One Rockers album	
Forward to Track Thirteen - Hot Milk	
Rewind to Track Five - Village Soul	
Go back to MP3 menu	
Play **Muse** album	
Stop music	
Increase temperature to Twenty Four degrees	
Turn 'air flow to head' on	
Go back to MP3 menu	
Go to Muse album	
Play music	
(Next page)	

Notes:

CONTROL TYPE: TSAM / TACTILE / TOUCHSCREEN   SHAUN HUTCHINSON

VD - RADIO QUESTIONS (Condition 1)

Radio instructions
Operate interface while driving

Task	Success
Set Volume to **Four**	
Tune the radio up to Radio 3	
Tune the radio down to Kerrang	
Tune the radio to Pre-set One	
Tune the radio to Pre-set Five	
Change the bandwidth to AM	
Tune radio up to Free Radio	
Change bandwidth to FM	
Tune the radio to Pre-set Three	
Tune up to Heart FM	
Tune down **Radio Two**	
Tune the radio to Pre-set Two	
Tune the radio to Pre-set Five	
Increase volume to **Seven**	
Decrease volume to Two	
Tune up to Smooth FM	
Increase volume to Five	
Play Jimmy Smith MP3 album	
Fast Forward to Watermelon Man	
Stop music	
Tune the radio to Radio Two	
(Next page)	

Notes:

CONTROL TYPE: TSAM / TACTILE / TOUCHSCREEN   SHAUN HUTCHINSON

APPENDIX 5.4 - QUESTIONNAIRE – VD: TASK INSTRUCTIONS

VD - CLIMATE QUESTIONS (Condition 1)

Climate instructions
Operate interface while driving

Task	Success
Turn Air flow to head on	
Turn Air flow to body on	
Increase air speed to Three	
Decrease temperature to Twenty degrees	
Decrease temperature to Eighteen degrees	
Increase temperature to Twenty One degrees	
Turn Air flow to head off	
Turn Air flow to feet on	
Decrease temperature to Sixteen degrees	
Decrease Air speed to One	
Increase Air speed to Two	
Turn Air flow to head on	
Turn Air flow to feet off	
Turn Air flow to body off	
Tune into BBC Radio Four	
Increase Air speed to Four	
Increase temperature to Twenty Two	
> Stop driving	

Notes:

CONTROL TYPE: (TSAHI) / TACTILE / TOUCHSCREEN   SHAUN HUTCHINSON

APPENDIX 5.5 - QUESTIONNAIRE – UX: ATTRAKDIFF

(Condition 1)

UX - AttrakDiff © User Interface Design GmbH

Following, are pairs of words to assist you in your evaluation. Each pair represents extreme contrasts. The possibilities between the extremes enable you to describe the intensity of the quality you choose.

Do not spend time thinking about the word-pairs. Try to give a spontaneous response. You may feel that some pairs of terms do not adequately describe the product. In this case please still be sure to give an answer. Keep in mind that there is no right or wrong answer. Your personal opinion is what counts!

With the help of the word-pairs please enter what you consider the most appropriate description for the interface just used. Please mark a box with an [x] on your choice in every line!

human						technical
isolating						connective
pleasant						unpleasant
inventive						conventional
simple						complicated
professional						unprofessional
ugly						attractive
practical						impractical
likeable						disagreeable
cumbersome						straightforward
stylish						tacky
predictable						unpredictable
cheap						premium
alienating						integrating
brings me closer to people						separates me from people
unpresentable						presentable
rejecting						inviting
unimaginative						creative
good						bad
confusing						clearly structured
repelling						appealing
bold						cautious
innovative						conservative
dull						captivating
undemanding						challenging
motivating						discouraging
novel						ordinary
unruly						manageable

CONTROL TYPE: (TSAHI) / TACTILE / TOUCHSCREEN   SHAUN HUTCHINSON

APPENDIX 5.6 - QUESTIONNAIRE – UX: CONDITION COMPARISON

UX

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Comparison of the Interface

(Place a cross [x] neatly on the scale where appropriate.)

How does the Touchscreen Interface compare to the other interfaces.

Comments: I FOUND THE TOUCHSCREEN HARDEST TO USE — VERY DISTRACTING — MADE MISTAKES OR NOT PAYING ATTENTION TO THE ROAD.

How does the Tactile Interface compare to the other interfaces

Comments: VERY INTUITIVE AND EASY TO USE, NOT DISTRACTING, SIMPLE

How does the TSAHI compared to the other interfaces

Comments: VERY SIMILAR TO TACTILE QUITE EASY TO USE ALTHOUGH I HAD TO LOOK AT THE CONTROLS MORE THAN USING THE TACTILE INSTRUMENTS SIMPLE

Please rank the different interfaces from 1 to 3 in terms of ease of use.

2	Tactile Show And Hide Interface
1	Tactile Interface
3	Touch screen interface

Please rank the different interfaces from 1 to 3 in terms of least distracting.

2	Tactile Show And Hide Interface
1	Tactile Interface
3	Touch screen interface

Please rank the different interfaces from 1 to 3 in terms of pleasurable to use.

1	Tactile Show And Hide Interface
2	Tactile Interface
3	Touch screen interface

CONTROL TYPE: TSAHI / TACTILE / TOUCHSCREEN   SHAUN HUTCHINSON

APPENDIX 5.7 - QUESTIONNAIRE – UX: TACTILE INTERACTION

UX

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Use of the Tactile Interfaces

Place a cross [x] neatly on the scale where appropriate.

Salience - Were all the buttons identifiable by touch while driving?

- Primarily visually
- [X] Combination of tactile and visually
- Primarily tactily

Comments:

Amplification – What was the sensation of touch on the buttons like while driving?

- Not good, very weak
- [X] Satisfactory
- Absolutely perfect, nice and strong

Comments:

Hyperbole – Was the sizes of the buttons good to use while driving?

- No
- Satisfactory
- [X] The perfect size

Comments:

Simplicity – How complicated were the buttons to use through touch only?

- Not at all, very complex
- Satisfactory
- [X] Perfectly simple

Comments:

CONTROL TYPE: TSAHI / TACTILE / TOUCHSCREEN   SHAUN HUTCHINSON

APPENDIX 5.7 - QUESTIONNAIRE – UX: TACTILE INTERACTION

UX

Mapping – Could you imagine the shapes of each buttons well in your mind while driving?

