NATURAL LANGUAGE INTERFACES FOR VEHICLE NAVIGATION SYSTEMS

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Thesis submitted to the University of Nottingham

for the degree of Doctor of Philosophy

September 2018

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Title: Natural language interfaces for vehicle navigation systems

Thesis submitted to the School of Engineering, University of Nottingham, in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

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To my parents, Jenny & Andy

ABSTRACT

Around three quarters of drivers in England regularly use a GPS system to guide them on journeys yet prefer to use a smartphone or personal device for navigation and wayfinding, rather than a factory-fitted system. For car manufacturers, therefore, it is important to consider the potential for novel Human-Machine Interfaces (HMIs) that are more integral to the vehicle. For the research community, there is also a fundamental desire to understand the balance required between HMIs for navigation systems as 'uncertainty minimisers' (the prevailing approach emphasising the desire for low workload/distraction) and a longer-term perspective in which engagement with the drivers' surroundings is encouraged.

This PhD, co-funded by the University of Nottingham and Jaguar Land Rover, explored the way in which drivers and passengers interact when navigating as a means of informing future HMIs. The work proposes that Natural Language Interfaces (NLIs) can be created which mimic this social relationship, allowing personalised, context-sensitive, environmental information to be presented.

Four on-road studies were conducted in the Clifton area of Nottingham, UK, aiming to explore the relationships between driver workload and environmental engagement associated with 'active' and 'passive' navigation systems. In a between-subjects design, a total of 61 experienced drivers completed two experimental drives comprising the same three routes (with overlapping sections), staged one week apart. Drivers were provided with the navigational support of a commercially-available navigation device ('satnav'), an informed passenger (a stranger with expert route knowledge), a collaborative passenger (an individual with whom they had a close, personal relationship) or a novel interface employing conversational natural language NAV-NLI). The NAV-NLI

was created by curating linguistic intercourse extracted from the earlier conditions, and delivering this using a Wizard-of-Oz technique. The different navigational methods were notable for their varying interactivity and the preponderance of environmental landmark information within route directions. Participants experienced the same guidance on each of the two drives to explore changes in reported and observed behaviour. Results show that participants who were more active in the navigation task (collaborative passenger or NAV-NLI) demonstrated enhanced environmental engagement (landmark recognition, route-learning and survey knowledge) allowing them to reconstruct the route more accurately post-drive, compared to drivers using more passive forms of navigational support (SatNav or informed passenger). Workload measures (TDT, NASA-TLX) indicated no differences between conditions, although objective workload dropped significantly, in the Informed and Collaborative passenger conditions, on their second final drive. Moreover, satnav users and collaborative passenger and NAV drivers reported lower subjective workload during this second drive. The research demonstrates clear benefits and potential for a navigation system employing two-way conversational language to deliver instructions. This could help support a long-term perspective in the development of spatial knowledge, enabling drivers to become less reliant on the technology and begin to re-establish associations between viewing an environmental feature and the related navigational manoeuvre.

ACKNOWLEDGEMENTS

Where to start?..... Gary, a little over four years ago you convinced me to start a PhD. I can say initially I wasn't sure whether it was for me – a new city where I didn't know anyone, starting a job that I wasn't sure I'd be great at. But looking back, I'm so pleased that I took the opportunity. I've met some amazing people, learned so much, made Nottingham a home, travelled to some amazing places, and was lucky to have been a part of the HFRG family during my time down here. So, thank you for encouraging me that a PhD *was* for me.

Thank you also for all the PhD related guidance, support and encouragement that you've given me along the way, you've made me a better researcher and given me confidence that I actually *do* know stuff. A big special thank you to David though, you joined my PhD mid-way through but you've injected enthusiasm and some much-needed dry humour to the whole process. Thank you especially, for meticulously going through drafts that were sent over and squeezing me in for meetings. You've been brilliant and I've been lucky to have you.

Also, big special thank you to my family, who, whilst I know you're still not sure *exactly* what I do, you continue to support me fiercely. You've injected some much-needed laughter (and delightful escapism) throughout the great and not-so-great times over the past four years, and I couldn't be luckier to have you all. I honestly cannot say thank you enough.

A massive thank you to my wonderful friends: the 'Rutland girls', Emma, Lorri, Sarah, Ayse, Liz & James who have kept me sane. Whether that was coming to visit me when I first moved down here, or when things weren't fantastic (thanks wrongstuff!), helping make Nottingham feel like home with the introduction of wine club, or just generally being my very own cheerleaders - believing and supporting me at every stage. A special mention to Liz, who has consciously

refrained from asking me how the write up is going – you're wonderful!

Finally, a big big thank you to Andy. Thank you for 'getting me', to say the last year has been one of my most stressful, it's also been one of the most fun, because it's been spent with you. Thank you for being kind, encouraging and generally a sunbeam of a human, I would've been lost without you (genuinely, I couldn't have *actually* done it without this PC you built for me). Thank you for everything my love.

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LIST OF ABBREVIATIONS AND ACRONYMS

AOI	Area Of Interest
FPS	Frames Per Second
GPS	Global Positioning System
HMI	Human Machine Interface
LED	Light Emitting Diode
NASA-TLX	National Aeronautics and Space Administration-Task Load Index
NLI	Natural Language Interface
PDT	Peripheral Detection Task
POI	Point Of Interest
RTLX	Raw-Task Load Index
Satnav	Satellite Navigation Device
SWAT	Subjective Workload Assessment Technique
TDT	Tactile Detection Task
WP	Workload Profile

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CHAPTER 1: INTRODUCTION TO THE THESIS

1.1 USE OF DRIVING NAVIGATION TECHNOLOGIES

The performance of in-vehicle tasks has evolved over the past few decades. Functions previously under driver control are now increasingly automated, from the early mechanisation of vehicle control tasks to assist drivers with braking (e.g. ABS) and steering (e.g. power steering), to later technological assistance with higher-level tactical and strategic driving tasks (e.g. lane keeping, collision avoidance, route-following) (Stanton & Marsden, 1997, April). Systems now frequently assist, augment and occasionally replace the driver in a number of critical driving-related tasks. This shift in task responsibility has prompted wider literature to caution on the perils of overreliance and over trust in such systems, amid fears of the potential safety implications if such systems were to fail or not act according to driver expectation (Inagaki & Itoh, 2013).

Route planning and navigation is a classic example of an automated in -vehicle task. The replacement of human with technology within the strategic task of driving navigation is now so commonplace that as of December 2017, prospective drivers in the UK are required to demonstrate their ability to safely use a navigation device ('SatNav') whilst driving in order to obtain their driver's licence (DVSA, 2017). Indeed, such is the proliferation of vehicle navigation technologies that

a recent survey suggested that around three quarters (71%) of drivers in England now regularly use a dedicated SatNav device or smartphone app to guide them on journeys (Smith, 2018).

Drivers frequently employ electronic navigation systems to assist them in the planning and following of efficient routes with such systems frequently acting as 'uncertainty minimisers' to assist users with effective navigation (King, 1986; Streeter & Vitello, 1986). 'Uncertainty minimisers' is a term coined in the literature (Burnett, 1998), which refers to the design of current navigation systems, which require the driver to continually refer back to the systems visual interface as they travel. Here, drivers glance back and forth between the roadway and system to check their progress along the visual map, to ensure they make the correct navigational decision. Thereby, reducing their own uncertainty regarding the accurate selection of roadway for an upcoming navigational manoeuvre.

Previous literature has reported that the experience of navigational uncertainty can reduce the mobility of individuals who are cautious of travel in unfamiliar environments, with drivers experiencing frustration or anxiety when they are unable to navigate effectively (Barrow, 1991; Burns, 1997). The use of an electronic navigation aid can assist users by automating the task of route planning, which can be a source of stress to the individual, and also by providing navigational assistance throughout a journey - potentially allowing the driver to focus on the primary, safety-critical task of driving.

The literature has also highlighted the efficiency advantages afforded by SatNavs, with those drivers using an electronic navigation aid benefitting from shorter journey times and travelling fewer miles to reach their destination compared to individuals navigating with a paper map (King, 1986; Streeter & Vitello, 1986; Speake & Axon, 2012). Additionally, unlike a paper map, a SatNav is able to visually and aurally represent a route, providing added value for motorists with limited spatial awareness (Lee & Cheng, 2008).

However, use of this navigational assistance is not without its problems. A survey (2015) conducted by the British road safety charity Brake has indicated that, of the 1000 drivers questioned, more than one in seven individuals (15%) using a SatNav device have performed an illegal or risky manoeuvre to correct mistakes made when following SatNav instructions. Additionally, one in fourteen (7%) drivers have had a near miss, having to swerve or brake rapidly to avoid a hazard, because they were distracted by a SatNav. This figure rose to one in ten (11%) amongst young drivers. These figures are further supported by the literature which has emphasised the tendency for drivers to follow inaccurate system guidance, even in instances where following these erroneous directions were perceived as dangerous or illegal (Forbes & Burnett, 2007). Indeed, the literature has highlighted the concerning frequency of media reports in which people are reportedly "*endangering themselves or others and/or causing extensive damage property damage due in part to their interaction with a personal navigation technology*" (Lin, Kuehl, Schoning, & Hecht, 2017, pg. 1154).

Additionally, wider academic literature has previously questioned the workload and distraction potential of navigation devices, suggesting that the employment of such systems can result in erratic lane changing behaviours, sudden braking and the inappropriate use of indicators from vehicles who are unsure of the correct route to follow (Burnett, 2000). Additionally, the literature has proposed that issues with the navigational display and the phrasing of wayfinding prompts can hinder the correct interpretation of navigation information (Forlizzi, Barley, & Seder, 2010).

Whilst a substantial corpus of vehicle navigation literature understandably focuses on distraction issues, usability and interface design (Kujala, Grahn, Mäkelä, & Lasch, 2016; Jensen, Skov, & Thiruravichandran, 2010; Lavie, Oron-Gilad, & Meyer, 2011), an increasing number of researchers are examining the wider, human implications of automating route planning and following. A further aspect where SatNavs have not compared favourably to the use of

paper maps is their ability to connect the driver with the world around them (Leshed, Velden, Rieger, Kot, & Sengers, 2008, April). This work has associated the use of electronic navigation devices with driver disengagement from the environment (Lorimer & Lund, 2003); Asserting that navigating with a SatNav supports only a reduced, fragmented understanding of a landscape (Lorimer & Lund, 2003), therefore impeding an individual's cognitive map formation, (i.e. SatNavs lead to poor reconstruction and memory of the environment that the individual is driving through) (Antrobus, Burnett, & Krehl, 2016; Burnett & Lee, 2005).

This literature has suggested that the resulting environmental disengagement, experienced by SatNav users, may be the effect of the content of navigation instructions and timing at which they are issued (Antrobus, Burnett, & Krehl, 2016; Brown & Laurier, 2012; Burnett & Lee, 2005; Leshed, Velden, Rieger, Kot, & Sengers, 2008) Specifically, authors have argued that drivers following turn-by-turn system guidance use fewer mental resources in comparison to drivers who utilise a traditional map reading approach (Noy, 1997). Here, the authors propose that inclusion of environmental descriptors in navigational prompts can help to promote environmental engagement and the subsequent formation of survey (configurational) knowledge (i.e. a higher order level of map-like spatial knowledge that builds on landmark/route knowledge and facilitates tasks such as detouring, distance/direction estimations to unseen targets etc). By providing drivers with varied, environmental cues authors suggest that the current navigational model of *'docile driver' who blindly follow(s) the instructions given* (Brown & Laurier, 2012, pg 1628), can shift to one where drivers inspect their environment and question navigational cues, with systems aiming to assist and educate instead of direct. That is, instead of 'telling the driver where to go' systems should provide drivers with the information they need to successfully navigate to their destination.

Similarly, the work of Burnett and Lee (2005) distinguishes between 'active' and 'passive' methods of driving navigation. According to this

distinction, active navigation methods refer to approaches which reference the environment and involve the driver in route planning, requiring drivers to maintain a sense of orientation throughout the journey. In such approaches drivers must utilise this orientation information to make specific turn decisions, often where there are a number of options available. Conversely, within passive systems the navigational decisions required by the driver are relatively simple, requiring fewer mental resources. For example, drivers must process basic turn-by turn information – such as an ego-centred direction (left, right, straight on) together with proximity information regarding the adjacency to a particular action (next turn, 2nd exit) over relatively short time periods (one to two manoeuvres ahead). The driving simulator study reported by Burnett and Lee (2005) suggests that in using more active forms of navigation people acquire spatial knowledge more readily. Consequently, drivers would require less exposure to the environment before they reach a point of system independence, which represents an important point in spatial knowledge acquisition.

However, the authors suggest that drivers utilising these more active forms of navigation would generate higher, initial workload values, than those following more 'passive' methods. Though, with further exposure to the environment these workload values would reportedly drop off at a quicker rate than with passive navigation methods. Figure 1-1 below (taken from Burnett & Lee, 2005) hypothesises the relationships between spatial knowledge and navigation task demands proposed by the authors.

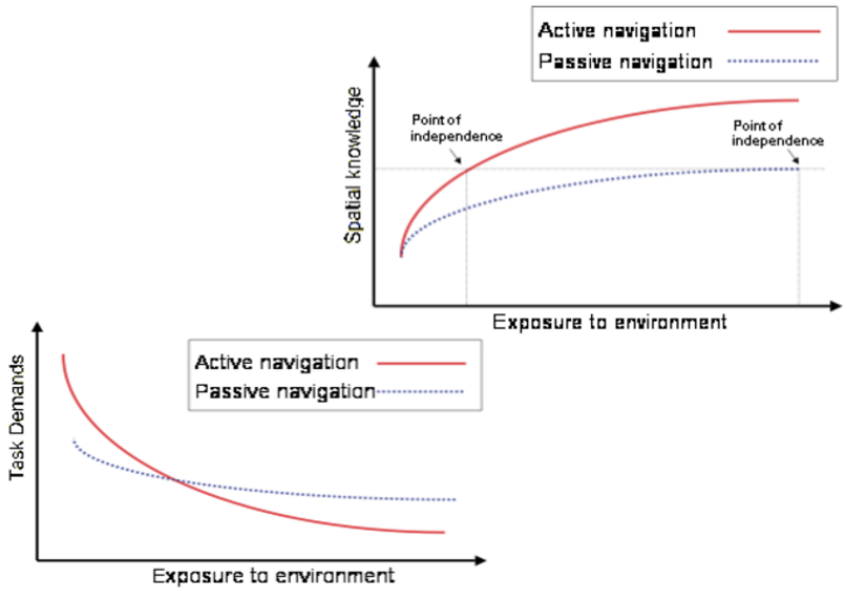


Figure 1-1: Hypothesised relationships between navigation task demands & cognitive map development (taken from Burnett and Lee, 2005)

1.2 USING THE DRIVER-PASSENGER MODEL TO INFORM IN-VEHICLE NAVIGATION DESIGN

A number of researchers have reasoned that navigation whilst driving works 'best' when performed collaboratively (Forlizzi, Barley, & Seder, 2010; Perterer, Sundström, Meschtscherjakov, Wilfinger, & Tscheligi, 2013; Perterer, Meschtscherjakov, & Tscheligi, 2015) -this is, when the driver is assisted by the passenger, providing information in a timely fashion, checking their understanding and offering clarification. On this basis, Perterer, Meschtschtscherjakow & Tscheligi (2015) made recommendations for a passenger-facing advanced driver navigation system. Acting as a secondary system, the authors proposed drivers should still have access to traditional, driver-facing turn-by-turn guidance so that they are able to navigate routes alone, without passenger assistance. However, in demanding driving situations (e.g. unfamiliar areas, bad weather conditions or during night time driving), the passenger could assist the driver with the navigation task. To do this, passengers were provided with tablet-based systems which provided enhanced environmental information, beyond traditional

turn-by-turn prompts. This enhanced information included a route overview, a detailed map containing landmark information and a number of 'demand' situations made easily identifiable by corresponding landmark information. Using this enhanced information, passengers could assist the driver during demanding periods so that drivers could focus their attention on the safe control of the vehicle. Whilst such a tool could provide workload alleviation for the driver during demanding periods and assist with environmental engagement, the presence of an in-car passenger is not always guaranteed, nor practical. Therefore, drivers may only benefit from such a device sporadically when they are accompanied on journeys.