- Not at all
- Satisfactorily
- Absolutely perfectly [X]

Comments: ....

Mapping – Could you easily discriminate between the different buttons while driving?

- Not at all
- Satisfactorily [X]
- Absolutely perfectly

Comments: ....

CONTROL TYPE: TSAHI / TACTILE / TOUCHSCREEN

SHAUN HUTCHINSON

UX

Best attribute for touch – Did the materials feel right?

- Not at all
- Satisfactory [X]
- The materials were perfect for touch

Comments: ....

Clustering – Were functional buttons logically clustered to be used while driving?

- No, completely random & un-ordered
- Satisfactorily
- Were clustered perfectly [X]

Comments: ....

Mind / hand calibration – Was it easy <u>see</u> where to press and then efficiently move your finger to the location while driving?

- Not at all
- Satisfactorily
- Could easily see and remember [X]

Comments: ....

Mind / hand calibration – Was it easy to <u>remember</u> where to press and then efficiently move your finger to the location while driving?

- Not at all
- Satisfactorily
- Could easily see and remember [X]

Comments: ....

CONTROL TYPE: TSAHI / TACTILE / TOUCHSCREEN

SHAUN HUTCHINSON

APPENDIX 5.8 - QUESTIONNAIRE – UX: TLX

(Condition 1)

UX - Climate TLX questions
Place an [x] where you think the descriptions apply in your case, Do not spend time thinking your answer. Try to give a spontaneous response.

a) **Mental Demand** - How mentally demanding was the task?
Very Low — Very High

b) **Physical Demand** - How physically demanding was the task?
Very Low — Very High

c) **Temporal Demand** - How hurried or rushed was the pace of the task?
Very Low — Very High

d) **Performance** - How successful were you in accomplishing what you were asked to do?
Perfect — Failure

e) **Effort** - How hard did you have to work to accomplish your level of performance?
Very Low — Very High

f) **Frustration** - How insecure, discouraged, irritated, stressed, and annoyed were you?
Very Low — Very High

CONTROL TYPE: (TSAHI) TACTILE / TOUCHSCREEN   SHAUN HUTCHINSON

APPENDIX 5.9 - QUESTIONNAIRE – UX: SUS

(Condition 1)

UX- System Usability Scale
Check the box that correctly represents your experience in the interface.

Strongly disagree 1 2 3 4 5 Strongly agree

1. I think that I would like to use this system frequently

2. I found the system unnecessarily complex

3. I thought the system was easy to use

4. I think that I would need the support of a technical person to be able to use this system

5. I found the various functions in this system were well integrated

6. I thought there was too much inconsistency in this system

7. I would imagine that most people would learn to use this system very quickly

8. I found the system very cumbersome to use

9. I felt very confident using the system

10. I needed to learn a lot of things before I could get going with this system

CONTROL TYPE: (TSAHI) / TACTILE / TOUCHSCREEN   SHAUN HUTCHINSON

Appendix 6

APPENDIX 6.1 - POST HOC DESCRIPTIVE OF EYE POSITION TESTS

Dependent Variable		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	Upper Bound	Minimum	Maximum
GLANCE TOTAL	Baseline	23	0.07	0.25	0.05	-0.03	0.18	0.00	1.16
	TSAHI	24	90.95	46.39	9.47	71.36	110.53	5.08	187.84
	Tactile	24	121.80	49.81	10.17	100.76	142.83	6.92	203.96
	Touchscreen	24	133.63	35.95	7.34	118.45	148.81	55.96	219.28
	Total	95	87.52	64.55	6.62	74.37	100.67	0.00	219.28
GLANCE NUMBER	Baseline	24	0.46	1.44	0.29	-0.15	1.07	0.00	6.00
	TSAHI	24	294.29	125.07	25.53	241.48	347.10	31.00	632.00
	Tactile	24	383.92	184.36	37.63	306.07	461.76	58.00	859.00
	Touchscreen	24	296.38	120.53	24.60	245.48	347.27	146.00	604.00
	Total	96	243.76	191.82	19.58	204.89	282.63	0.00	859.00
GLANCE MEAN	Baseline	23	0.03	0.08	0.02	-0.01	0.06	0.00	0.29
	TSAHI	24	0.32	0.15	0.03	0.25	0.38	0.05	0.57
	Tactile	24	0.33	0.12	0.03	0.28	0.38	0.07	0.57
	Touchscreen	24	0.50	0.19	0.04	0.42	0.58	0.19	1.03
	Total	95	0.30	0.22	0.02	0.25	0.34	0.00	1.03
GLANCE MAX	Baseline	23	0.04	0.13	0.03	-0.01	0.10	0.00	0.56
	TSAHI	24	1.95	0.97	0.20	1.54	2.36	0.24	4.40
	Tactile	24	2.04	0.85	0.17	1.68	2.39	0.68	4.40
	Touchscreen	24	2.46	0.84	0.17	2.11	2.82	1.36	4.44
	Total	95	1.64	1.20	0.12	1.39	1.88	0.00	4.44
PEORT	Baseline	24	4.78	3.25	0.66	3.40	6.15	1.30	16.40
	TSAHI	24	26.63	6.44	1.31	23.91	29.35	9.60	36.30
	Tactile	24	29.85	5.94	1.21	27.34	32.36	12.70	42.40
	Touchscreen	24	31.31	5.21	1.06	29.11	33.51	22.20	42.80
	Total	96	23.14	12.01	1.23	20.71	25.58	1.30	42.80

APPENDIX 6.1 - POST HOC COMPARATIVE ANALYSIS OF EYE TRACKING DATA

	Dependent Variable	Mean Difference (I-J)	Std. Error	Two Tailed Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
GLANCE TOTAL	Baseline — TSAHI	-90.87362*	11.2922	.000	-120.4270	-61.3203
	Baseline — Tactile	-121.72362*	11.2922	.000	-151.2770	-92.1703
	Baseline — Touchscreen	-133.55529*	11.2922	.000	-163.1086	-104.0020
	TSAHI — Baseline	90.87362*	11.2922	.000	61.3203	120.4270
	TSAHI — Tactile	-30.85000*	11.1714	.033	-60.0872	-1.6128
	TSAHI — Touchscreen	-42.68167*	11.1714	.001	-71.9189	-13.4444
	Tactile — Baseline	121.72362*	11.2922	.000	92.1703	151.2770
	Tactile — TSAHI	30.85000*	11.1714	.033	1.6128	60.0872
	Tactile — Touchscreen	-11.83167	11.1714	.712	-41.0689	17.4056
	Touchscreen — Baseline	133.55529*	11.2922	.000	104.0020	163.1086
	Touchscreen — TSAHI	42.68167*	11.1714	.001	13.4444	71.9189
	Touchscreen — Tactile	11.83167	11.1714	.712	-17.4056	41.0689
GLANCE NUMBER	Baseline — TSAHI	-293.83333*	36.5599	.000	-389.4967	-198.1700
	Baseline — Tactile	-383.45833*	36.5599	.000	-479.1217	-287.7950
	Baseline — Touchscreen	-295.91667*	36.5599	.000	-391.5800	-200.2533
	TSAHI — Baseline	293.83333*	36.5599	.000	198.1700	389.4967
	TSAHI — Tactile	-89.62500	36.5599	.075	-185.2883	6.0383
	TSAHI — Touchscreen	-2.08333	36.5599	1.000	-97.7467	93.5800
	Tactile — Baseline	383.45833*	36.5599	.000	287.7950	479.1217
	Tactile — TSAHI	89.62500	36.5599	.075	-6.0383	185.2883
	Tactile — Touchscreen	87.54167	36.5599	.085	-8.1217	183.2050
	Touchscreen — Baseline	295.91667*	36.5599	.000	200.2533	391.5800
	Touchscreen — TSAHI	2.08333	36.5599	1.000	-93.5800	97.7467
	Touchscreen — Tactile	-87.54167	36.5599	.085	-183.2050	8.1217
GLANCE MEAN	Baseline — TSAHI	-.28910*	0.0412	.000	-.3972	-.1810
	Baseline — Tactile	-.30360*	0.0412	.000	-.4117	-.1955
	Baseline — Touchscreen	-.47577*	0.0412	.000	-.5838	-.3677
	TSAHI — Baseline	.28910*	0.0412	.000	.1810	.3972
	TSAHI — Tactile	-.01450	0.0408	.985	-.1214	.0924
	TSAHI — Touchscreen	-.18667*	0.0408	.000	-.2936	-.0798
	Tactile — Baseline	.30360*	0.0412	.000	.1955	.4117
	Tactile — TSAHI	.01450	0.0408	.985	-.0924	.1214
	Tactile — Touchscreen	-.17217*	0.0408	.000	-.2791	-.0653
	Touchscreen — Baseline	.47577*	0.0412	.000	.3677	.5838
	Touchscreen — TSAHI	.18667*	0.0408	.000	.0798	.2936
	Touchscreen — Tactile	.17217*	0.0408	.000	.0653	.2791
GLANCE MAX	Baseline — TSAHI	-1.90993*	0.2262	.000	-2.5021	-1.3177
	Baseline — Tactile	-1.99326*	0.2262	.000	-2.5854	-1.4011
	Baseline — Touchscreen	-2.42159*	0.2262	.000	-3.0138	-1.8294
	TSAHI — Baseline	1.90993*	0.2262	.000	1.3177	2.5021
	TSAHI — Tactile	-.08333	0.2238	.982	-.6692	.5025
	TSAHI — Touchscreen	-.51167	0.2238	.106	-1.0975	.0742
	Tactile — Baseline	1.99326*	0.2262	.000	1.4011	2.5854
	Tactile — TSAHI	.08333	0.2238	.982	-.5025	.6692
	Tactile — Touchscreen	-.42833	0.2238	.225	-1.0142	.1575
	Touchscreen — Baseline	2.42159*	0.2262	.000	1.8294	3.0138
	Touchscreen — TSAHI	.51167	0.2238	.106	-.0742	1.0975
	Touchscreen — Tactile	.42833	0.2238	.225	-.1575	1.0142
PEORT	Baseline — TSAHI	-21.85417*	1.5438	.000	-25.8939	-17.8144
	Baseline — Tactile	-25.07500*	1.5438	.000	-29.1147	-21.0353
	Baseline — Touchscreen	-26.53750*	1.5438	.000	-30.5772	-22.4978
	TSAHI — Baseline	21.85417*	1.5438	.000	17.8144	25.8939
	TSAHI — Tactile	-3.22083	1.5438	.165	-7.2606	.8189
	TSAHI — Touchscreen	-4.68333*	1.5438	.016	-8.7231	-.6436
	Tactile — Baseline	25.07500*	1.5438	.000	21.0353	29.1147
	Tactile — TSAHI	3.22083	1.5438	.165	-.8189	7.2606
	Tactile — Touchscreen	-1.46250	1.5438	.779	-5.5022	2.5772
	Touchscreen — Baseline	26.53750*	1.5438	.000	22.4978	30.5772
	Touchscreen — TSAHI	4.68333*	1.5438	.016	.6436	8.7231
	Touchscreen — Tactile	1.46250	1.5438	.779	-2.5772	5.5022

APPENDIX 6.3 - DESCRIPTIVE VALUES OF RADIO, MP3, AND CLIMATE TASKS OF MAXIMUM GLANCE DURATION

	Dependent Variable	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	Upper Bound	Min	Max
RADIO	BASELINE	24	0.0000	0.00000	0.00000	0.0000	0.0000	0.00	0.00
	TSAHI	24	1.5417	.69292	.14144	1.2491	1.8343	.44	3.60
	TACTILE	24	1.7083	.57089	.11653	1.4673	1.9494	.56	2.80
	TOUCHSCREEN	24	1.7200	.58823	.12007	1.4716	1.9684	.64	3.00
	Total	96	1.2425	.89664	.09151	1.0608	1.4242	0.00	3.60
MP3	BASELINE	24	0.0000	0.00000	0.00000	0.0000	0.0000	0.00	0.00
	TSAHI	24	1.6217	.92449	.18871	1.2313	2.0120	.32	4.08
	TACTILE	24	1.9133	.84653	.17280	1.5559	2.2708	.32	4.40
	TOUCHSCREEN	24	2.1233	.82903	.16923	1.7733	2.4734	.96	4.24
	Total	96	1.4146	1.11934	.11424	1.1878	1.6414	0.00	4.40
CLIMATE	BASELINE	24	0.0000	0.00000	0.00000	0.0000	0.0000	0.00	0.00
	TSAHI	24	1.1883	.58876	.12018	.9397	1.4369	.16	2.92
	TACTILE	24	1.2933	.64484	.13163	1.0210	1.5656	.68	3.64
	TOUCHSCREEN	24	1.8317	.71535	.14602	1.5296	2.1337	.96	3.72
	Total	96	1.0783	.87198	.08900	.9017	1.2550	0.00	3.72

APPENDIX 6.4 - TUKEY POST HOC TABLE OF DATA FOR THE MULTIPLE CONDITION ANALYSIS OF THE RADIO, MP3, AND CLIMATE TASKS TESTED FOR THE MAXIMUM GLANCE DURATION.