Whilst this thesis is not proposing the development of passenger facing systems to assist drivers with the navigation task, there are a number of components, grounded within the driver-passenger model, which may help to promote in-car communication and assistance behaviours. Building upon the previous work of Clark, Stanton and Revell (2018) who explored how human verbal dialogue can improve vehicle hand over in level 3 & 4 autonomous vehicles, analysis and exploration of the components within driver and passenger communications can be used to enhance our understanding of in-vehicle interactions and driver information requirements. Perterer, Meschtschtscherjakow, Wilfinger & Tscheligi (2013) analysed this cooperative relationship and the communications of driver-passenger pairs in an ethnographic observation which revealed a number of behaviours performed by passengers to assist and support drivers throughout the course of the journey. One such behaviour included the adoption of various communication strategies according to driving context. The authors referred to this as the possession of 'common ground', stating its importance to successful in-car communications. Each observed instance of 'common ground' saw passengers mediating verbal interactions according to the perceived demand of the driving task. Passengers could be observed withholding and delaying interactions until driving manoeuvres had been completed (e.g. lane changes). Conversely, more frequent interactions were

evident during hazardous road conditions (e.g. driving on snow covered roads), where passengers repeatedly checked the well-being of the driver.

When travelling together, driver and passenger share the same environment, and they are able to take into account what one another sees and experiences. This can include an understanding of the focus of the other's attention or where he or she may be pointing. Additionally, driver and passenger frequently have a pre-existing, personal relationship with one another. This means that the passenger can have an awareness of the driver's prior knowledge and experience, thus enhancing their 'common ground', such that guidance and interactions can be tailored according to driver preference and competence. Forlizzi, Barley and Seder (2010) examined how varying familiarity between driver-passenger pairs can influence in-car interactions and how each pairing approaches a navigation exercise. Findings illustrated that previously unacquainted driver-passenger pairs communicated with one another formally, with in-car interactions solely focused on the navigation task at hand. Alternatively, parents within parent and child collaborations used the navigation task as a teaching exercise, with passengers situating navigational prompts in the driver's previous experience, giving meaning to places observed on the drive. Finally, more informal interactions were observed within married couple pairings. Here, conversations frequently drifted from the navigation task and navigational information was provided at a more conversational level, with passengers using their shared, common knowledge to situate route instructions, with drivers frequently challenging or ignoring instructions if they felt there was a more appropriate navigation choice. These observed, varying interactions, highlight the diversity of navigational interchanges, with each passenger approaching the navigational task differently according to driver experience and preference. Something which is not currently considered in electronic navigation systems, which utilise a one-way information exchange, relaying direct, task-oriented navigational prompts to drivers.

In addition to personalising route instructions, Forlizzi et al (2010) reported that passengers informally discussed and directly referenced landmark information within their navigation instructions – a practice which the wider literature has suggested is common amongst human generated route instructions (Michon & Denis, 2001). Indeed, within Allen's (1997) rules for effective direction-giving the importance of referencing landmarks at navigational choice points is emphasised, with Allen (1997) reasoning that performance is better when instructions are more detailed and frequently refer to landmarks, reducing navigational uncertainty at places where directional choices have to be made. This is in contrast to how electronic navigation systems frequently present wayfinding information. Such systems predominantly issue turn-by-turn navigational guidance, utilising distance to turn information alongside directional (left and right) instructions. Such verbal prompts are predominantly issued alongside a visual representation of the junction/driver's immediate environment.

The literature has long discussed the incorporation of landmark information within navigation system prompts (May, Ross, & Osman, 2005; May & Ross, 2006; Reagan & Baldwin, 2006), reasoning that systems which provide drivers which this rich information promote engagement with the wider environment, making in-vehicle navigation more effective (fewer navigational errors), efficient (reduced workload, changes to driving behaviours e.g. lane keeping) and satisfying (increasing driver confidence) to use (May & Ross, 2006; Bengler, Haller, & Zimmer, 1994). However, there remain a number of challenges associated with relaying landmark information to drivers. Namely, the creation of the underlying database of landmarks from which systems would draw wayfinding information and select appropriate, salient landmarks within the driver's immediate environment, which are able to be quickly identified.

Rather than focus on the appropriate selection of landmarks for use within vehicle navigation systems, this thesis will explore the environmental landmarks which passengers (acting as navigators)

naturally refer to within route instructions and how drivers interpret and deal with such references.

Due to the realities of everyday car travel, it is not always possible, or practical for drivers to be accompanied by a passenger, a large proportion of journeys now see drivers travelling alone, which means they are unable to able to make use of the contextually sensitive, interactive assistance of an in-car passenger. However, the recent proliferation of voice-based systems has prompted researchers to consider the advantages of combining the knowledge of driver-passenger collaborations and speech-based interfaces to explore the employment of voice technologies within vehicles, which are capable of simulating an obliging, loquacious passenger (Large, Clark, Quandt, Burnett, & Skrypchuk, Steering the conversation: a linguistic exploration of natural language interactions with a digital assistant during simulated driving, 2017).

1.3 SPEECH BASED SYSTEMS AND HUMAN FACTORS CONCERNS

Despite Barrow's early assertion that "*probably the most time demanding piece of electronic equipment which could be installed in a car is a monitor*" (1991, p.1248), modern vehicles now almost universally contain at least one visual interface to communicate a vast array of information. Drivers are now able to receive and follow navigation information presented on interfaces, select and move between radio stations and other music platforms and newer vehicles often provide drivers with a road legal link to their smartphones. Despite this continual growth of functionality amongst in-vehicle information systems, concerns remain surrounding their potential to degrade driver performance (Bach, Jæger, Skov, & Thomasse, 2009; Nwakacha, Crabtree, & Burnett, 2013). It is, in part, due to these performance and workload concerns that the literature (Carter & Graham, 2000; Neßelrath, Moniri, & Feld, 2016) has offered voice-based interfaces as an alternative in-vehicle interaction method, as

such interfaces would purportedly allow drivers to interact with systems with minimal visual and manual distraction.

As speech is a fundamental means of human communication, using spoken language as an archetype for human-system interaction seems intuitive. Speech recognition interfaces have a number of advantages within the car environment. As an interaction method, speech communication is both hands-free and eyes-free, allowing drivers to keep their hands on the steering wheel whilst maintaining visual attention on the roadway. Additionally, as human-human speech is such a natural, everyday activity, humans would require minimal to no training in order to actively engage with systems designed to process natural language and generate appropriate, conversational responses. Indeed, the literature has explored the implementation of speech interfaces for a number of in-vehicle tasks including: navigation destination entry, email processing, mobile phone dialling and music selection tasks (Barón & Green, 2006). Here, the literature suggested that utilising speech-based interfaces within vehicles improved driving performance, enhancing secondary task performance, whilst reducing driver workload and improving eye glance behaviours.

In addition to the performance benefits widely reported from previous research, there are the wider social perspectives on the use of speech – especially natural language systems. Speech is the primary means of social identification amongst humans (Barthes, 1977) and from an early age we develop the ability to quickly extract salient, social and paralinguistic cues from conversations (Barthes, 1977), quickly making determinations about the speaker's gender, emotion, personality and even hometown from the pitch, cadence, volume and rate of their speech (Nass & Brave, 2005). In addition to extracting this granular detail from our conversations, we also, unconsciously, make use of conversational principles, to ensure that our colloquies work effectively and do not break down. These principles, referred to as conversational maxims have become so intertwined with language we are frequently unaware of their importance (Thomas, 2014). Maxims related to quantity, relevance and clarity ensure that we provide no

more or no less information than the conversation demands (quantity), whilst asking the right questions or making appropriate comments to ensure the advancement of the conversation (relevance), finally the maxim of clarity relies the propagation of 'common ground' between speaker and listener. We achieve this by ensuring our responses are tailored to our listener by adopting words and referencing concepts which we believe they are able to understand (Grice, 1975).

As humans, we are so proficient in our use of speech that we frequently employ all of these principles at once, quickly making numerous determinations about speakers without conscious thought. This represents a considerable challenge for speech-based interfaces, if we are to interact with these systems in the same way as another human, designers must consider the appropriateness of system responses and how best to design systems to mitigate user frustration and acceptance. Indeed, the literature has made recommendations for how systems should interact with users in instances of misrecognition, an important feature to consider when even systems with a 95 percent word recognition accuracy, will have one recognition error in every 20 user commands or initiations (Olive, 1997). In these cases of misrecognition, research suggests that voice-based systems should behave 'modestly', that is, systems should take the blame for any misrepresentations using statements such as 'the system could not process your selection, please say again'. Utilising modesty, within the system's language subsequently makes users feel better and more comfortable with the interface. However, systems which use this 'self-criticism' approach, suffer from attributions of blame, in a similar way to humans who blame themselves for mistakes. This is because there is a generalised belief that when people say things which they should not be motivated to say (i.e. taking responsibility for a mistake), they are likely to be telling the truth. Therefore, in the system's case, use of this modest, 'self-critical' language means that users perceive these systems as less competent, taking the interface at its word when it professes to have performed poorly.

These nuances of human speech are of particular importance when considering natural language system design, as research has suggested that during interactions with voice-based systems, humans are unable to overcome their evolutionary instincts, continuing to impute human-like characteristics to system outputs. Subsequently, attending to and interacting with voice outputs in the same way whether they are human generated or machine synthesised, with such behaviours enduring even when an individual is consciously aware that the speech they are attending to has a non-human origin.

Our inability to overcome the evolutionary instincts associated with speech-based interactions therefore allows designers to manipulate these behaviours through strategic system design. For example, previous work has shown that varying the linguistic characteristics and speech content of system interactions can influence an individual's learning, trust, performance and even their buying habits (Nass & Brave, 2005). Large, Clark, Quandt, Burnett, and Skrypchuk (2017) suggest that this knowledge coupled with continual developments in software integration, personalisation and context awareness mean that in addition to advancements in linguistic competences, modern speech-based interfaces are becoming *increasingly intelligent and socially aware* (Large et al, 2017, pg. 54).

Indeed, the recent proliferation in Artificial Intelligence (AI) systems such as Siri, Cortana and Alexa, enables users to perform a plethora of tasks using voice commands. Their use of 'smart' technology means they interact with consumers using human-like linguistic features or 'personalities' (communicated via speech and language characteristics) such agents are now beginning to acknowledge and respond to the communicative feedback of users, adapting their subsequent 'behaviours' to the interlocutors needs and preferences. Whilst these assistants were not primarily designed for the in-vehicle environment, the literature points to the potential for use of such AI systems within the driving domain, where their 'eyes and hands free' interaction method could offer real safety advantages (Large, Clark, Quandt, Burnett, & Skrypchuk, 2017; Large, Burnett, Anyasodo, &

Skrypchuk, 2016). In addition to the proposed visual demand advantages and the intuitiveness of speech-based interactions, voice-based systems could offer researchers an opportunity to reengage drivers with their environment by offering voice-based navigational information which references the world around them. Simulating a loquacious passenger, navigation systems could utilise voice technologies in navigational dialogue, moving away from the one-way information exchange of current systems, to a two-way interaction model where the driver is able to question the navigational information which is issued, prompting the system for clarification should they require additional information.

1.4 SCOPE AND AIMS OF THESIS

This section will describe the aims of the research and the main contributions of the thesis. For clarity, the aims which are presented below intend to inform natural language system development, rather than providing any input into their technical development.

Overall aim:

- Understand how drivers and passengers interact when navigating as a means of informing future HMIs that utilise natural language

Specific aims:

1. Explore the relationships between driver workload and environmental engagement when using active versus passive navigation systems
2. Develop design principles for navigation natural language interfaces that adopt a long-term perspective in the development of spatial knowledge
3. Create a series of descriptive models of active and passive wayfinding methods which depict the relationship between navigational method, driver interaction and subsequent environmental engagement

Objectives:

i. Conduct a literature review focusing on driving navigation, environmental engagement, wayfinding dialogue and speech-based interfaces
ii. Develop a methodology appropriate for the study of navigation in a driving context and the effectiveness of varying navigation methods, including natural language interfaces
iii. Conduct a series of on-road trials to explore how both active and passive navigational methods impact driver workload and environmental engagement

1.5 STRUCTURE OF THE THESIS

The thesis is structured as follows:

Chapter 1 - Provides a general introduction, background to the research, aims and objectives and organisation of the thesis.

Chapter 2 – This thesis naturally brings together literature and research from a number of different fields and disciplines. The relevant research literature is therefore extensive and diverse and includes areas such as: Spatial knowledge acquisition and the cognitive map, human and driving navigation research, driver distraction and workload and speech-based interfaces.

Chapter 3 - Describes and justifies the methodological approach adopted in this research. The methods which have been used within this thesis are then discussed – their advantages and limitations, and relevance for use. The development of and implementation of these methods are then further detailed in their respective chapters.

Chapter 4 - Details the experimental methodology utilised within the on-road trials within this the thesis – SatNav, Informed passenger and Collaborative experimental conditions are defined, along with the demographics and recruitment details of the participant cohort. All apparatus and post-trial tests employed within trials are detailed.

Finally, the on-road test environment is discussed alongside any methodological adaptations (e.g. due to seasonal considerations) which were required to retain experimental control within the dynamic on-road environment.

Chapter 5 - Reports results related to workload measures (NASA-TLX, TDT, eye tracking data) recorded in the first three on-road trials. These trials saw participants navigate the same three intersecting routes, twice, one week apart. Participants were guided through these routes using different navigational aids including; SatNav, informed passenger, or collaborative passenger.

Chapter 6- Reports results related to route learning measures - once participants had completed their final, second drive they were required to complete a battery of post-trial route learning tests to provide an indication of acquired landmark, route and survey knowledge. This data was examined for differences between experimental/ navigational condition (Satnav, Informed passenger, Collaborative passenger).

Chapter 7 – Discusses the findings of chapters 5 & 6 and the differences observed across experimental conditions. These results are then discussed in terms of how they informed guidelines for the next phase of on-road trials - a natural language navigational assistant (NAV).

Chapter 8 - Presents the methodology used to create a navigational transcript from the wayfinding information contained within collaborative partnership dialogue - the highest rated Collaborative transcripts (the navigational instructions which resulted in the highest route learning scores in drivers) were analysed for common features and novel content which may play a role in higher route learning scores. Transcripts were firstly separated into junction specific guidance creating a mega description for each junction. This lengthy script was then reduced by eliminating all non-essential navigational information, resulting in a succinct navigational transcript for use in the NAV NLI which was employed within the next phase of trials.

Chapter 9 – Provides an overview of the technological solutions employed during the next phase of testing, detailing the Wizard-Of-Oz approach utilised to issue navigation information to participants, providing justification for use of this approach. Secondly, results from the NAV condition are presented (workload, visual behaviour, environmental engagement and system interaction) and compared against the findings observed within the earlier SatNav condition.

Chapter 10 - Discusses the main findings of thesis and examines them in relation to previous literature. Contributions of the work of this thesis are then highlighted, and overall discussion points and limitations addressed. Chapter 10 concludes by highlighting the value of the earlier contributions, and makes recommendations for future research.

1.6 PAPERS TO EMERGE FROM THESIS

Antrobus, V., Burnett, G., Krehl, C., Skrychuk, L., Mouzakitis, A. Adaptive HMIs for In-Vehicle Navigation Systems. Adjunct Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '15), September 1-3, 2015, Nottingham, UK.