		Dependent Variable	Mean Difference (I-J)	Std. Error	Two-tailed Sig.	95% Confidence Interval Lower Bound	Upper Bound
RADIO	BASELINE	TSAHI	-1.54167*	.15492	.000	-1.9470	-1.1363
		TACTILE	-1.70833*	.15492	.000	-2.1137	-1.3030
		TOUCHSCREEN	-1.72000*	.15492	.000	-2.1254	-1.3146
	TSAHI	BASELINE	1.54167*	.15492	.000	1.1363	1.9470
		TACTILE	-.16667	.15492	.705	-.5720	.2387
		TOUCHSCREEN	-.17833	.15492	.659	-.5837	.2270
	TACTILE	BASELINE	1.70833*	.15492	.000	1.3030	2.1137
		TSAHI	.16667	.15492	.705	-.2387	.5720
		TOUCHSCREEN	-.01167	.15492	1.000	-.4170	.3937
	TOUCHSCREEN	BASELINE	1.72000*	.15492	.000	1.3146	2.1254
		TSAHI	.17833	.15492	.659	-.2270	.5837
		TACTILE	.01167	.15492	1.000	-.3937	.4170
MP3	BASELINE	TSAHI	-1.62167*	.21692	.000	-2.1893	-1.0541
		TACTILE	-1.91333*	.21692	.000	-2.4809	-1.3457
		TOUCHSCREEN	-2.12333*	.21692	.000	-2.6909	-1.5557
	TSAHI	BASELINE	1.62167*	.21692	.000	1.0541	2.1893
		TACTILE	-.29167	.21692	.537	-.8593	.2759
		TOUCHSCREEN	-.50167	.21692	.103	-1.0693	.0659
	TACTILE	BASELINE	1.91333*	.21692	.000	1.3457	2.4809
		TSAHI	.29167	.21692	.537	-.2759	.8593
		TOUCHSCREEN	-.21000	.21692	.768	-.7776	.3576
	TOUCHSCREEN	BASELINE	2.12333*	.21692	.000	1.5557	2.6909
		TSAHI	.50167	.21692	.103	-.0659	1.0693
		TACTILE	.21000	.21692	.768	-.3576	.7776
CLIMATE	BASELINE	TSAHI	-1.18833*	.16293	.000	-1.6147	-.7620
		TACTILE	-1.29333*	.16293	.000	-1.7197	-.8670
		TOUCHSCREEN	-1.83167*	.16293	.000	-2.2580	-1.4053
	TSAHI	BASELINE	1.18833*	.16293	.000	.7620	1.6147
		TACTILE	-.10500	.16293	.917	-.5313	.3213
		TOUCHSCREEN	-.64333*	.16293	.001	-1.0697	-.2170
	TACTILE	BASELINE	1.29333*	.16293	.000	.8670	1.7197
		TSAHI	.10500	.16293	.917	-.3213	.5313
		TOUCHSCREEN	-.53833*	.16293	.007	-.9647	-.1120
	TOUCHSCREEN	BASELINE	1.83167*	.16293	.000	1.4053	2.2580
		TSAHI	.64333*	.16293	.001	.2170	1.0697
		TACTILE	.53833*	.16293	.007	.1120	.9647

APPENDIX 6.5 - TACTILE INTERACTIONS FREQUENCY COUNT DATA

salience	Frequency	%	Valid %	Cumulative %
0	0	0	0	0
1	4	16.7	16.7	16.7
2	16	66.7	66.7	83.3
3	4	16.7	16.7	100.0
4	0	0.0	0.0	100.0

clustering	Frequency	%	Valid %	Cumulative %
0	0	0	0	0
1	2	8.3	8.3	8.3
2	3	12.5	12.5	20.8
3	10	41.7	41.7	62.5
4	9	37.5	37.5	100.0

amplification	Frequency	%	Valid %	Cumulative %
0	0	0	0	0
1	3	12.5	12.5	12.5
2	7	29.2	29.2	41.7
3	11	45.8	45.8	87.5
4	3	12.5	12.5	100.0

mind/hand: see	Frequency	%	Valid %	Cumulative %
0	0	0	0	0
1	1	4.2	4.2	4.2
2	6	25.0	25.0	29.2
3	7	29.2	29.2	58.3
4	10	41.7	41.7	100.0

hyperbole	Frequency	%	Valid %	Cumulative %
0	1	4.2	4.2	4.2
1	3	12.5	12.5	16.7
2	11	45.8	45.8	62.5
3	6	25.0	25.0	87.5
4	3	12.5	12.5	100.0

mind/hand: remember	Frequency	%	Valid %	Cumulative %
0	0	0	0	0
1	2	8.3	8.3	8.3
2	9	37.5	37.5	45.8
3	6	25.0	25.0	70.8
4	7	29.2	29.2	100.0

simplicity	Frequency	%	Valid %	Cumulative %
0	1	4.2	4.2	4.2
1	3	12.5	12.5	16.7
2	9	37.5	37.5	54.2
3	8	33.3	33.3	87.5
4	3	12.5	12.5	100.0

mapping imagine	Frequency	%	Valid %	Cumulative %
0	0	0	0	0
1	4	16.7	16.7	16.7
2	6	25.0	25.0	41.7
3	9	37.5	37.5	79.2
4	5	20.8	20.8	100.0

best for touch	Frequency	%	Valid %	Cumulative %
0	0	0	0	0
1	2	8.3	8.3	8.3
2	10	41.7	41.7	50.0
3	8	33.3	33.3	83.3

mapping discrimination	Frequency	%	Valid %	Cumulative %
0	1	4.2	4.2	4.2
1	0	0.0	0.0	4.2
2	8	33.3	33.3	37.5
3	10	41.7	41.7	79.2

APPENDIX 6.6 - POST-HOC ANALYSIS OF THE CONDITIONS IN THE TASK LOAD INDEX STUDY

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Mental Demand	TSAHI	Touchscreen	-0.587	1.276	0.890	-3.643	2.468
		Tactile	1.025	1.276	0.702	-2.030	4.080
	Touchscreen	TSAHI	0.587	1.276	0.890	-2.468	3.643
		Tactile	1.613	1.276	0.420	-1.443	4.668
	Tactile	TSAHI	-1.025	1.276	0.702	-4.080	2.030
		Touchscreen	-1.613	1.276	0.420	-4.668	1.443
Physical Demand	TSAHI	Touchscreen	-1.125	1.131	0.583	-3.835	1.585
		Tactile	-0.413	1.131	0.929	-3.123	2.298
	Touchscreen	TSAHI	1.125	1.131	0.583	-1.585	3.835
		Tactile	0.712	1.131	0.804	-1.998	3.423
	Tactile	TSAHI	0.413	1.131	0.929	-2.298	3.123
		Touchscreen	-0.712	1.131	0.804	-3.423	1.998
Temporal Demand	TSAHI	Touchscreen	0.146	1.184	0.992	-2.689	2.981
		Tactile	0.175	1.184	0.988	-2.660	3.010
	Touchscreen	TSAHI	-0.146	1.184	0.992	-2.981	2.689
		Tactile	0.029	1.184	1.000	-2.806	2.864
	Tactile	TSAHI	-0.175	1.184	0.988	-3.010	2.660
		Touchscreen	-0.029	1.184	1.000	-2.864	2.806
Performance	TSAHI	Touchscreen	0.200	1.139	0.983	-2.529	2.929
		Tactile	0.587	1.139	0.864	-2.142	3.317
	Touchscreen	TSAHI	-0.200	1.139	0.983	-2.929	2.529
		Tactile	0.388	1.139	0.938	-2.342	3.117
	Tactile	TSAHI	-0.587	1.139	0.864	-3.317	2.142
		Touchscreen	-0.388	1.139	0.938	-3.117	2.342
Effort	TSAHI	Touchscreen	-0.375	1.281	0.954	-3.443	2.693
		Tactile	0.221	1.281	0.984	-2.847	3.289
	Touchscreen	TSAHI	0.375	1.281	0.954	-2.693	3.443
		Tactile	0.596	1.281	0.888	-2.472	3.664
	Tactile	TSAHI	-0.221	1.281	0.984	-3.289	2.847
		Touchscreen	-0.596	1.281	0.888	-3.664	2.472
Frustration	TSAHI	Touchscreen	-0.021	1.213	1.000	-2.926	2.884
		Tactile	0.579	1.213	0.882	-2.326	3.484
	Touchscreen	TSAHI	0.021	1.213	1.000	-2.884	2.926
		Tactile	0.600	1.213	0.874	-2.305	3.505
	Tactile	TSAHI	-0.579	1.213	0.882	-3.484	2.326
		Touchscreen	-0.600	1.213	0.874	-3.505	2.305

APPENDIX 6.7 - DESCRIPTIVE DATA OF THE CONDITIONS IN THE TASK LOAD INDEX STUDY

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
						Lower Bound	Upper Bound		
Mental Demand	TSAHI	24	9.217	4.542	0.927	7.299	11.135	1.00	15.30
	Touchscreen	24	9.804	4.449	0.908	7.926	11.683	2.00	16.70
	Tactile	24	8.192	4.261	0.870	6.392	9.991	2.00	15.30
	Total	72	9.071	4.408	0.519	8.035	10.107	1.00	16.70
Physical Demand	TSAHI	24	6.442	3.653	0.746	4.899	7.984	1.00	12.70
	Touchscreen	24	7.567	4.288	0.875	5.756	9.377	1.70	15.70
	Tactile	24	6.854	3.788	0.773	5.255	8.454	1.70	13.70
	Total	72	6.954	3.892	0.459	6.040	7.869	1.00	15.70
Temporal Demand	TSAHI	24	7.838	4.199	0.857	6.064	9.611	1.00	14.30
	Touchscreen	24	7.692	3.935	0.803	6.030	9.353	2.00	16.30
	Tactile	24	7.663	4.162	0.850	5.905	9.420	1.30	15.30
	Total	72	7.731	4.043	0.476	6.781	8.681	1.00	16.30
Performance	TSAHI	24	7.900	4.230	0.864	6.114	9.686	1.00	16.70
	Touchscreen	24	7.700	3.982	0.813	6.019	9.381	2.00	14.70
	Tactile	24	7.313	3.604	0.736	5.791	8.834	1.00	13.00
	Total	72	7.638	3.899	0.460	6.721	8.554	1.00	16.70
Effort	TSAHI	24	9.013	4.406	0.899	7.152	10.873	1.00	14.30
	Touchscreen	24	9.388	4.533	0.925	7.473	11.302	2.30	19.00
	Tactile	24	8.792	4.369	0.892	6.947	10.636	1.00	16.00
	Total	72	9.064	4.381	0.516	8.034	10.093	1.00	19.00
Frustration	TSAHI	24	7.625	4.285	0.875	5.816	9.434	1.00	13.30
	Touchscreen	24	7.646	4.175	0.852	5.883	9.409	1.00	17.70
	Tactile	24	7.046	4.144	0.846	5.296	8.795	1.00	14.00
	Total	72	7.439	4.151	0.489	6.463	8.414	1.00	17.70

APPENDIX – 6.8 PARTICIPANT COMPARATIVE COMMENTS

A1

Touch screen:	Easy to use because most things are touch screen. It was more long winded than the other interfaces as you had to keep pressing things to get the desired actions done - the other interfaces are more simple especially with USB music.
Tactile:	It was rubbish!! Everything is too big, too far apart in inconvenient places. Not visually appealing.
TSAHI:	Size wise they are too big. They are practical but could be better. Touchscreen is more relatable.

A2

Touch screen:	Quicker, more responsive, intuitive to use.
Tactile:	Visually off-putting, slightly more confusing.
TSAHI:	Novel, exciting, easier than tactile.