Antrobus, V., Burnett, G., Krehl, C., Skrychuk, L., Mouzakitis, A. Human-Machine Interface Design for Vehicle Navigation Systems: The Need to Balance Short-Term Versus Long-Term Distraction Effects. 4th Conference on Driver Distraction and Inattention, November 9-11, 2015, Sydney, Australia.

Antrobus, V., Burnett, G., & Krehl, C. (2017). Driver-passenger collaboration as a basis for human-machine interface design for vehicle navigation systems. Ergonomics, 60(3), 321-332.

Antrobus, V., Burnett, G., Skrychuk, L. "Turn left at the Fairham pub" Using Navigational Guidance to Reconnect Drivers with their Environment. Adjunct Proceedings of the 8th International Conference

on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '16), October 24-26, 2016, Ann Arbor, MI, USA.

Antrobus., V. "Is it left at the next lights?" Encouraging Conversation in Navigational Dialogue to Reconnect Drivers with their Environment and Manage Workload. 49th Annual UTSG Conference, 4-6 January, 2017, Trinity College Dublin, Dublin, Ireland.

Antrobus, V., Large, D.R., Burnett, G. (2018). Enhancing Environmental Engagement with Natural Language Interfaces for In-Vehicle Navigation Systems. The International Navigation Conference (INC2018), Bristol, UK

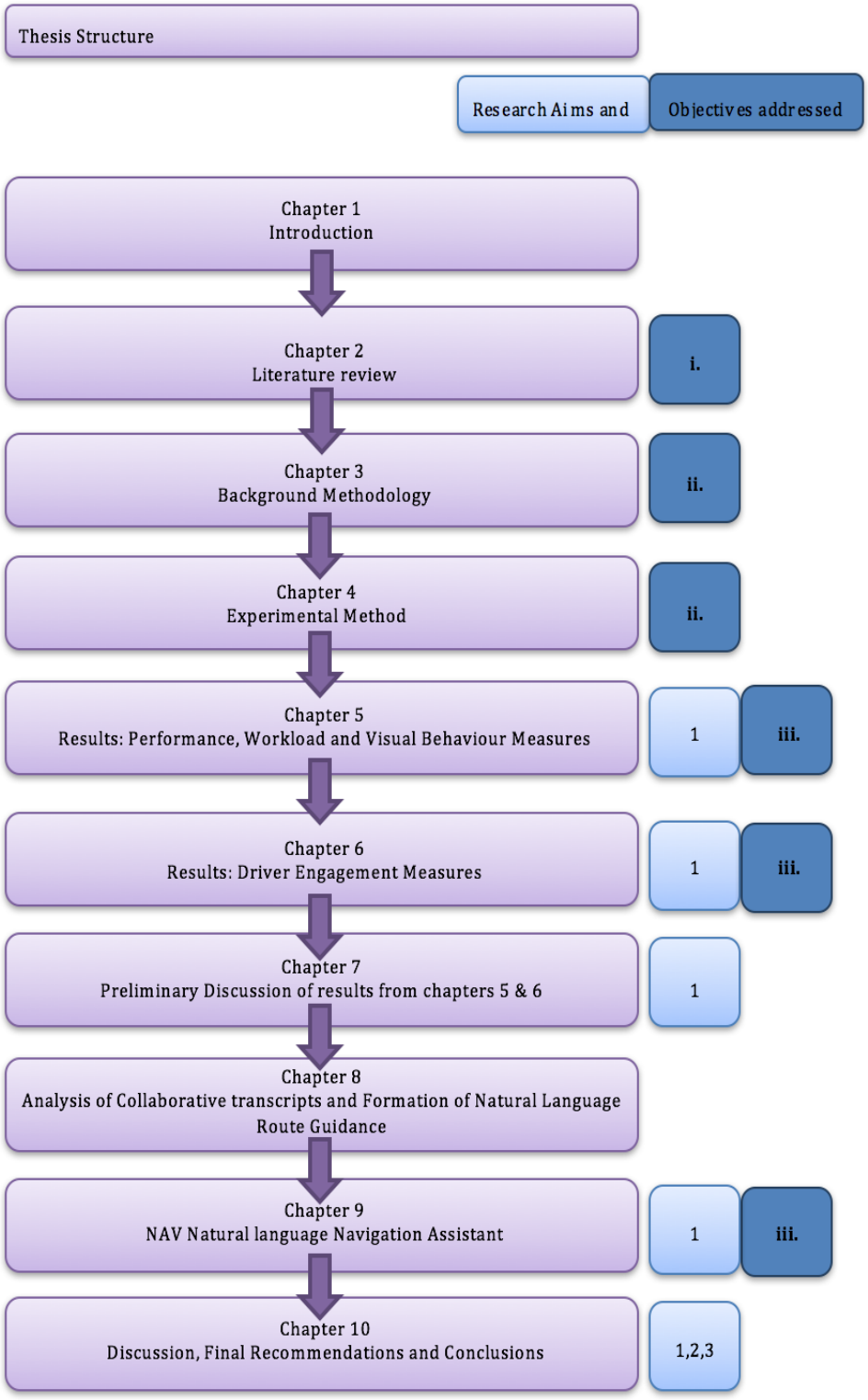


Figure 1-2 Thesis structure and aims

2

CHAPTER 2: LITERATURE REVIEW

The thesis brings together literature and research from a number of different fields and disciplines – including human geography, environmental psychology, human factors engineering and the social sciences – and utilises techniques and methodologies from these fields of research. The relevant research literature is therefore extensive and diverse, and includes topics such as spatial cognition, human navigation behaviours, driving navigation technologies, distraction, workload and environmental disengagement. Although the thesis draws inspiration from all of these areas, it is fundamentally grounded in driving navigation technologies and human factors, and it is here that it aims to inform. The literature is therefore presented and reviewed from this perspective.

The literature review is structured as a progression from a more general discussion around spatial knowledge acquisition and human navigation through to the more specific use case of driving navigation and the concerns, presented in the literature, of distraction, workload and environmental disengagement. A subsequent discussion is presented around the development of future natural language in-vehicle navigation technologies which are modelled on the contextually sensitive, interactive assistance of the in-car passenger. Figure 2-1 on the following page presents each of the research areas covered by the literature review in this chapter:

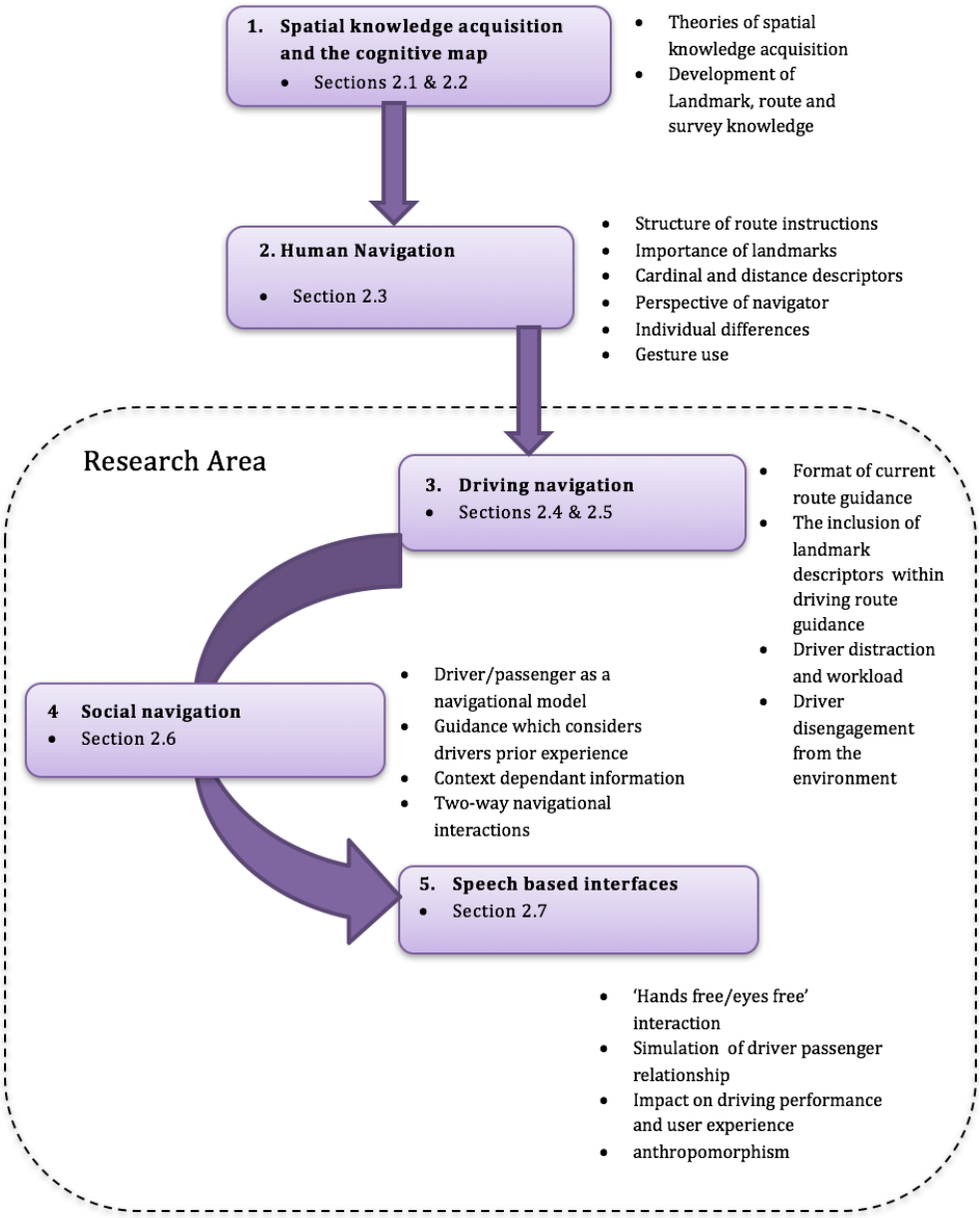


Figure 2-1 Research areas covered by literature review

2.1 DEVELOPMENT OF ENVIRONMENTAL KNOWLEDGE

The literature identifies three competing arguments which attempt to explain how humans acquire spatial knowledge in their early years. Each of these arguments can be defined as fundamental positions on a continuum, where at one end, spatial ability is viewed is an innate faculty, similar to language acquisition, where any acquired knowledge or behaviours are of a hereditary and biological nature (nativism). At the other end of this continuum is the idea that environmental acquaintance is solely the result of external environmental forces and

lived experience (empiricism). The third argument seeks to strike a balance between these two polarising positions, the constructivist position instead asserts that spatial ability is the result of an interaction between inherited skills and lived experience.

Nativism

Nativism suggests that children are born with predispositions and react to their environment in pre-ordained ways, these reactions occur independently of lived experiences or a learning context. The premise of this point of view is that knowledge is innate and therefore advances alongside biological maturity. Stea (1976) suggested that the cognitive mapping (refer to section 2.2) of an environment is an evolutionary adaption and an individual possessing a 'sense of place' is a vital part to human survival. In this sense, he supported Hewes (1982) assertion that 'geographical awareness' was a vital part of human survival. However, whilst there is some evidence that the brain possesses inherently broad structures that coordinate our spatial experience there is little support for any innate knowledge.

Empiricism

Empiricism takes an opposing view to nativism. It suggests that all behaviours and knowledge are shaped through interactions and exchanges with the environment. According to Langer (1969) '*the child is born empty of psychological content into a world of coherently organised content… like an empty slate he is written upon by external stimuli: like a wax tablet he stores the impression left by these stimuli*' (p.51). Matthews (1992) summarized three empiricist theories. The first is the clearest form of stimulus-response theory where an individual's actions or knowledge (responses) are determined solely by the external environment (stimulus). The second is a variation of stimulus-response theory where expectancies influence the response of the individual within the environment (stimulus). The third empiricist viewpoint is derived from cognitive behaviourism (Tolman, 1948). Here, the cognitive map is the representation which holds basic information spatial relations built through prior experience, this

internal representation mediates the responses of the individual within an environment. However, the empiricist tradition has been criticised from a number of perspectives. Firstly, for it's over reliance on animal observations on which it bases its assertions. Secondly, for its favoured methodology, this is, small scale laboratory studies which lack ecological validity.

Constructivism

Constructivism can be seen as an attempt to amalgamate the two polarising positions of nativism and empiricism. From the constructivist perspective knowledge of the environment is not just accumulated and imprinted upon an individual (empiricism), nor is it the unfurling of pre-determined knowledge over time (nativism). Instead, it is viewed as a continually evolving process. According to Piaget and Inhelder (1956) this continual integration of new knowledge is defined as assimilation and accommodation. Assimilation is the integration of new information into existing ideas or perspectives. Accommodation is the reorganisation of the individual's perspectives to cope with the assimilated information. In other words, information is continually amassed from experience and interactions with the environment and the process of assimilation and accommodation determine how this information is organised and structured.

These theoretical perspectives have generated discussion surrounding the origins and maturation of spatial knowledge. However, on their own they are more broad ideas about the alternative ways in which environmental knowledge is gathered. Whilst offering insight into the potential learning processes these ideas do not lend themselves easily to experimental examination. They are instead offered here as an illustration of the competing perspectives within the literature. Whilst it is not within the scope of this thesis to debate these competing perspectives in more detail, a position is adopted throughout this body of work that the nature of environmental interactions and experiences can shape an individual's spatial knowledge and abilities. It is this spatial knowledge and how an individual thinks about, and moves

through their environment which has been the subject of much debate in the literature (Walmsley & Lewis, 2014; Kitchin & Blades, 2002; Denis, 2017). It is the position of a breath of work that interactions and exchanges with an environment influence the spatial knowledge system, also commonly referred to as an individual's cognitive map.

2.2 SPATIAL KNOWLEDGE ACQUISITION AND THE COGNITIVE MAP

The concept of the cognitive map was first put forward by Tolman (1948) who proposed that following a period of sufficient environmental learning animals (including humans) begin to spatially represent their surroundings in a map like format. Whilst some authors have questioned the validity of this metaphor many researchers accept the traditional definition put forward by Downs & Stea (1973)which states that *cognitive mapping is a process composed of a series of psychological transformations by which an individual acquires, recalls, and decodes information about the relative locations and attributes of the phenomena in his everyday spatial environment* (pg.7).

Early literature has suggested that this transformation of environmental knowledge into a holistic, internal mental map begins in our early years (Herman & Siegel, 1978). In a series of studies Herman and Siegal (1978) asked children aged five to ten years, from various school grades to repeatedly walk through a large-scale model town, composed of simplistic pathways and buildings, placed at various locations. After experiencing this scene children were asked to accurately reconstruct building placement within the town. Results indicated that when children as young as five years of age were given repeated walking and reconstruction experience their building placement accuracy dramatically increased. Indeed, after performing the final building reconstructions placement accuracy was essentially equal across all age groups indicating that children as young as five years are capable of employing Euclidean spatial concepts. Once these internal spatial structures, formed in our early years, become established over time the literature has suggested that their use can have far reaching applications beyond navigation. Subsequently

cognitive mapping concepts have also been successfully applied to the tracking of criminal activity, search and rescue operations and the study of population movement patterns within urban areas (Jackson & Kitchin, 1998). Essentially the examination of cognitive maps promotes the understanding of where people want to go and why (Kitchin R. M., 1994).

Whilst cognitive mapping theories have important, broad applications in numerous fields, the most established application of this environmental knowledge remains within the field of navigation and spatial problem solving (Arthur & Passini, 1992). That is, individuals who are able to form comprehensive cognitive maps can execute various navigation tasks, with little cognitive demand, using their own internal representations of the environment. Individuals with these strong environmental representations are afforded greater route choice flexibility meaning that they are able to select the most appropriate routes for particular journeys (e.g. scenic routes versus efficient routes), they are also able to respond to the changing driving context and select alternative routes in unexpected instances e.g. in heavy traffic and road closure incidences. Burnett and Lee (2005) state that a well-formed cognitive map provides an individual with a wider transport efficiency and social function, as the navigational skills afforded by these mental representations mean that individuals may be more willing to navigate on behalf of others, providing verbal directions as a passenger, to pedestrians or even over the phone.

Many authors have defined the process that individuals go through to acquire spatial knowledge differently, though it is generally agreed that individuals move through several developmental stages or levels (Gould, 1989; Stern & Leiser, 1988). Although the literature specifies that these are discrete, independent stages that individuals may not necessarily progress through in order it is generally agreed that there are three levels that individuals move through when forming a cognitive map:

1. Landmark knowledge - individuals remember prominent or conspicuous objects or distinctive road views within the environment.

2. Route knowledge – individuals begin to link landmarks which appear along a route, remembering the order in which they appear, the distances between them and the actions which are performed at their location.
3. Survey knowledge – the memory which is created when landmark and route knowledge are integrated to form a comprehensive, map-like spatial representation of an environment.

Earlier literature has suggested that the process through which individuals acquire environmental information subsequently informs the content and veracity of the cognitive map which is formed (Richardson, Montello, & Hegarty, 1999). Traditionally individuals would amass this knowledge through the direct exploration of their environment or indirectly via the study of formal maps or through following verbal instructions. In this sense in-vehicle navigation systems present a novel means through which individuals interact with their environment when traversing routes, elements of the navigation task which would have been performed using an individual's prior experience or through the study of traditional maps are now automated, resulting in individuals being distanced from the route planning and tactical aspects of their journey. This has prompted researchers to question how interaction with in-vehicle navigation systems affects an individual's relationship with their environment and subsequent cognitive map formation (Leshed, Velden, Rieger, Kot, & Sengers, 2008; (rown & Laurier, 2012; Burnett & Lee, 2005; Forlizzi, Barley, & Seder, 2010).

Leshed et al (2008, April) conducted an ethnographically informed study where individuals were observed interacting with GPS devices on a number of pre-planned and artificial routes. These observations provided evidence that navigating with the assistance of these technologies promotes environmental disengagement. The authors explain that when individuals utilise navigation systems they have a reduced need to understand their current location within the environment and the geographical placement of their destination, meaning the drivers pay less attention to physical landmarks

throughout the journey and rarely require navigational assistance from others. This reduced need to feel oriented and keep track of locations in addition to the breakdown of the social navigation interactions prompted the authors to the state that use of navigation systems hinders the process of experiencing the physical world by navigating through it. The barrier created by the use of in-vehicle navigation systems means that drivers could remain detached from the environments they travel through, failing to establish the same level of familiarity that drivers utilising traditional methods are afforded. Earlier literature also questioned whether this dependence upon a GPS system for navigational guidance (Burnett & Lee, 2005; Jackson, 1996) ever truly allows users to reach a point of independence from the system and subsequently experience the workload advantages that navigational autonomy affords.

Burnett and Lee (2005) used a simulator trial to study how the method of navigation influences cognitive map formation and the workload experienced throughout the navigation task. Participants were asked to navigate through simulated routes using either traditional paper-based maps for route guidance or following the turn-by-turn prompts of a navigational system. The results of the study indicate that the use of vehicle navigation systems negatively impact cognitive map formation, with drivers who followed navigational prompts remembering fewer scenes experienced along the route. Additionally, these drivers were less accurate in their ordering of route images and drew simpler sketch maps of traversed areas, incorporating fewer landmarks than those using traditional methods. The authors reason that a major factor for these results is the depth of decision-making required by drivers in the two conditions. Where drivers utilising traditional paper maps are required to maintain their orientation throughout the journey, making specific turn decisions where there may be number of available options, drivers following automated navigational prompts instead are required to make relatively simple navigation decisions requiring few mental resources. Burnett and Lee (2005) reason that the dedication of these additional mental resources is associated with higher levels of stress which may

be the reason why individuals navigating with a map demonstrated better route knowledge than their GPS counterparts. Previous environmental psychology literature has asserted that the experience of stress can have a positive effect on cognitive map formation (Evans, Skorpanich, Garling, Bryant, & Bresolin, 1984). This is because individuals who are stressed are resource limited in aspects of working memory which means that they focus on the most obvious task elements (such as the order of events) rather than aspects which may require more processing.

These findings prompted Burnett and Lee (2005)to question whether the use of current passive vehicle navigation systems, where associated task demands are relatively low, can ever provoke individuals to work at a level which induces stress, subsequently encouraging cognitive map formation and fostering independent navigators. They argue that whilst these systems assist drivers in navigating, whilst keeping workload low drivers may never reach a point of independence from the system, continually relying on an external source of information to navigate. Ultimately this means that drivers may fail to form strong environmental representations and therefore never experience the lower levels of workload afforded by the ability to navigate using a strong internal cognitive map. These concerns have prompted a wealth of work to consider the benefits of learning orientated navigation systems where individuals could be guided through routes based on their prior experience or using navigational prompts which refer to environmental information to assist route learning (Pfleging, Schneegass, Meschtscherjakov, & Tscheligi, 2014; Reagan & Baldwin, 2006; Oliver & Burnett, 2008).

Oliver and Burnett (2008) conducted a driving simulator study to explore whether the criticisms of environmental disengagement associated with current Satnav technologies could be ameliorated through the use of novel, learning oriented navigation systems. The authors made adaptations to a basic turn-by-turn navigation system design, incorporating a range of additional features; including landmarks, compass bearings and previously traversed routes. This

additional information was communicated to the driver either visually (compass bearings/previously traversed routes) via the systems visual interface, or through the systems auditory route guidance instructions (landmarks). Findings revealed that users of the learning-oriented system displayed better memory for driven routes when compared to those drivers navigating using the basic turn-by-turn system. There was also evidence that participants utilising enhanced guidance developed more complete cognitive maps, and were able to draw more detailed sketch maps of the virtual world.

However, within post-trial interviews, participants indicted that the compass bearings and previously traversed routes, presented visually on the systems interface were not as useful as the auditory landmark information. Oliver and Burnett (2008) suggest that the compass and previous route information, may have been too subtle to make an impact over the short testing period. Whilst the authors go on to suggest that such information may have a greater impact on a driver's environmental engagement over time, drivers may instead benefit from incorporating information regarding previously traversed routes within the verbal prompts of systems.

So that systems are able to promote environmental engagement and encourage spatial learning we must first understand what environmental components influence spatial knowledge acquisition, the logical place to begin this exploration is in the natural language contained within navigational prompts.

2.3 NAVIGATION AND THE WIDER ENVIRONMENT

Previous work has looked at the development and information contained within route directions to further our understanding of how we perceive space and the elements within the environment that we use to navigate. Allen (1997) suggests that the route directions we provide are the linguistic expression of environmental information stored in our cognitive system, and through accessing this stored environmental information we can begin to understand individuals' mental representations of space and the information that they use to

guide themselves through routes. Previous literature has utilised a number of approaches in an attempt to access this stored environmental information within issued route descriptions. In one notable study Denis et al (1999) asked participants to orally describe a designated route which they were familiar with, subsequently using the corpus of participant route accounts to create a fundamental skeletal route description. This contained the key aspects of each participant narrative whilst eliminating any 'added value' descriptions deemed irrelevant by a separate cohort of participants. This approach suggested that route descriptions which were deemed to be 'successful' shared a number of common traits, including pairing the mention of a landmark with a prescribing action (e.g. at the church turn right) and descriptions which were succinct were preferable to those which were highly detailed (Daniel & Denis, 2004).

In later work, Lovelace, Hegarty & Montello (1999) utilised a number of methods to extract the spatial knowledge participants acquired after being 'walked through' a number of pre-defined routes. In a series of tests, participants were asked to identify 'on-route' images from an array, accurately retrace the path which they had previously travelled and write a set of route instructions for an individual unfamiliar with the area. Lovelace et al (1999) used the findings of this research to create a set of characteristics for good route descriptions. These include, but are not limited to:

1. Providing an individual with preview information about approaching choice point
2. Including landmarks at choice points
3. Issuing an individual with confirmatory information throughout the route to reassure them that they remain on the correct path
4. Using landmark information over street names
5. Presenting route instructions in a sequential manner
6. Limiting the use of 'added value' information

The works of Denis (1997)and Lovelace et al (1999) both highlight a number of key features associated with 'good' route directions. With the importance of landmarks within route directions being heavily

emphasised by both authors. Landmarks are discussed widely throughout navigational literature and can be defined as the physical features of an environment that are external to the observer (Burnett, 1998; Burnett, Smith, & May, 2001; Lynch, 1960). The physical elements of these landmarks may have an extensive range with the quality of a landmark being determined by its singularity, that is, its uniqueness or identifiable features that make it distinguishable from its surroundings (Lynch, 1960).

Allen (1997) acknowledged the navigational benefits of landmarks describing their use as environmental reference points, which act like markers, keeping an individual connected to their geographical starting point and their final destination, along a specific path of movement. However, Allen (1997) suggested that landmarks were just one environmental feature which individuals could refer to, throughout a journey, to assist wayfinding, suggesting that utilising the natural and artificial information contained within pathways and choice points could also aid route navigation. Pathways refer to the potential avenues of movement that an individual can follow; these include various roadways, streets and trails. However, choice points pertain to areas where a number of pathway options are available to an individual: junctions and intersections are common examples of these. The significant feature of a choice point is the potential for navigational error, by presenting individuals with a number of wayfinding options there is an increased probability that they may select the wrong pathway for their journey and move further away from their desired destination.

This increased likelihood for navigational error at choice points has led to authors (Allen, 1997; Allen, 2000; Denis, Pazzaglia, Cornoldi, & Bertolo, 1999) to suggest that landmark information is only beneficial to individuals when it corresponds to a decision point (Denis, Pazzaglia, Cornoldi, & Bertolo, 1999). Indeed Allen (2000) found that navigational errors occurred less when moving through routes containing landmark information at choice points in comparison with routes that contained landmark information at non-choice points, this

was of the utmost importance at the end of the route when demands on memory were highest. Allen (1997) reasons that the incorporation of landmark information at choice points allows individuals to build a mental representation of a route, this representation is constructed using these environmental features and so as an individual moves through the route they can continually fix their position to their location, comparing their current view to their mental representation of the space. However, the findings of Lovelace, Hegarty and Montello (1999) provide support for the use of landmark information at non-choice points. Reporting that individuals' subjective ratings of route quality for familiar and unfamiliar routes increased when landmark information was available at non-choice points. One possible explanation for this is that individuals like to use landmarks to check their progress along a route; therefore, the incorporation of these environmental features throughout route instructions allows individuals to continually check their orientation. However, it is important to note that Lovelace et al (1999) presented these directions to participants in written format rather than verbal instructions. Where individuals must remember a set of verbal directions to navigate, this richness of environmental information may overload working memory, resulting in errors and hindering navigation.

In addition to landmark information, previous work has considered the importance of cardinal (north, south, east and west) and distance descriptors in route directions. Hund and Minarik (2006) found that participants navigated through a model town faster, making fewer errors when using cardinal descriptors in comparison to landmarks. Taylor and Tversky (1996) bolster this support for use of cardinal information over landmarks, reporting that people took longer to read route descriptions containing landmark information and left and right turns compared to descriptions containing cardinal directions and distance descriptors. Hund and Minarik (2006) suggest that these findings provide support for the notion that landmark information is inherently more difficult to process than cardinal information. However, these findings are in contrast to those of Allen (2000) who

found that navigational errors were more frequent when following routes that contained cardinal descriptors than those containing landmark descriptors. It has been suggested (Hund & Minarik, 2006) that the scale of the space and the perspective of the navigator may provide an explanation for these differences in preference for cardinal and landmark descriptors. Studies that have shown an advantage for landmark descriptors have involved large-scale spaces where participants move through an environment, experiencing them through a ground level perspective (Allen, 2000; Lawton, 1996). In contrast, cardinal information was found to be superior when navigating small-scale spaces with an overhead perspective (Hund & Minarik, 2006). These findings have important implications for providing individuals with wayfinding information appropriate to their specific navigational scenario.

Previous work has highlighted this relationship between perspective of the navigator and the cues they use to move through space, looking specifically at route descriptors. Much of this literature distinguishes between the use of route and survey perspectives in navigation information (Hund, Haney, & Seanor, 2008; Padgitt & Hund, 2012; Taylor & Tversky, 1996). Route perspectives are comparable to mental tours of a route, adopting an intrinsic frame of reference they present individuals with a set of procedures for route navigation, describing the changing environment as the individual moves through it. Route directions will often contain landmark information and frequently use ego-centred left, right, forward and back as descriptors (Hund, Haney, & Seanor, 2008; Taylor & Tversky, 1996). In contrast, a survey perspective examines the environmental layout from above. Like viewing a map, an individual experiences the environment from a fixed, external viewpoint, the position of objects are described relative to one another and cardinal directions and distance information are the primary descriptors used to navigate the route (Hund, Haney, & Seanor, 2008; Taylor & Tversky, 1996). Whilst both route and survey perspectives can be effective, previous work has shown that people using route directions can easily become lost when straying from their designated route. This is in contrast to individuals using integrated

survey descriptions who have been found to navigate more successfully when deviating from their given route, finding efficient alternative routes and detours (Lawton, 1994; Saucier, et al., 2002). These findings suggest that those individuals who use a survey perspective when navigating are afforded a more complete mental representation of the landscape in contrast to those individuals adopting a route perspective who may learn a specific route independent from its environment, which subsequently hinders wayfinding should they veer off route. Despite this, recent work suggests that there remains a dislike for cardinal directions (Hund, Haney, & Seanor, 2008; Hund & Padgitt, 2010) with people indicating that they found their use unhelpful, particularly when they were unsure of a northerly direction (Devlin, 2003).

Although route descriptors, navigator perspective and the cognitive demands associated with route directions all have a marked effect on wayfinding ability, individual differences in spatial skills could also account for these observed differences in navigational ability (Hund & Nazarczuk, 2009; Kato & Takeuchi, 2003). One such individual difference is sense of direction or "awareness of orientation or location" (Kozlowski & Bryant, 1977, p. 590). Individuals with a good sense of direction explore their surroundings actively, remembering in detail the features of the environment. These individuals are capable of remembering new routes effectively, compared to those with a poor sense of direction (Padgitt & Hund, 2012). Conversely, unconfident navigators, or those with a poor sense of direction worry more about losing their way (Bryant, 1982), subsequently becoming lost more frequently in new buildings or cities (Lorenz & Neisser, 1986)resulting in feelings of increased anxiety (Kozlowski and Bryant, 1977). Gender differences have also been well documented in the literature, with previous research illustrating men's general preferences for survey perspective descriptions, in contrast to women who have typically been shown to prefer route perspective navigation information (Hund & Minarik, 2006; Hund, Haney, & Seanor, 2008; Lawton & Kallai, 2002). Additionally, women have been shown to present more landmark information in route directions, where men include more

cardinal descriptors (Cherney, Brabec, & Runco, 2008; Ward, Newcombe, & Overton, 1986).

Although individuals vary greatly in their navigational ability and information preferences, the use of gestures to convey spatial information is an action which is frequently seen to cross the gender and population divide (Alibali, 2005). Gestures can be defined as movements of the hands and arms, performed when the speaker is engaged with a difficult cognitive activity. Speakers habitually use gestures when producing linguistic units containing spatial information, these movements are usually intended to enhance or supplement their communicative statements (Allen, 1997), with individuals performing gestures more frequently when discussing spatial topics rather than abstract or verbal subjects (Alibali, 2005).