A3

Touch screen:	Felt a lot more distracting as there was a lot more buttons to get the end result. Would be best for a passenger to use instead of a driver. Easy to use - just caused a lot of looking down.
Tactile:	Extremely simple. Buttons on the tactile were simple and easy to use. Looks quite old fashioned with simple amount of buttons.
TSAHI:	Extremely novel, easy to reach, easy to figure out.

A4

Touch screen:	It was easy enough to use, however, there were the occasions when you had to select more options to get where you want as opposed to a one push button. Also, not being a button, you can't feel you've pressed it.
Tactile:	Very simple to use and very conventional. Something close to what I'm used to.
TSAHI:	Very neat and innovative. Similar to the tactile interface but more conceptual and unusual!

A5

Touch screen:	I personally like the touchscreen due to it looking/feeling more modern and technical, however can see how some people would find hard to use due to not being able to recognise functions with your fingers.
Tactile:	Easy to use. Once you've remembered the location of the different functions. You can memorise easily due to always being visible.
TSAHI:	Made me jump! You have to remember to make sure it's on the right dial, however, the location is always the same, which stops you having to move/reach around.

A6

Touch screen:	It's all in one place. My and only has to move once. It's more direct. It looks more futuristic/advanced. Too far from line of sight and can't feel.
Tactile:	You can feel the buttons once memorised. The screen is in a better position in relation to the road. Easy to understand instantly.
TSAHI:	Nice, minimal design. Intuitive once you get to know it.

APPENDIX 6.8 - PARTICIPANT CONDITION COMPARISON COMMENTS

B1

Touch screen:	More traditional, familiar, user friendly.
Tactile:	Difficult to access all of the interface due to reach of lower section.
TSAHI:	Most enjoyable to use. Keys in the same place/position.

B2

Touch screen:	I preferred the touchscreen as it was more visual
Tactile:	I liked the size of the buttons however less visual
TSAHI:	I liked it, however felt like more effort than the tactile interface

B3

Touch screen:	I found the touchscreen hardest to use. Very distracting - made mistakes of not paying attention to the road.
Tactile:	Very inutuitive and easy to use, not distracting, simple.
TSAHI:	Very similar to tactile. Quite easy to use, although I had to look at the controls more than using the simple tactile instruments.

B4

Touch screen:	Slightly more complex layout with smaller menu buttons but more enjoyable.
Tactile:	Very difficult to use the further down you go for radio and MP3.
TSAHI:	Fun element of use and easy to navigate once familiarised.

B5

Touch screen:	Feel as if I spent more time with my eyes off the road - considered premium, sleek, customisable.
Tactile:	Too many buttons at once! Combined with wheel controls. Why would the buttons not respond on touch? Frustrating to have to ensure the steering wheel selection is made first - which seems an unnecessary step.
TSAHI:	This was my favourite. The right buttons are where you need them/select them from steering wheel controls; seemed slicker - less frustrating. Quirky!

B6

Touch screen:	The touchscreen was very stylish and easy to use - I think I would soon be able to use it with a good level of accuracy. The location of the MP3 feature on the screen was slightly out of peripheral vision and so took my attention off the road.
Tactile:	I liked the location of the buttons behind the steering wheel and of the screen, which was more in line with my view of the road than the touchscreen. Again, the MP3 button was slightly out of visible range whilst looking at the road. Climate control was perfectly placed.
TSAHI:	The pop-up feature was fun and placed the controls in an equal position within my peripheral vision. I think this is quite a novel way of presenting the functions and automating where your hand goes to use the controls.

APPENDIX 6.8 - PARTICIPANT CONDITION COMPARISON COMMENTS

C1

Touch screen:	Easier to use than roundels. Simpler graphic layout - easier to learn.
Tactile:	Reassuring to select right function once learnt. Harder to remember and learn layout.
TSAHI:	Novel. Easy to use once learnt but as easy as touchscreen to remember function locations.

C2

Touch screen:	Tidy compared to others. Lack of paddles on wheel made it slightly harder to use and flicking between screens harder to keep eyes on road than others.
Tactile:	Clunky. Less appealing to the eye, but lacking technical edge - which I'm now used to.
TSAHI:	Placement same for each component, therefore much easier than tactile.

C3

Touch screen:	Enjoyed the touchscreen. Found the menus could be a little easier, (not so many), or quicker access. Faster access.
Tactile:	Good. I enjoyed the interface. Would be better on touchscreen.
TSAHI:	OK. Preferred the others.

C4

Touch screen:	Distracting and difficult to use. Had to keep looking to ensure I had selected appropriate item.
Tactile:	Easy to use. Responsive.
TSAHI:	Bit cumbersome.

C5

Touch screen:	I found the touchscreen easier to use than the 2 previous tests. Clearer to understand and better visually.
Tactile:	This interface was the hardest to get used to, maybe because I was new to the test.
TSAHI:	I liked this interface as it turned off info when not needed, so less distraction.

C6

Touch screen:	Too many things to look at initially, would need a lot of practice to use without having to check it.
Tactile:	Easier, except for the MP3 which is lower and means you have to take your eyes off the road.
TSAHI:	Easiest of the 3 because you can look in the same direction and find the buttons in the same place.

APPENDIX 6.8 - PARTICIPANT CONDITION COMPARISON COMMENTS

D1

Touch screen:	Easier once used to it but more distracting because you're looking directly at screen. Good position would help. More complicated and can become distracting when remembered.
Tactile:	Easiest. Got used to it sooner. Reasonably easy once you get used to it. * Because screen is at front of dash, can keep an eye on the road and easy to understand. Colour coding helped.
TSAHI:	Weird until got used to it. *Ditto. Easy once you know what you are bringing up.

D2

Touch screen:	Easier to use and to get a quick response. Functions are more centred on a smaller space. Easier to remember the locations of the functions.
Tactile:	Old fashioned. Needs more concentration to operate.
TSAHI:	Distracting to use. Harder to operate. Slower response.

D3

Touch screen:	More familiar to me as my car has one. Design of interface not intuitive.
Tactile:	Easier to familiarise with and use quickly.
TSAHI:	interesting idea. Tactility of prototype let the experience down. (felt clunky). Properly engineered prototype would be interesting.