The literature has distinguished between two types of gesture; representational and beat gestures. Representational gestures are movements which are intended to convey semantic content by creating shapes, identifying placement or simulating motion trajectory, this classification of gestures is the focus within spatial cognition literature because of the ability of these movements to convey spatial information, relationships and actions. The second group of gestures are termed beat gestures which are simple movements, where the performance of these actions is unrelated to the sematic content within speech these movements are often utilised to keep the rhythm and flow of speech. The literature has suggested that the use of gestures to support spatial language can have a number of benefits for both the speaker and the addressee. Indeed, previous work has demonstrated the increased likelihood for gesture production when discussing spatial topics (Alibali, Heath, & Myers, 2001) and conversely the difficulty of conveying spatial information when gestures are prohibited (Rauscher, Krauss, & Chen, 1996), providing support for the notion that spatial discourse and gesture production are intrinsically linked. Gestures have been shown to support verbal descriptions of environments from varying viewpoints with speakers adjusting gesture movements to accommodate the

addressee perspective (route or survey perspective) (Emmorey, Tversky, & Taylor, 2000).

Previous work has also illustrated that speakers often intend their gestures to be communicative, with the frequency of a speaker's gestures increasing or decreasing dependent on whether the speaker was physically facing the addressee (Cohen, 1977). Following this, the performance of redundant gestures, or gestures which are matched with the content of the accompanying speech have been shown to facilitate comprehension of the message (Glenburg & Robertson, 1999) particularly when the verbal message is complex or ambiguous (Graham & Heywood, 1976;(McNeil, Alibali, & Evans, 2000; Thompson & Massaro, 1994). Therefore, the communicative significance of gestures is somewhat reliant on the quality of the associated speech.

With the literature pointing to factors such as sense of direction, and gender playing real roles in our wayfinding ability, in addition to individual preferences for landmark or cardinal descriptors, and the natural propensity to use gestures to communicate and comprehend spatial language. This presents a real challenge for navigation systems that must provide route guidance information on a one-way interaction platform, for a variety of individuals, with differing preferences, expectations and varying levels of experience.

2.4 DRIVING NAVIGATION

Navigating in an unfamiliar environment is one of the most frequent and demanding tasks that drivers undertake. A plethora of previous research has illustrated that people experience difficulties when planning and following efficient routes (King, 1986) (Streeter & Vitello, 1986) (Wierwille, Antin, Dingus, & Hulse, 1989). When drivers are unable to navigate successfully research has shown that they can become frustrated or anxious, with navigational uncertainty even reducing the mobility of those individuals who are wary of travel in unfamiliar environments (Barrow, 1991; Burns, 1997). In addition to these personal consequences, navigational uncertainly can impact other roads users, through the inappropriate or lack of use of

indicators, sudden lane changes or sudden braking by vehicles who are unsure of the correct routes to follow (Burnett, 2000). Vehicle navigation systems aim to offer a technological solution to this problem, guiding individuals through a route, to a destination with the use of visual and auditory information.

The use of vehicle navigation systems has become increasingly commonplace over recent years. Typically, they can be observed in three forms; as integrated vehicle systems; portable dedicated devices; or as apps for smartphones. Their timesaving qualities and reduced cost have made them particularly attractive to consumers (Rowell, 2001). In-vehicle navigation systems typically work using a combination of satellite GPS and digital map data to provide the driver with route directions to a destination. Systems are usually able to provide drivers with information for the shortest and fastest routes in addition to routes which travel via particular destinations or avoid sections of road. This information is usually presented to the driver in a number of map overviews and through a series of turn-by-turn instructions, using visual (text and graphics) and auditory (verbal and nonverbal) modalities to convey route instructions (Burnett, 2000) (May & Ross, 2006). A typical turn-by-turn instruction is usually composed of an auditory message which utilises distances, road names or more recently road sign descriptors in route instructions. For example, 'turn left in 400 yards' or 'turn right onto Wicksten drive'. This auditory prompt is usually accompanied with a visual representation of the turn, this may be in the form of a turn arrow or a simulated representation of the junction (Burnett, 2000) (May & Ross, 2006). Typically, systems also employ a distance-to-turn countdown icon and/or numeric that updates in real time, reducing the distance information to zero as the manoeuvre is approached (May & Ross, 2006). Though satellite navigation systems generally operate successfully, this is largely dependent on the completeness and veracity of the underlying map databases which they operate from, thus a large amount of variation can be observed across systems (May & Ross, 2006).

Whilst the components within each system's map database may vary, the way in which information is presented to the driver (visually and aurally) is largely consistent across systems, presenting some human factors concerns. The distraction potential of in vehicle visual displays has long been recognised in the literature. With the early work of (Dingus, Hulse, Antin, & Wierwille, 1989) highlighting the distraction concerns of display guidance information where individuals needed to extract navigation information from complex map representations. Here, the authors found that where individuals were required interpret complex visual interfaces to extract junction, roadway name and distance information this resulted in the operator making long, repeated glances toward the display. This is of particular concern because of the dual task nature of driving navigation; an individual must be able to extract the navigational information they require from a system whilst navigating potentially complex driving environments. The distraction potential of a navigation interface is something which has continued to be discussed in later literature. Kun et al (2009, September) looked at the time drivers spent looking toward the road when using a standard system which communicated information both visually and aurally and comparing this to a system which issued spoken directions only. Here, the authors found that when using a system which issued both visual and aural information, drivers spent less time looking at the road scene. Therefore, if an in-vehicle navigation system is to be successful, it must firstly be safe and not distract the user from the primary safety critical task of driving.

Previous work has also raised questions about the appropriateness of distance information as descriptors within navigation systems. May, Ross and Bayer (2003) point out that humans have an inherent difficulty in judging distances, particularly struggling to map distance judgments onto the visual representation of routes. Indeed, when participants were asked to identify the information within routes that they felt a driver, who was unfamiliar with the environment, would need to navigate successfully. They used distance information as descriptors infrequently, particularly when participants were trained along the route using a video as appose to those individuals who had

extensive knowledge of the area and extracted route information from their own mental representations of the space. This illustrates that individuals are unlikely to naturally use distance information as navigation descriptors and those individuals who are unfamiliar with an environment find distance estimation difficult. This may be partially the reason why distance descriptors are accompanied by a visual representation of the driving environment, via the navigation interface. Without this, individuals are unlikely to map the navigation instructions accurately onto the environment.

To address this discrepancy between the environmental descriptors we naturally use when navigating and those presented by in vehicle systems, a wealth of literature has explored the potential for landmarks to assist driver navigation. This previous work has illustrated that the incorporation of landmark descriptors in route information could make systems more efficient, reducing visual glancing behaviours along with driving and navigation errors and even increase wayfinding confidence and driver satisfaction (May, Ross, & Osman, 2005) (May & Ross, 2006) (Reagan & Baldwin, 2006). In one such study May and Ross (2006) incorporated landmark information within verbal navigation instructions to examine the effect that different descriptors had on driver performance. Three sets of auditory prompts were recorded, utilising different environmental information, including "good" landmark information, "poor" landmark information and distance to turn instructions. Here, the authors found that those participants using "good" landmark information made fewer (actual or near) navigation errors than those using either "poor" landmark information or distance to turn information. This same effect was observed for driving errors, with those participants utilising "good" landmark information having a significantly lower error score relating to vehicle braking and indicator use than those using "poor" landmarks or distance to turn information to navigate. These findings are consistent with those of Bengler, Haller and Zimmer (1994) who found that the incorporation of landmarks in navigation information

significantly reduced the incorrect use of indicators. May and Ross (2006) also found that incorporating landmarks within verbal navigation instructions resulted in a 40% decrease in glances made toward the navigation display leading toward target manoeuvres. These findings are consistent with Burnett (1998) who found that emphasising landmarks (in contrast to stressing distance information) within a vehicle navigation system resulted in fewer glances toward the display. These studies illustrate the potential that landmark incorporation into vehicle navigation systems has for improving road safety, by making a system less reliant on visual cues, glances directed toward the display are reduced, potentially meaning more time is spent with eyes on the road.

In addition to these safety benefits, Alm, Nilsson, Järmark, Savelid and Hennings (1992) presented participants with simultaneous visual and aural route directions and found that those participants who received landmark information in addition to simple direction descriptors (left, right, straight on) felt significantly more confident about where to turn, also reporting higher levels of satisfaction toward the content of the visual display. However, the incorporation of landmark information into vehicle navigation systems is not without obstacles, with the main hurdle being the selection of appropriate landmarks to incorporate within a system. Burnett, Smith and May (2001)stated that for a landmark to be of value in a vehicle navigation system it should possess a number of attributes including permanence, visibility, location in relation to a decision point, uniqueness and brevity. That is, for a landmark to be classed as “good” it should have longevity, either in form or function, for instance over time landmarks may change labelling but retain their form or function, an example of this would be a petrol station which changes ownership and associated signage but retains its basic function as a vehicle fuelling station. A landmark should also be visible in all weather conditions and be located in close proximity to a navigational decision point so that driver can associate viewing the landmark to the performance of a particular action. The uniqueness of a landmark was also considered important in that it should be distinguishable from other

environmental 'furniture'. Finally, brevity was considered key in using landmarks as descriptors, this relates to the understanding that for a landmark to be considered "good" in a driving context it should require minimal descriptive words.

Another important component of route guidance instructions thought to be integral to navigation efficiency is the timing of navigation information issued to the driver. Ross and Brade (1995, January) developed a series of equations which used vehicle speed to calculate the optimum timing (in terms of distance) of navigation information issued to the driver. These equations allowed for the calculation of minimum, maximum and ideal distance values at which to present navigation information to the driver for non-sudden manoeuvres, based on vehicle speeds of between 18 and 101 Km/h. Ross and Brade (1995, January) stated that the appropriate timing of navigation information is crucial to system acceptability and safety, explaining that the premature issue of navigation information to the driver may result in route guidance information being forgotten as the driver attends to other tasks. Conversely, if this information is issued too late it may cause the driver to miss a turning or brake/change lanes suddenly in order to make the turn. Other work has illustrated the potential impact on drivers of the late issue of route guidance information. Fairclough (1991) found that drivers reported high levels of temporal demand in response to being given route instructions too close to a junction. Though, these findings fell short of providing any specific values (in terms of distance or time) regarding what was considered the 'late' issue of guidance information.

Other work has recommended timing the issue of auditory navigation cues to correspond with external environmental features. Schraagen (1990) proposes that on main roads (containing signage) the next route guidance instruction should be issued immediately following the completion of the last manoeuvre. He goes on to suggest that on highways, navigation information should be issued as soon as the driver is able to see the associated road sign. These findings are consistent with Kishi and Sugiura (1993) who suggest that tailoring

route guidance to correspond with existing road signs is a desirable way to increase driver confidence in the system. Whilst it appears to be useful from a driver's perspective to be able to check the route guidance instructions to their corresponding environmental scene, using road signs as a basis for navigational information would require systems to have knowledge of sign placement and may not be an appropriate approach for roads with sparse or no signage.

Reagan and Baldwin (2006) also recognised the potential for auditory route guidance systems in place of electronic maps, reasoning that their use is associated with lower levels of mental workload with drivers utilising auditory systems being afforded the safety advantage of keeping their eyes on the road. However, the auditory descriptors used within route guidance systems must aid the driver in navigation whilst keeping auditory instructions clear and concise; one way this could be achieved is to present drivers with auditory wayfinding information which uses similar descriptors to those used in human wayfinding strategies. Regan and Baldwin (2006)attempted this, presenting participants with standard auditory route instructions or standard auditory instructions plus landmark based or cardinal descriptors. Participants were then asked to learn a specific route whilst driving a simulated vehicle using one of these three route guidance formats. The incorporation of landmark descriptors within auditory route guidance was found to lower levels of driver workload and aid route learning in comparison to standard auditory messages and cardinal information. These findings illustrate that the inclusion of particular navigation descriptors can potentially increase our learning of routes, expanding the development of our cognitive maps.

The creation of navigation systems which could foster confident, more adept, independent navigators is of particular interest as previous research has associated the use of current in-car GPS devices with driver disengagement from the environment (Leshed, Velden, Rieger, Kot, & Sengers, 2008, April). This work has argued that navigating with 'passive' GPS devices supports only a reduced, fragmented understanding of a landscape (Lorimer & Lund, 2003), therefore

impeding an individual's cognitive map formation, subsequently resulting in poor reconstruction and memory of the environment that one is driving through (Burnett & Lee, 2005; Forbes, 2006). Burnett and Lee (2005) reasoned that drivers using in-vehicle GPS may experience this environmental disengagement as a result of the content of navigation instructions and timing at which they are issued, they explain that drivers using a turn-by-turn navigation system use relatively few mental resources in comparison to drivers who utilise a traditional map reading approach. For example, a driver following a GPS device is provided with an ego-centred instruction (left, right, straight on) which they must follow in combination with proximity information (next turn, second exit). This information is usually issued over a short time frame, often just prior to the manoeuvre. In contrast, drivers utilising a traditional map reading method must check their orientation throughout their journey whilst they are presented with specific turn decisions which can often have a number of available options. By navigating in this way drivers using traditional paper maps interact with their environment, extracting elements of the environmental scene, using this to create a holistic cognitive map that they can draw upon in subsequent journeys. However, the findings of Regan and Baldwin (2006) illustrate that by incorporating natural navigation language into systems and using this to interact with the driver, individuals can potentially learn routes independent of the system, possibly easing a driver mental workload and decreasing attention demands.

2.5 DRIVER DISTRACTION AND WORKLOAD

In the safety critical task of driving the design of in-vehicle information systems is of considerable importance. As drivers are required to keep their eyes on the road to ensure safe driving the distraction potential of any secondary tasks which the driver performs whilst on-the-move must be carefully considered. Indeed, the findings of Horberry, Anderson, Regan, Triggs and Brown (2006) confirm that the level of task complexity of a concurrent secondary task is correlated with the level of driver distraction. A wealth of previous literature has explored this issue from a driver input and system output perspective. That is,

the distraction potential and workload associated with drivers either interacting with systems or responding to system outputs.

Burnett, Summerskill and Porter (2004) compare the control interface for navigation systems to that of a desktop computer. The authors explain that interacting with the navigation interface requires users to engage in highly visually oriented tasks, such as scrolling, menu exploration, selecting items from lists and choosing individual characters from a large array. The demands associated with the performance of these tasks have prompted many authors to express concern about the biomechanical, visual and cognitive distraction which may arise as a result of system interaction (Green, 2000; Dewar, 2002). The work of Tijerina, Palmer and Goodman (1998) illustrated this distraction potential of navigation interfaces in a destination entry task, participants were required to drive around a test track and simultaneously input a destination into one of four commercially available navigation devices. Depending on their age participants took between 40 seconds and 2 minutes to complete this task and a mean number of 0.9 lane departures were recorded, meaning that drivers typically left their lane when they began entering a destination. As a comparison when drivers tuned a radio or dialled a phone their mean task times were 15-20 seconds with a mean number of lane departures of 0.1- 0.2. These results indicate that the practice of interacting with a navigation device whilst on the move places a large burden on driver's resources in comparison to other in-vehicle system interactions.

A wealth of research has acknowledged the workload concerns associated with system interaction and has begun to explore the different modalities through which drivers could interact with and manipulate systems. Geiger, Zobl, Bengler, and Lang (2001) conducted a comparative study which evaluated the use of haptic and gestural controls in the performance of secondary in-vehicle tasks. Their findings demonstrated that the use of haptic pushbuttons and rotary controls resulted in lengthier task completion times and poorer object recognition, suggesting that participants had found these tasks more

difficult to complete using these controls, spending less time with their eyes directed toward the road scene. However, the gesture-based interface which required participants to make dynamic hand movements in a designated space facilitated drivers in performing secondary tasks more accurately. Additionally, drivers also perceived this form of system interaction to be less distracting. Although this work didn't explore these methods of system interaction for use within vehicle navigation systems it is worthwhile to consider the potential workload and attention advantages afforded by the employment of novel forms of interaction which exploit the under loaded, free sensory channels of the driver.

In addition to the workload and distraction concerns associated with drivers physically interacting with systems (for example, to enter a destination) a wealth of literature has focused on the distraction potential of system output and explored potential future means of communicating navigation information to drivers. The work of Kun et al (2009, September) compared the driving performance of individuals navigating their way through a simulated city environment, using two different navigation aids, drivers were required to move through two routes following either a standard navigation device which issued wayfinding information via a visual interface and through spoken turn-by-turn prompts or following spoken direction only, issued in the same turn-by-turn style. Results found significant differences in the visual attention directed at the outside world between the two navigational aids. Individuals spent significantly less time looking at the road ahead when they had a visual display despite this dedication of visual resources not being integral to the completion of the navigation task. That is, there were no observed cases of navigational error in either condition suggesting that the aural spoken directions were sufficient to guide drivers successfully without introducing a visual distraction. However, despite the potential driving performance advantages afforded by the use of an auditory navigation device the majority of participants still expressed a strong desire for the presence of a visual interface within the system. This demonstrates the need to

balance what is desirable from a distraction and workload perspective with the expectations and preferences of the end user.

The potential for visual navigation interfaces to distract drivers is further supported by the work of Jensen, Skov & Thiruravichandran (2010) who conducted a road trial to study how different navigation output configurations affected driving behaviour and performance. Participants were required to move through a predefined route following the navigational prompts from one of three devices, these devices communicated wayfinding information to drivers using either a visual only interface, auditory spoken prompts or a using a combination visual and audio device. Results illustrated that those participants in conditions that navigated with the assistance of a visual interface logged significantly more driving performance errors, including speeding and lane keeping violations, than those following the spoken prompts of the auditory only device. Perhaps unsurprisingly these drivers in the visual only and combination visual/audio condition also made significantly more glances away from the road scene, toward the navigation display, than those drivers who were issued only auditory prompts. However, despite the driving performance and visual attention advantages afforded by the auditory only device drivers reported a preference for the presence of a visual interface within the navigation display. The authors reason this may be due to participants in the auditory condition experiencing a higher workload when navigating as a result of being unable to control the timely issue of navigational prompts and being unable to refer back to the system to ensure that they are travelling along the right path. This heighted workload experienced by drivers following auditory only prompts was illustrated when all drivers in this condition slowed down upon the issue of an auditory navigation instruction, a practice which in previous work has been associated with an increase in cognitive workload (Uchiyama, Kojima, Hongo, Terashima, & Wakita, 2002, September).

The workload concerns associated with traditional visual and aural navigation displays has prompted a breath of work to consider novel

ways in which systems can interact with drivers to communicate navigation information. Much of this work has focused on auditory navigation instructions and the incorporation of landmark descriptors into auditory route information. This previous research argues that the addition of these environmental descriptors could make systems more efficient, reducing visual glancing behaviour along with driving and navigation errors and even increase wayfinding confidence and driver satisfaction (May, Ross, & Osman, 2005; May & Ross, 2006; (Reagan & Baldwin, 2006). In addition to this, the work of Uchiyama et al (2002, September) explored the potential to adapt the issue of auditory navigation instructions according to the mental workload experienced by the driver, which was most reliably indicated through the driver's release of the accelerator pedal. Here the authors reasoned that the changing nature of driving requires drivers to perform varying tasks resulting in their workload fluctuating throughout the journey. This changeable nature of workload experienced throughout driving was also acknowledged in the work of Van Erp and Van Veen (2004) who utilised a tactile navigation display to alleviate driver workload. This system indicated directional information through the issue of a vibration under the left or right thigh and communicated distance to turn using vibration rhythms that were issued at closer temporal rhythms when approaching a turn. The success of this navigational display highlights the potential for systems to exploit this tactile channel in communicating information. However, it isn't only interface design, the modality of system communication or the timing of information issue which can affect the workload of the driver. Traffic conditions, driver experience and prior route knowledge can also influence driver workload and subsequent driver performance (Patten, Kircher, Östlund, Nilsson, & Svenson, 2006; Yanko & Spalek , 2013).

2.6 SOCIAL NAVIGATION

With a growing number of drivers replacing traditional navigation methods with the use of in vehicle navigation systems the literature has looked to ways to reduce the distraction potential of systems and ease the attention demands on the driver. Subsequently, a number of

authors have advocated for the development of systems that utilise the collaborative driver and passenger navigation relationship (Forlizzi, Barley, & Seder, 2010; Perterer, Sundström, Meschtscherjakov, Wilfinger, & Tscheligi, 2013; Perterer, Meschtscherjakov, & Tscheligi, 2015) . This traditional social interaction between driver and passenger is viewed as the most beneficial navigation strategy, as the passenger considers the drivers previous experience, knowledge and the current context when issuing navigation information. Indeed, Forlizzi et al (2010) suggest that one of the main limitations of current passive systems is how they interact with the driver, with many of the current systems following a one-way information exchange. Forlizzi, et al (2010) argue that presenting navigation information to the driver in this way is not an adequate substitute for the collaborative driver and passenger navigation relationship, instead they assert that a navigation task works best when performed collaboratively, with the driver being assisted by the passenger who provides information in a timely fashion, whilst continually checking the drivers understanding of these instructions and offering further clarification where appropriate.

Forlizzi et al (2010) suggested that a successful collaboration or communication is dependent upon individuals finding common ground, with a successful collaboration more likely to be the result of a relationship where individuals had shared knowledge or experience. To study how different social relationships can affect our ability to collaborate and the quality of the interaction Forlizzi et al (2010) asked groups of parent and teens, married couples and unacquainted individuals to collaborate on a driving navigation task. Individuals were randomly assigned to the roles of driver and navigator with the exception of the parent/teen condition where the teen always assumed the role of the driver, with the authors reasoning that the teen's lack of driving experience and unfamiliarity with the area would encourage a richer, more in depth interaction. Navigators guided drivers along a route using directions which had been generated via their preferred means. The authors found that the familiarity of the relationship between driver and navigator affected the navigation

relationship and the social interaction amongst the pairs. Parents and teens, who had little previous experience navigating together treated the navigation task as an opportunity to learn. With parents often assuming the role of teacher, situating routes in their previous experience, offering lane guidance and pointing to landmarks on route, attempting to attach meaning to environmental objects so that routes were more likely to be remembered in future journeys. Married couples, who had the most experience navigating together, adopted the least formal, most efficient means of communication of all the pairs. Conversations appeared less restricted and more fluid, not always following a navigation theme. These pairs appeared to display high levels of trust in their partner throughout the task, though they occasionally abandoned their task roles, with the driver assuming the role of navigator if they had a particular route preference. Finally, unacquainted teams displayed a navigation exchange most similar to current individual navigation systems. As this paring had no previous experience navigating together navigators were unable to situate routes in the driver's previous experience, attempting to instead establish common ground by consistently approaching directions with the same prompt-manoeuvre-confirmation exchange.

These findings illustrate that our familiarity with a passenger can mediate the navigation information which is issued, with collaborative partnerships working best when a navigator can draw upon the previous experience or knowledge of the driver, in these relationships the navigators are more likely to know the best way to describe directions to drivers, issuing navigation information which can help the driver form a mental representation of the space. Additionally, in successful collaborative relationships, the driver feels able to selectively choose the navigation information they use, ignoring navigation instructions where they feel they may know a more appropriate route.

Forlizzi et al (2010) used these findings to make recommendations for the design of future navigation systems, stating that current systems (which employ a one-way information exchange with the driver) could

benefit from incorporating characteristics of human-to-human interactions. From analysing the social navigation interactions of participants, the authors recommended that future systems should be capable of issuing a more varied range of information to the driver, which should be issued in a flexible manner depending on the drivers' information requirements and attention constraints. The authors also recommended that drivers should be able to interact with the system to exercise greater control over the timing of information delivery and the modality used to present this information, tailoring the system to meet their preferences. Additionally, the authors stated the importance of situating routes in a driver's previous experience; this could mean that drivers are able to navigate independently of the system, reducing the system's associated attention demands.

Whilst these findings are able to inform some interesting recommendations it is important to note that the qualitative nature of this research means that these recommendations require further grounding to ensure that the results obtained are applicable to a wider population.

The work of Perterer et al (2015) also considered the value of the in-car passenger within in-vehicle navigation. Informed by earlier ethnographic research (Perterer, Sundström, Meschtscherjakov, Wilfinger, & Tscheligi, 2013, Feburary) which demonstrated the frequently collaborative navigation relationship between driver and passenger, the authors developed a prototype dual interface designed to utilise the available cognitive resources of the passenger. The prototype system, made up from two interfaces: driver-facing and passenger facing, would issue the standard turn by turn navigational prompts to the driver when they occupied the vehicle space alone. However, when drivers were accompanied by a passenger, the navigation experience was designed to be enhanced, issuing detailed landmark information and upcoming hazard warnings to passengers, allowing them to assist drivers with the navigating task. Indeed, the authors suggested that the main advantage of the system, identified by participants was the opportunity for both driver and passenger to

utilise the same, shared map view. Allowing them to react collaboratively to unfolding driving situations. With this ability to manipulate system view being perceived as particularly advantageous in dangerous driving conditions (e.g. bad weather conditions, night time driving).

In addition to this work other literature has highlighted the importance of considering the driver's current context when issuing navigation information. Whilst Forlizzi et al (2010) and Perterer et al (2015) looked to the collaborative driver/passenger relationship to inform the redesign of navigation systems, other research has looked to the development of current digital maps and the use of novel sensors to reduce the cognitive load of drivers and create a more interactive driving environment. Lee, Forlizzi & Hudson (2008) attempted to reduce the perceptual and cognitive load drivers experience by reducing the visual clutter of current digital maps featured within vehicle navigation displays. To achieve this the authors altered the system view to reflect the navigational importance of roads or turnings, with the most important items, essential to navigation being represented with the most salient, attention demanding icons. Conversely, other environmental features, not essential to navigation, were designed to appear less eminent, or alternatively removed from the display altogether. In addition to this Lee et al (2008) further decreased the visual clutter of the navigation display by scaling important segments of the journey, distorting actual road length according to its navigational importance, the use of labels and symbols were also carefully considered, with care being taken to avoid any overlap of street names and labels representing environmental features. These system adjustments resulted in the development of a display which was quicker for drivers to process, with drivers spending less time fixating on and glancing toward the display.

By redeveloping digital maps in this way Lee et al (2008) produced a system that considered the context demands of the drivers' environment and how a corresponding digital view may become more

cluttered in rich environments. Whilst this is useful, this system does not tailor navigation information at the individual level, taking the view that all drivers may prefer this simplified environmental view, or even that drivers may prefer to have information presented to them in a visual format.

Rodzina and Krisofferson (2013, May) instead looked to the future of in car navigation and considered the development of a system which is capable of tailoring its output according to the varying social situations of the driver. Rodzina and Krisofferson (2013, May) state that there are a number of aspects that can impact what an individual will require of the navigation system. These can include whether a driver is travelling for business or personal reasons, the time of the day, the weather, the driver's familiarity with the route and current route traffic. All these factors can have various impacts, on which roads the system should select for travel and the navigational instructions it should issue. For example, if travelling for business a driver may prefer to take the quickest route thorough a journey, travelling via toll roads and non-scenic, fast routes. However, if they are travelling on the weekend with their family they may wish to treat the journey as an experience, travelling via scenic roads, passing particular points of interest along the way. Similarly, if a system is capable of detecting when a driver is familiar with a route it could tailor the issue of navigation instructions accordingly. For example, systems could sit in silent mode along familiar journeys, becoming 'active' along routes which the driver has not travelled before. Rodzina and Krisofferson (2013, May) suggest that systems which are able to intelligently infer the purpose for a journey and give the appropriate level of route guidance, whilst also reading the emotional state of the driver (with the use of sensors) are not far away from being produced.

However, further increasing the level of technology within vehicles can raise the potential for driver distraction and whilst advances in technology mean that vehicle designers are able to incorporate these increasingly novel displays within systems, human processing constraints mean that it is not always responsible to do so. By

'stripping back' the navigation task to the traditional driver-passenger collaborative, navigation relationship researchers can explore the language and cooperation strategies of individuals navigating together in a shared space. By examining the social interaction of the driver and the passenger it may be possible to inform the design of a new wave of navigation systems. Such systems could aim to replicate this collaborative relationship, issuing useful descriptors to drivers at appropriately timed points, whilst remaining aware of the driving context and times where the attentional demands of drivers may be too great to process additional navigation information.

2.7 SPEECH BASED INTERFACES

The employment of speech-based interfaces within vehicles presents a novel way in which the driver-passenger collaborative relationship can be modelled within next generation in-vehicle interfaces. Speech recognition technology translates spoken words into machine-readable content, this content enables the machine to recognise the words the person is speaking in order to process the content of the message, subsequently identifying and acting upon user commands (Hua & Ng, 2010, November 11). Speech based interfaces allow the user to manipulate a system verbally rather than utilising manual controls. This type of interaction can therefore ease task completion and allow users to perform multiple tasks simultaneously.

Previous works have explored the relative benefits of speech-based interfaces over manual entry for a number of in-vehicle tasks including: Navigation task entry, mobile phone dialling, email processing, music selection, radio tuning and adjusting climate control (Barón & Green, 2006). Within this literature, it is generally agreed that individuals drive better (less lane variation and with a steadier speed), find tasks less challenging and spend more time with eyes on the road when interacting with speech interfaces rather than communicating with an interface manually (Barón & Green, 2006). However, not all in-vehicle tasks lend themselves equally to voice control. (Mazzae, Ranney, Watson, & Wightman, 2004) found that the manual entry of a phone number into a hand-held device was

invariably faster (<20 seconds - <25 seconds) than for drivers utilising speech recognition technology operated via a headset hands free (<35 seconds - < 45 seconds). Although this task was able to be performed more quickly using a different hands-free technology, task completion times remained favourable in the manual dialling condition. These results suggest that not all tasks are afforded the same time and safety advantages associated with speech-based systems and certain habitual tasks where the user is highly experienced are more suited to traditional manual inputs.

However, the driving behaviour advantages afforded by interaction with speech-based interfaces are particularly important in the safety critical task of driving where eyes off road time can result in a collision or near miss. Previous literature has highlighted that the method used to interact with an interface can have a significant effect on the visual attention directed toward the road scene. Itoh et al (2004), compared manual and speech-based interactions for changing a radio station and a destination entry task into a navigation display and found that a speech-based entry method significantly reduced total glance and task completion time, with participants taking up to 12 seconds to manually enter a destination on an instrument panel compared to the same task being completed in less than two seconds under voice control. These findings are supported by the work of Ranney and Harbluk (2002, June) who reported that drivers who were interacting with a voice-based interface detected significantly more peripheral targets (an indicator of road scene awareness) whilst performing a series of secondary tasks including phone dialling and message retrieval when compared to drivers who interacted with displays manually.

These behaviour advantages experienced by drivers utilising speech-based systems can subsequently impact driving performance and vehicle control. Itoh et al (2004) found that in addition to a reduction in task time drivers interacting with speech-based interfaces demonstrated a significant reduction in standard deviation of lateral lane position, that is, out of lane excursions or weaving of the vehicle

compared to drivers who were interacting with a manual display. In addition to this, Gärtner, König & Wittig (2001) illustrated that drivers interacting with speech-based interfaces made fewer lane keeping and speed-based errors compared to drivers interacting with systems using manual inputs. Here, the authors reported that when participants were requested to manipulate audio or navigational functions within the vehicle, using either speech or manual inputs drivers in the manual input condition logged more lane keeping errors, made less traffic observations and significantly reduced their speed to try to compensate for their additional mental load.