D4

Touch screen:	This was easier. More comfortable on the whole - more efficient.
Tactile:	This one was probably more practical. Quite efficient - more than Show and Hide but less than touchscreen.
TSAHI:	This one was my least favourite - more cumbersome and fussy.

D5

Touch screen:	A) It was very easy to use when NOT driving BUT demanded more of my attention than the other systems while driving. The reach to the far left of the controls was really a long way and distracting. B) MP3 interface too hard to do while driving. It's very difficult to use. AKA, mental workload. Tring to drive the car and reach and hand wobbles, emotionally upsetting - have to go back so many times. Very much to the sides/more stressful.
Tactile:	A) This seemed quite chunky to use, but actually felt easier while driving. The climate control was especially easy to use because I didn't have to think or read anything. B) There is a lot going on in your head going up and down in the numbers or scrolling across MPS. I need to look at it. It's very hard. Easiest is head/body/feet. Easy to recognise and position is high. MP3 is hardest position etc.
TSAHI:	A) This seemed slightly easier to use than the others while driving. It was annoying to have to choose which one to show/hide each time. B) Mobile panels are easier because once you choose a mode there are less choices. It's a two-step process, but it feels easier. Whilst you're driving, you don't need to remove eyes off the road. Can do it progressively. Felt like a harder workload.

D6

Touch screen:	Simpler. Easier to use.
Tactile:	Bit more confusing. Even though the colour is there, I get confused about which one is which.
TSAHI:	Okay. Less confusing than the one with all three on it. I find that easy to use as well.

APPENDIX 6.9 - PARTICIPANT USE OF TACTILE INTERFACES COMMENTS

A1	Comments
Salience	Generally had no idea what they did until I used them.
Amplification	Not very sensitive. Did not react at a good speed/atall.
Hyperbole	Too Big.
Simplicity	Did not really work.
Best attributes for touch	Has a weird texture - feels too soft.
Clustering	N/A
Mind/hand : see	N/A
Mind/hand remember	N/A
Mapping: imagine	N/A
Mapping discriminate	N/A

A2	Comments
Salience	N/A
Amplification	N/A
Hyperbole	Bit big
Simplicity	N/A
Best attributes for touch	N/A
Clustering	N/A
Mind/hand : see	N/A
Mind/hand remember	N/A
Mapping: imagine	N/A
Mapping discriminate	N/A

A3	Comments
Salience	Easy to feel but easier to look at.
Amplification	Click was satisfying.
Hyperbole	Some buttons felt too big - climate control.
Simplicity	The raised area made it simple.
Best attributes for touch	Felt sturdy. Could have been nicer to touch.
Clustering	N/A
Mind/hand : see	The colour and placement helped on tactile. Hiding others and being in one place helped with TSAHI.
Mind/hand remember	N/A
Mapping: imagine	Each button had easily memorable shapes.
Mapping discriminate	N/A

A4	Comments
Salience	They were tactile, however, until I was really used to the button layout I needed to view the button.
Amplification	Usable, tactile button, Apart from touchscreen where you had to look.
Hyperbole	They were good being large as it's easier to push the right button but it made it look less premium.
Simplicity	I could usually tell what I was doing.
Best attributes for touch	They were practical and usable but not premium.
Clustering	Very logical
Mind/hand : see	Most of the time I felt it efficient.
Mind/hand remember	I feel with more time it would have gotten easier.
Mapping: imagine	Most of the time.
Mapping discriminate	Not always with them being similar and the touchscreen; No.

A5	Comments
Salience	The button symbols were easier to read by touch.
Amplification	Could feel them easily due to the pronounced shapes.
Hyperbole	The buttons were too large, but easy to use.
Simplicity	Fairly easy, the radio buttons were more confusing.
Best attributes for touch	N/a
Clustering	Radio tuning and presets were a little confusing.
Mind/hand : see	Yes. Very easy.
Mind/hand remember	I feel with more time it would have gotten easier.
Mapping: imagine	Yes. They are very memorable.
Mapping discriminate	Yes, apart from the radio.

APPENDIX 6.9 - PARTICIPANT USE OF TACTILE INTERFACES COMMENTS

A6	Comments
Salience	N/A
Amplification	Buttons were large.
Hyperbole	Too large - had to move hand more than I would like.
Simplicity	N/A
Best attributes for touch	A nice click, but material could be better.
Clustering	N/A
Mind/hand : see	Large and minimal amount of button made everything simple.
Mind/hand remember	N/A
Mapping: imagine	Familiar shapes although numbers on radio might be more intuitive.
Mapping discriminate	N/A

B1	Comments
Salience	Still had to look.
Amplification	Acceptable. Differing surface finishes would help.
Hyperbole	Perhaps too big?
Simplicity	Due to familiarity. You would get used to them.
Best attributes for touch	Not quite.
Clustering	Clear layout. Very functional as you would expect.
Mind/hand : see	After a while it became easier.
Mind/hand remember	.As above.
Mapping: imagine	N/A
Mapping discriminate	Kind of after using them for a while.

B2	Comments
Salience	N/A
Amplification	N/A
Hyperbole	N/A
Simplicity	N/A
Best attributes for touch	N/A
Clustering	N/A
Mind/hand : see	N/A
Mind/hand remember	N/A
Mapping: imagine	N/A
Mapping discriminate	N/A

B3	Comments
Salience	N/A
Amplification	N/A
Hyperbole	N/A
Simplicity	N/A
Best attributes for touch	N/A
Clustering	N/A
Mind/hand : see	N/A
Mind/hand remember	N/A
Mapping: imagine	N/A
Mapping discriminate	N/A

B4	Comments
Salience	TSAHI - combination, Tactile - Mainly tactile, Touch - visual.
Amplification	Nice bold icons to aid identification.
Hyperbole	Maybe raised buttons to help define boundaries.
Simplicity	See above.
Best attributes for touch	Maybe different textures/raised borders for more definition.
Clustering	
Mind/hand : see	B4
Mind/hand remember	It got easier throughout the trial.
Mapping: imagine	Yes
Mapping discriminate	A bit tricky at first but easier after repetition.

APPENDIX 6.9 - PARTICIPANT USE OF TACTILE INTERFACES COMMENTS

B5	Comments
Salience	Once familiarised with the rough location via visuals, then the tactile part confirms the selection.
Amplification	Good feedback to confirm the selection has been made.
Hyperbole	Too big - Smaller buttons would make it easier to navigate by touch alone - rather than waving your arm around in space/relying on visual feedback.
Simplicity	Too big to confirm the selection (ie. Raised graphics couldn't be recognised with a small 'sweep')
Best attributes for touch	Solid enough/refined. No sharp edges!
Clustering	Very methodically arranged, you wouldn't want to do it any other way!
Mind/hand : see	Once practised and committed to memory it was easy, yes.
Mind/hand remember	Missing the final confirmation by touch. Just too large.
Mapping: imagine	Very logical grouping/shaping makes them easy to remember. Colour also works well.
Mapping discriminate	No mistaking which buttons were which.

B6	Comments
Salience	MP3 button out of peripheral vision range for me.
Amplification	Soft touch buttons would be good but the press was nice and strong.
Hyperbole	Probably larger than necessary in terms of space on the control panel, but this makes them easier to locate.
Simplicity	N/A
Best attributes for touch	They were a little hard when pressed. A softer touch would be preferable.
Clustering	N/A
Mind/hand : see	On some functions took my eyes off the road to press, however, I believe you'd soon find the buttons without having to look.
Mind/hand remember	Not within the trial period, but this would soon become autonomous with regular use.
Mapping: imagine	N/A
Mapping discriminate	N/A

C1	Comments
Salience	N/A
Amplification	N/A
Hyperbole	N/A
Simplicity	N/A
Best attributes for touch	N/A
Clustering	N/A
Mind/hand : see	N/A
Mind/hand remember	N/A
Mapping: imagine	N/A
Mapping discriminate	N/A

C2	Comments
Salience	Would learn placement over time.
Amplification	N/A
Hyperbole	N/A
Simplicity	Good size, not complicated once totally offay with layout.
Best attributes for touch	N/A
Clustering	Well placed and simple to understand.
Mind/hand : see	Decent size.
Mind/hand remember	Easier on TSAHI.
Mapping: imagine	Given time, would be easy.
Mapping discriminate	MP3 on tactile slightly more difficult, perhaps due to placement at bottom of panel.

APPENDIX 6.9 - PARTICIPANT USE OF TACTILE INTERFACES COMMENTS

C3	Comments
Salience	N/A
Amplification	N/A
Hyperbole	N/A
Simplicity	N/A
Best attributes for touch	N/A
Clustering	N/A
Mind/hand : see	N/A
Mind/hand remember	N/A
Mapping: imagine	N/A
Mapping discriminate	N/A

C4	Comments
Salience	N/A
Amplification	N/A
Hyperbole	N/A
Simplicity	N/A
Best attributes for touch	N/A
Clustering	N/A
Mind/hand : see	N/A
Mind/hand remember	N/A
Mapping: imagine	N/A
Mapping discriminate	N/A

C5	Comments
Salience	N/A
Amplification	N/A
Hyperbole	N/A
Simplicity	N/A
Best attributes for touch	N/A
Clustering	Would improve with practise.
Mind/hand : see	N/A
Mind/hand remember	N/A
Mapping: imagine	N/A
Mapping discriminate	N/A

C6	Comments
Salience	Ideally this would be tactile when you get more used to it.
Amplification	A bit hit and miss, you need to know how to press them.
Hyperbole	I don't think they would be this big in a finished product, however.
Simplicity	They get easier as you get used to them, but initially distracting because you have to look.
Best attributes for touch	O.K. on the whole.
Clustering	They were reasonably logical.
Mind/hand : see	They are easy to remember but too much moving around needed for the tactile interface.
Mind/hand remember	It's easier to do the more you use it.
Mapping: imagine	Beginning to, but still checking during the exercise. Again, tactile was more difficult.
Mapping discriminate	Easier with the TSAHI because it was always in the same place.

D1	Comments
Salience	N/A
Amplification	N/A
Hyperbole	N/A
Simplicity	N/A
Best attributes for touch	N/A
Clustering	N/A
Mind/hand : see	N/A
Mind/hand remember	N/A
Mapping: imagine	N/A
Mapping discriminate	N/A

APPENDIX 6.9 - PARTICIPANT USE OF TACTILE INTERFACES COMMENTS

D2	Comments
Salience	n/a
Amplification	Normal
Hyperbole	n/a
Simplicity	Okay
Best attributes for touch	N/A
Clustering	N/A
Mind/hand : see	N/A
Mind/hand remember	N/A
Mapping: imagine	N/A
Mapping discriminate	N/A

D3	comments
Salience	I don't have particularly good muscle memory even for tactile switches.
Amplification	See above
Hyperbole	Too big and spaced out. Need big movements which I found distracting.
Simplicity	I didn't just use touch. Perhaps with familiarity, I would.
Best attributes for touch	I didn't really rely on touch.
Clustering	I would need to learn them over extended use.
Mind/hand : see	No because seat/handwheel/interface positioning didn't suit me.
Mind/hand remember	But as mentioned, that may be me and not the interface.
Mapping: imagine	See previous.
Mapping discriminate	But visually. It would take me a while to learn by touch.

D4	Comments
Salience	N/A
Amplification	N/A
Hyperbole	N/A
Simplicity	N/A
Best attributes for touch	N/A
Clustering	N/A
Mind/hand : see	N/A
Mind/hand remember	N/A
Mapping: imagine	N/A
Mapping discriminate	N/A

D5	Comments
Salience	I felt I usually needed to look at them to be sure. I learned the position of some of them.
Amplification	n/a
Hyperbole	Way too big!
Simplicity	N/A
Best attributes for touch	Not really the right texture.
Clustering	The climate control buttons were brilliantly logical. The others not so well arranged.
Mind/hand : see	Difficulty seeing the visual screen behind the wheel.
Mind/hand remember	Some were easy to remember, others less so.
Mapping: imagine	Wasn't really aware of the shapes, more the position of the buttons.
Mapping discriminate	I could discriminate but it required attention from driving.

D6	Comments
Salience	N/A
Amplification	N/A
Hyperbole	N/A
Simplicity	Simple enough once you get used to them.
Best attributes for touch	N/A
Clustering	N/A
Mind/hand : see	N/A
Mind/hand remember	N/A
Mapping: imagine	N/A
Mapping discriminate	N/A