Additionally, Eriksson and Stanton (2017) have advocated for the use of natural language interfaces within future autonomous vehicles, suggesting that their employment can enhance human-system communication by providing timely, intuitive feedback to drivers, ensuring they are aware of current system status, informing users why the system has chosen a particular path of action, and what the next projected action will be. The authors liken such system communications to a 'chatty co-driver', explaining that natural language can be used to relay information about vehicle sensor limitations and potential obstructions in the roadway, ensuring that users are continually kept in the control loop should automation failures arise, thereby reducing the likelihood of incident.

Whilst the literature has demonstrated the behavioural and performance advantages associated with the use of speech recognition technologies within vehicles, the practicalities of interacting with speech recognition systems of varying quality can diminish the benefits associated with their use (Nass & Brave, 2005). Speech based technologies remain relatively new and despite the advent of more sophisticated systems such as Androids Alexa, Apple's Siri and windows Cortana such applications remain unable to recognise and act upon all inputs. Speech is something which, dependant on the individual, can happen at a varying pace, in plethora of geographical accents meaning that even other humans can misunderstand or misinterpret what someone is saying, this presents a real challenge for

the development of speech-based systems. Indeed, Gellatly and Dingus (1998), investigated this concept, and found that when recognition accuracy of speech-based systems was manipulated, poor recognition accuracy was associated with longer task completion times which, in an everyday context could deter their use in favour of traditional manual inputs. However, a wealth of other research has suggested that whilst higher recognition accuracies are desirable within speech-based systems, users still interact socially and are influenced by anthropomorphic agents which are limited in their functionality and adaptability (Baylor & Kim, 2005, 2009; Guadagno et al, 2007) demonstrating that, although desirable, systems need not be at full operational functionality to be of benefit to users.

Individuals may respond and be influenced by the interactions with speech-based systems as these exchanges simulate human to human conversations. Indeed, previous research has shown that using spoken language as an archetype for human-computer interaction can engage and comfort users as system exchanges draw upon the experiences and expectations the individual has built from human interactions (Nass & Brave, 2005). Recent work has further explored the benefits afforded to drivers when interacting with natural speech-based systems where the interface initiates and engages the driver in prolonged, varied exchanges. Large, Burnett, Antrobus & Skrypchuk (2016) explored whether natural language interfaces could be successfully employed as a combatant to fatigue. Participants completed two counterbalanced simulation drives, one with the assistance of natural language interface dubbed the 'digital driving assistant' and one without. Drives were designed to be monotonous so as to encourage fatigue and conducted during times of the day when circadian influences are naturally reduced. During intervention drives participants engaged in natural language interactions with the digital driving assistant, centred around navigation advice, meeting reminders and calendar conflicts. This interaction was delivered through a Wizard of Oz approach (see section 9.1) where a professional actor generated and delivered 'system' responses. Interaction with the digital driving assistant was shown to increase

driver alertness, with participants in the intervention condition demonstrating a trend toward lower perceived sleepiness and higher arousal. Objective measures also demonstrated that interactions with the digital assistant improved lane keeping behaviours and encouraged earlier responses to the presentation of a hazard situation. These findings suggest that the employment of a natural language interface can enhance driver alertness, helping to combat the effects of driver fatigue which has important implications for driver safety. However, the cognitive costs associated with interaction with natural language systems should not be overlooked. Whilst speech-based interactions have the benefit of being both 'hand-free' and 'eyes-free', research has shown that speech-based activities and interfaces can increase cognitive demand (Strayer, Turrill, Coleman, Ortiz & Cooper, 2014).

Large, Burnett, Anyasodo and Skrypchuk (2016, October) explored the cognitive implications of engaging with natural language interfaces, drawing workload comparisons with hands-free phone conversations and baseline driving. Again, utilising the Wizard-of-Oz approach to simulate system interactions participants were required to complete four drives in a medium fidelity fixed based driving simulator: 1. Interacting with a natural language digital driving assistant, 2. Engaged in a hand-free phone conversation, 3. Undertaking a delayed digit recall task (2 back) and 4. A baseline drive with no concurrent task. Workload was assessed using a variety of measures including: physiological indicators (heart rate and heart rate variability), employment of a tactile detection task (see section 3.3.3), driving performance measures (as indicated through standard deviation of lane position, headway and speed variability) and the participant's own subjective assessment of their cognitive demand through the use of NASA TLX questionnaires. Results indicated that interactions with the digital driving assistant were generally associated with low or medium levels of cognitive demand, and natural language system interactions were largely equivalent to hands free mobile phone conversations across all measures of workload. Suggesting that interaction with speech-based interfaces carries an acceptable level of

secondary task cognitive demand, equivalent to engaging in a hands free mobile phone conversation. However, it is important to note that previous works have also reported observed changes in the visual behaviours of drivers who are engaged in mobile phone conversations whilst driving. With the visual inspection patterns of drivers engaged in verbal tasks being impacted (Recarte & Nunes, 2000), meaning that important driving events usually detected from regular mirror inspections may be missed. Therefore, the visual and manual distraction implications associated with engaging with natural language interfaces should be considered.

The favourable workload implications of interactions with speech-based interfaces have been echoed in other works where driver's subjective ratings of workload were lower when using speech recognition interfaces compared to manual inputs. Itoh et al (2004) reported that NASA TLX ratings decreased more than 40% for drivers using speech rather than manual inputs to interact with systems in a number of tasks including radio station change and navigational destination entry. These findings are supported by the work of Tsimhoni et al (2002) where participants perceived keyboard entry in system interfaces to be more difficult than either single character or full word voice entry conditions. Whilst these results suggest that the cognitive demand associated with interacting with voice-based systems may be considered lower and the preferred form of interaction over than traditional manual inputs there are a number of considerations which researchers point to which could influence the acceptance and usability of natural language interfaces. These include system speech recognition capabilities as well as system capacity to synthesise natural language to communicate with users. In addition to this research has raised questions as to how context aware and personalised systems should be so that they can respond to prevailing traffic situations in real time, giving personalised responses tailored to specific driver preferences and requirements (Leong, Kobayashi, Koshizuka, & Sakamura, 2005; Pakucs, 2003). One important aspect of this is the voice which the system embodies to communicate with users, something which previous work has shown may influence the

driver's acceptance and trust of the system (Large & Burnett, 2014; Waytz, Heafner, & Epley, 2014).

Large and Burnett (2014) explored the effect that character voice had on the trust of users when presented with a scenario in which there was navigational conflict. In a between subject's design participants travelled through a simulation following the navigational guidance issued by a system. These auditory route prompts were issued in either a voice which was considered 'high trust' or one deemed to be 'low-trust', road signs accompanied this auditory route assistance allowing drivers an additional source of information on which to base their route selection. At the final junction in the simulation participants were presented with a conflict scenario where the verbal route guidance differed to the information contained within the road signs. Here, 22 out of a possible 29 drivers followed the incorrect auditory guidance issued by the in-vehicle navigation system. Of these, the majority were using the 'high trust' voice. Post drive questionnaires revealed that although the content and message delivery were equivalent in both conditions, drivers recognised different attributes associated with the navigational voices. This then influenced their attitudes toward the system, their predilections for use and the level of trust which they then associated with each voice, subsequently impacting the navigational decision made when conflicting information was presented. Though it not desirable that a misplace of trust in systems could result in users following incorrect guidance, leading to a potentially hazardous situation, it offers important food for thought in system development. Where design strategy could be steered toward fostering trust and therefore motivating the user to engage. Additional research has explored this concept and made suggestions surrounding the functional components of systems which could encourage user engagement and therefore promote system acceptability (Pfeifer & Bickmore, 2009; Eriksson & Stanton, 2017).

Perhaps one of the most important features for speech-based systems is the voice which the system utilises to communicate with users.

Speech is a powerful carrier of emotional information and previous research has demonstrated that the most rudimentary emotions are connected with the acoustic properties of an individual's voice, such as loudness, frequency, frequency range and speech rate (Nass & Brave, 2005). Therefore, as individuals can make judgements and determinations about the characteristics and personality of an individual upon hearing them talk, the selection of a systems voice which aids user interaction is an integral component to system acceptability. Because of these subconscious emotional connections people draw from speech, research suggests that speech activated systems should utilise a voice which is as human-like as possible in its tone and prosody, in order to promote system engagement and generate user trust (Waytz, Heafner, & Epley, 2014; Nass & Brave, 2005). Indeed, previous work has suggested that when voice-based systems do not conform our social and linguistic norms within user interactions they are perceived as ineffective and are subsequently criticised and rejected by users (Goleman, 1995). Nass et al (2005) explored this concept further, examining how the characteristics of an in-car voice can affect driver performance and behaviour. Participants had emotion induced through watching five-minute video clips and subsequently drove through a simulated environment whilst interacting with a natural language interface. Here, the voice of the system was matched to the perceived emotional state of the driver. That is, interactions were delivered in either an energetic or subdued voice to match the emotional states induced in the drivers. Results indicated that when the system interacted using a voice which was matched with the participants' mood drivers had fewer accidents, attended more to the road scene and had more extensive system interactions. This has important implications for system design. With the advent of technologies, now capable of reading driver emotion, system voice interactions could be tailored according the mood of the driver. Subsequently influencing driver state, potentially reducing on-road incidents where driver emotion or state is a contributory factor.

Alongside selecting an appropriate system voice to communicate with users the literature has made other recommendations which aim to

make natural language interfaces more usable and desirable from the user perspective. These recommendations include moving away from unnatural voice commands to the use of a two-way, interactional dialogue. The use of voice commands requires the user to remember specific prompts to trigger system interaction, use of such prompts have been previously shown to impact task completion times and hinder a user's ability to correct system errors (Halverson, Horn, Karat, & Karat, 1999; Karat, Halverson, Horn, & Karat, 1999). Whilst the use of voice prompts were initially implemented so that system commands were clearly identifiable from one another, (therefore increasing recognition success rates), the use of these commands can feel unnatural to the driver potentially discouraging system interaction. The literature also acknowledges that not all tasks are equally suited for control by voice recognition systems. For example, basic tasks such as pausing music or skipping a song can often be slower and more tedious when operated under voice command (Barón & Green, 2006). There are therefore situations where voice interactions shouldn't be the primary method of control, in such instances the implementation of hard keys on the steering wheel could allow users to complete tasks more quickly, without taking their eyes off the road. In addition to these recommendations the authors argue that the use of visual feedback in speech recognition systems can provide a critical memory aid to users regarding the progress of their interaction, visual cues could provide users with a visible prompt about what commands the system is currently processing and when the system requires a user response to progress.

Whilst presenting users with visual system feedback allows them to assess the state of a request. Future speech-based systems could promote interactive, two-way dialogue, allowing the user to verbally check the progress of a request in real time, akin to driver-passenger interactions (as discussed in section 2.6). The location of the passenger within the same shared vehicle space as the driver means that they are ideally suited to support the driver in the most appropriate manner – they are likely to be aware of the demands of the driving environment (particularly if they are also an experienced driver) and the driver's

current navigational dilemma, and can therefore mediate the support they provide, and the method in which they deliver it. It also provides the opportunity to subsequently check the driver's understanding of any instructions and offer clarification, if and when necessary (Forlizzi, Barley, & Seder, 2010; Perterer, Sundström, Meschtscherjakov, Wilfinger, & Tscheligi, 2013; Perterer, Meschtscherjakov, & Tscheligi, 2015)

Due to the realities and practicalities of everyday car travel, it is not always possible for drivers to be accompanied by a passenger, and therefore a large proportion of journeys now see drivers travelling alone. This means that they are unable to access or make use of the contextually sensitive, interactive assistance of an in-car passenger. However, the recent proliferation and popularity of 'intelligent' voice-based systems in everyday applications presents an ideal opportunity to consider how such technology may be employed within the navigation task. Specifically, to explore whether such technology could adopt the role of knowledgeable, loquacious passenger to support bilateral dialogue based on the collaborative effort of both interactants to ensure mutual understanding (Buschmeier & Kopp, 2011). Thus, it may be possible to provide the benefits of collaborative driving and navigating in the absence of a passenger, and thereby deliver 'active' engagement during the navigation task to improve performance and ultimately promote system independence, without increasing workload.

Evidently, such capabilities are not yet available in commercially-available, speech technologies, which are often restricted to a single vocal exchange, initiated by the human interlocutor, in which a request is made and an isolated response is delivered. Nevertheless, it is possible to envisage a future scenario in which cars are embodied by highly-capable, digital assistants, communicating through the use of conversational language, as highlighted by scholars (Large, Clark, Quandt, Burnett, & Skrupchuk, 2017).

2.7 SUMMARY OF LITERATURE REVIEW

In general terms, the literature review illustrates that the way current navigation technologies relay information to the driver (i.e. distance to turn information) is not consistent with how humans naturally convey spatial information to one another (i.e. landmarks at navigational choice points). Previous work has argued for the inclusion of landmark information within route guidance information to remedy this discrepancy and environmental disengagement concerns. The review also highlights the large number of human factors issues which exist concerning the design of current HMI for route guidance systems and looks to recent research to inform design of future navigation systems. The examined literature suggests that future navigation systems could move away from current passive guidance which communicate distance-to-turn information in a one-way information exchange, to interactive natural language systems, modelled on a familiar driver-passenger relationship, such systems could issue navigational guidance in a loquacious, two-way verbal exchange. The following summary points, relevant to each of the main headings are presented below: -

2.7.1 Cognitive maps, navigation and the wider environment

Cognitive maps can be defined as the transformation of environmental knowledge into a holistic, internal mental map. Such internal maps mean that individuals are able to execute various navigation tasks with relatively little cognitive demand. Previous work has examined how individuals generate these internal map-like structures, and the stages of environmental learning which individuals progress through upon exposure to a new environment. Although there is debate within the literature surrounding the order in which individuals acquire survey knowledge (see Kitchin & Blades, 2002 for a review), it is generally agreed that individuals move through three, independent stages when developing a cognitive map:

1. Landmark knowledge - individuals remember prominent or conspicuous objects or distinctive road views within the environment.

2. Route knowledge – individuals begin to link landmarks which appear along a route, remembering the order in which they appear, the distances between them and the actions which are performed at their location.
3. Survey knowledge – the memory which is created when landmark and route knowledge are integrated to form a comprehensive, map-like spatial representation of an environment.

A breath of work has subsequently demonstrated the importance of landmarks to human navigation, how individuals frequently utilise them to orient themselves, incorporating them into route directions. Indeed, researchers have suggested that one of the key components of 'good' route directions is the inclusion of landmarks at navigational choice points. A feature which is not currently mirrored in electronic navigation systems which instead commonly utilise distance-to-turn information within wayfinding instructions.

Whilst the literature has argued for the inclusion of landmark information into route guidance instructions. There has been little human factors work considering alternative channels, outside of traditional navigation system design, which could effectively communicate landmark information to drivers. Rather, previous research has considered the incorporation of landmarks descriptors as an 'add on' to current visual or verbal navigation system guidance, issued to the driver in a passive, one-way information exchange.

2.7.2 Driving navigation, distraction and workload

The use of current electronic navigation devices has been associated with driver disengagement from the environment. Previous work has suggested that navigating with a SatNav that utilises simple turn-by-turn instructions supports only a reduced, fragmented understanding of a landscape, and therefore impedes an individual's cognitive map formation. As such, drivers who rely on electronic navigation devices are typically only able to demonstrate a poor reconstruction and memory of the environment through which they have travelled.

Consequently, drivers may become reliant on the technology even during regular journeys or routinely navigable environments.

The literature has suggested that the level of engagement with the environment during route-following is associated with the extent to which the navigation task is 'active' or 'passive'. Active navigation involves the driver in route planning and utilises environmental elements within more extensive route instructions, with the aim of ensuring that the driver maintains a sense of orientation throughout the journey. In such approaches, drivers must interpret this information to identify and select a specific turn, often where there are a number of options available. Conversely, within passive navigation systems, drivers are presented with simpler instructions, typically incorporating an ego-centred direction (e.g. 'left', 'right', 'straight on') together with proximity information regarding the adjacency to a particular action (e.g. 'next turn', '2nd exit'). Such instructions are presented over shorter time periods (typically one or two manoeuvres ahead), and therefore require fewer mental resources to process.

Whilst more active forms of navigation can assist environmental engagement and spatial learning the literature has suggested that more active forms of navigation are also associated with higher workload. However, it is important to note that this work has largely been conducted within a driving simulator environment and centred around the use of traditional paper maps as an example of an active navigational method. Little work has explored the workload implications of passive and active navigational methods within the context of an on-road driving environment, comparing current passive navigation technologies with increasingly active navigational models, which vary in their level of interactivity.

Furthermore, whilst previous work clearly demonstrates user preference for a combination of visual and auditory information within navigation system design, reasoning that the presence of a visual interface is preferred as it allows the user is able to refer back to the visual interface to confirm that they are travelling along the right path. There has been no work which has explored utilising interactive

natural language interfaces which can instead offer timely verbal confirmations to the driver when route guidance is questioned.

2.7.3 Social navigation and Voice based interfaces

The limitations of current navigation systems mean that a number of researchers have looked to the collaborative navigation relationship between the driver and the passenger to inform future design. Analysis of the dynamic interactions between driver and passenger has led to recommendations for the development of systems which are able to issue a varied range of information to the driver, whilst considering the drivers context and specific navigation scenario.

Whilst research has detailed the benefits of the in-car passenger issuing situated, contextually sensitive navigation information. Little work has explored how to provide the benefits of driver-passenger collaborative navigation in the absence of a passenger.

The recent proliferation and popularity of 'intelligent' voice-based technologies mean that it may soon be possible to provide the benefits of collaborative driving and navigating in the absence of a passenger, and thereby deliver 'active' engagement during the navigation task to improve performance and ultimately promote system independence, without increasing workload. Researchers have begun to examine the workload implications of interacting with voice-based technologies whilst driving, exploring how such systems could be used within the driving environment as a combatant to fatigue and an influencer of trust and system acceptance. Additionally, researchers are exploring how variations in the linguistic properties of voice-based interactions can influence driver performance and behaviour.

Whilst the findings of previous research represent important initial data regarding the value of speech-based assistance within the driving domain, this work has largely been conducted within a simulated driving environment which offers limited information as to how drivers would naturally interact with speech-based technologies in a demanding driving scenario conducted in an unfamiliar, dynamic on-road environment.

3

CHAPTER 3: METHODOLOGY

3.1 ENVIRONMENTS: SIMULATOR VS ROAD

Laboratory studies are characterised by taking place in a controlled environment created for the purpose of conducting research. However, such work is frequently not conducted in dedicated laboratories, but rather in a variety of controlled environments such as an office space, or as is the case with a large portion of driving research, a simulator. Laboratory based experiments allow for the manipulation of variables, in a structured, methodical fashion resulting in consistent, replicable data (internal validity). However, whilst laboratory studies allow for increased experimental control, disadvantages include a limited relation to the real world (ecological validity) and with unknown levels of generalisability outside of the laboratory setting (external validity). Schneiderman and Plaisant (2004) also proposed that laboratory-based methods are reductionist and therefore do not permit a full understanding of the results. In the study of navigational methods and how people interact and engage with their surroundings, this is a particularly important point; the navigational task is a fundamentally situated task bound by context and should therefore be studied within this natural setting so that results are as ecologically valid and generalisable as possible (Darken & Peterson, 2002).

Field studies sit on the opposite end of the experimental spectrum to laboratory studies and are characterised by taking place in the "real

world" as oppose to the controlled, laboratory setting. Field studies comprise a broad range of qualitative and quantitative approaches from ethnographic explorations of experiences in their social and cultural context, derived from the field of social and cultural anthropology to field experiments in which a number of independent variables are manipulated. The ethnographic perspective highlights the role of the researcher as a participant, meaning that researchers often spend significant portions of time in the field, immersing themselves in the environment and the research problem, so that they are able to gain a true understanding of complex human practices (Lazar, Feng, & Hochheiser, 2010). Ethnography therefore offers the opportunity for researchers to perform in-depth explorations to garner an understanding of the interactions and behaviour in the wild. However, whilst this method generates a wealth of rich, grounded data, the approach is non-experimental (Kjeldskov & Graham, 2003) and therefore not appropriate for the scientific examination and manipulation of variables.

In contrast to the ethnographic approach, field experiments are characterised by the manipulation of a number of independent variables in order to examine the impact on dependent variables in a natural setting. The predominant advantages of field experiments are increased realism, enhanced face validity and ecological validity as well as a heightened level of control compared to ethnographic methods. Kjeldskov and Graham (2003) state that the employment of field studies supports the analysis of "complex situated interactions and processes". However, the authors reason that the approach is not without its disadvantages which include reduced control over investigations and more complex data collection, meaning that the researcher must strike a balance between experimental manipulation and the realism of the work. However, a number of researchers have adopted this approach, each with varying levels of experimental control to examine how individuals navigate in the real world (Antrobus, Burnett, & Krehl, 2016; Forlizzi, Barley, & Seder, 2010; Webber, 2013).

Leshed et al (2008, April) conducted an ethnographically informed study in which researchers travelled with participants on pre-planned journeys and conducted observations on how drivers interact with electronic navigation devices and subsequently how this interaction influences the driver's engagement with the world around them. Jensen et al (2010) also utilised a field study approach where participants navigated pre-defined routes following the wayfinding assistance of navigational interfaces which issued prompts via different modalities (audio, visual, audio/visual) to examine how interface output influences driver attention. Forlizzi et al (2010) adopted a similar approach requiring participants to navigate predefined routes following the navigational guidance of an individual with whom they had a pre-existing social relationship. Here, drivers were paired according to the relationship they held with the navigator (spouse, parent/child, co-workers) with the researchers examining whether the degree of familiarity and the frequency with which they perform a navigation task influences the navigational dialogue between driver and passenger.

Similarly, within this thesis, drivers will navigate predefined routes using different navigational methods. Here, the term field study will be used to describe an experimental study conducted in a real-world setting. The controlled manipulation of variables in a situated, real world setting makes the use of field studies an ideal platform to examine how different methods of navigation can influence both an individual's workload and how an individual interacts and engages with their environment.

3.2 DRIVER ENGAGEMENT

The navigation archetype can be regarded as a particular type of field study where experimental variables are manipulated and controlled to explore and generate understanding of individual's wayfinding processes and behaviours. In this context, the manipulation of experimental variables can influence environmental learning. These

manipulations have been implemented in numerous ways by researchers. For example, the use of an electronic navigational aid compared to traditional methods or direct experience (Ishikawa, Fujiwara, Imai, & Okabe, 2008; Burnett & Lee, 2005), or comparing navigational aids which utilised different sensory modalities to convey navigational information (Yung-Ching, 2001). Due to the higher levels of experimental control and replicability afforded by lab-based methods a number of studies have utilised desktop and immersive simulator environments to compare navigation aids and processes (Burnett & Lee, 2005). However, a wealth of researchers are opting to conduct these experiments in the field, producing ecologically valid research by combining experimental control and situated behaviour to study navigation and subsequent environmental learning (Münzer, Zimmer, Schwalm, Baus, & Aslan, 2006; Antrobus, Burnett, & Krehl, 2016).

The methodologies employed to examine how wayfinding method impacts upon environmental learning vary considerably across the literature. In some studies researchers predefine a destination and require participants to formulate a route to reach this designated point (Ishikawa, Fujiwara, Imai, & Okabe, 2008). In other works, researchers predefine entire routes for participants to follow (Munzer et al, 2006). Dependent on the aims and scope of the research, studies have utilised both single (May, Ross, & Osman, 2005) and multiple route (Ishikawa et al, 2008) paradigms to examine environmental learning. The route and location in which researchers select to conduct their research is dependent on a number of factors including the aims of the research, as well as logistical and technical restraints. For example, how well the route reflects different types of environments and driving, the proximity of the testing site to the research institute and the feasibility of transporting participants. Finally, how many routes are required to examine the depth of environmental learning that has occurred and the availability of mapping or GPS. The availability of mapping or GPS coverage may not be a limitation when using dedicated portable navigation devices for example “SatNavs”, as such devices utilise satellite technology which is unaffected by local infrastructure.

However, should a study which utilises mobile mapping technology (e.g. smartphone navigation applications) to navigate, GPS coverage could determine the modality and fidelity of navigation information issued by the device.

As discussed in the previous section (section 3.1) a number of field studies have explored how individuals navigate, utilising a number of approaches. Drivers have been evaluated interacting with current (Leshed, Velden, Rieger, Kot, & Sengers, 2008, April) and modified navigation systems (Jensen, Skov, & Thiruravichandran, 2010) as well as examining how drivers naturally interact with their co-passengers when navigating to pre-defined destinations (Forlizzi, Barley, & Seder, 2010). All of these approaches can provide us with an indication of how individuals interact with their navigation devices, why they may prefer to receive wayfinding information in a particular format, and what strategies individuals may employ according to the navigational method which they utilise. In this way, a field study can offer a platform for researchers to gather data from a situated, naturalistic setting whilst controlling key experimental variables such as the route taken and the navigational method which participants utilise. Meaning that specific research questions can to be answered without employing a reductionist, lab-based approach.

In experiments which study navigation and assess environmental learning it is important that the researcher exercises a degree of control in participant selection to ensure that participants have similar levels of environmental familiarity upon commencing the research. Individuals should preferably be selected for participation on the basis that they have no previous knowledge of the environment, they should then be exposed to the same environmental information and travel the same routes during the experimental period (Ishikawa & Montello, 2006; Ishikawa et al, 2008). The methodologies which previous research has utilised to examine spatial knowledge can be characterised according to how participants are briefed about environmental learning tests. In a number of works participants have been instructed prior to their commencement of the study that they

are required to remember the spatial layout of an environment for a battery of post-trial tests (Willis, Hoelscher, & Wilbertz, 2007). However, other work has opted to study individual's incidental learning, meaning post-trial tests are administered to unsuspecting participants (Oomes, Bojic, & Bazen, 2009; Antrobus, Burnett , & Krehl, 2017). When assessing spatial knowledge acquisition, the tests implemented by researchers vary according to the type of environmental knowledge being assessed and the aims of the research.

3.3 MEASURES

3.3.1 Assessing environmental engagement

If environmental engagement leads to enhanced environmental learning, tests of individual spatial knowledge acquisition can provide an indication as to how actively-engaged participants were with their test environment. To evaluate spatial knowledge acquisition, tests of environmental learning are administered upon the participant's completion of the designated route(s). The tests which participants will complete are dependent on both the research questions being asked and the component of environmental knowledge being studied.

The experimental design and route configurations employed within the methodology of this thesis allowed for all three components of environmental knowledge (landmark, route and survey knowledge) to be assessed during a battery of post-trial tests. Participants in each experimental condition travelled three routes, twice, one week apart. With each of these routes intersecting another at three separate points.

The decision to incorporate a second drive into the experimental design was taken to increase each participant's environmental exposure time, this was done to promote engagement and encourage the encoding of their spatial environment. Time spent on-route is especially important to encourage the development of comprehensive survey knowledge.

Whilst there is debate surrounding the developmental stages of environmental knowledge (Kitchin & Blades, 2002), previous literature has suggested that landmark and route knowledge are usually formed prior to the development of the more complete survey knowledge (Siegel & White, 1975; Golledge, Smith, Pellegrino, Doherty, & Marshall, 1985). By allowing participants this increased on-route time, it was the hope that this higher-level processing could occur, allowing participants to represent spatial imagery from a configurational perspective. The following section will present methodologies used within the literature to assess landmark, route and survey knowledge. Each will be discussed in turn before providing a justification for the approach utilised within this thesis.

3.3.1.1 Environmental knowledge tests

The following measures were used to assess the landmark, route and survey knowledge acquired by drivers during the experimental drives:

- Landmark knowledge assessed via Iconic recognition tasks
- Route knowledge assessed via Sequential ordering tasks
- Survey knowledge assessed via Cued sketch map

Each of these methods will now be presented and discussed in turn.

Iconic recognition tasks are one method used to assess the acquisition of landmark knowledge. Here, target images are presented to participants alongside distractor images. The participant must correctly identify which images are from scenes along their route (target images) and which images are non-route scenes from other environments (distractor images). This approach has been implemented across a number of studies examining the acquisition of landmark knowledge in both virtual and real-world environments. The employment of this approach is recognised for its simplicity – the issuance of flashcards to participants is simple and speedy to both administer and score (producing a final mark of percent correct) (Kitchen and Blades, 2002). Despite time saving advantages, previous

works have raised concerns around the employment of iconic recognition tasks in real world environments (Webber, 2013). Here the author asserted that "the recollection of a scene or landmark can be comprised of views from a variety of angles, with differing light and weather conditions and various occlusions to a scene that cannot be controlled" (Webber, p59). This means that we cannot be certain as to whether the images which we present to the participants are an accurate representation of their view of the scene. Presenting participants with a view of the road scene which is different to the one which they hold from their own travel experience, could result in an image not being recognised, subsequently influencing the obtained results. Despite this criticism, the time saving and simplistic qualities of this approach, when issued as a battery of tests, make it a desirable assessment tool in environmental learning. It is therefore employed throughout this thesis, with particular precautions; such as selecting imagery from the driver cab perspective and the use of images sensitive to seasonal change.

To assess levels of individual route knowledge, sequential ordering tasks are implemented. Here, participants are presented with a number of scene images, taken from a single route. Participants must then order these images in the sequence they believe they encountered them. Therefore, replicating the participant's best memory of the route. Employment of this approach complements the use of iconic recognition tasks, in that, both have similar, speedy approaches which allow tests to be administered and analysed quickly. However, they can be subject to the same perspective difficulties, in that the real-world environment in which participants experienced the road scene is dynamic and changeable, meaning the image which they are presented with, may not fully represent how they experienced the environment. Other work has instead looked to directional knowledge to provide an indication of individual levels of route learning. Here, upon completion of a navigation task participants are shown images of each decision point on route and asked to indicate the subsequent direction of travel at the junction displayed in the image. This approach explores an individual's directional knowledge at junctions

rather than their sequential memory of a route (examined in sequential ordering tasks). Whilst the employment of this methodology allowed Aslan et al (2006) and Kruger et al (2004) to draw direct comparisons within their own research, utilising this approach can make the generalisability to other works difficult. Therefore, it is important to use a consistent approach within a body of work so that we can be sure that any differences in spatial knowledge acquisition are due to the manipulation of experimental variables rather than a variation in testing method.

To evaluate the acquisition of an individual's survey knowledge a number of previous works have asked participants to produce a cued sketch map (Appleyard, 1970; Burnett & Lee, 2005; Rovine & Weisman, 1989). Here, participants are instructed to draw a map of the environment which they have just navigated through, paying particular attention to a number of key aspects, such as the inclusion of landmarks, pathways, road names and junction types. Using of this method can provide a rich source of information about how individuals perceive their environment, indicating the degree to which individuals have abstracted information from route sequences and assimilated the knowledge garnered from these different experiences into a single, integrated model (Kitchin & Blades, 2002). Although this method offers a holistic insight into the structure and completeness of an individual's cognitive map, allowing for comparison with the real world and across experimental variables, there remains a number of drawbacks to its implementation. Administering sketch maps can often be a lengthy process, as sketch map production lies solely on the participant's memory, the recall of individuals can vary dramatically. This means there can be large fluctuations in the time taken to complete the sketch map, which can be troublesome in a field environment with changeable weather conditions. Analysis can also be lengthy and open to subjective bias where one researcher is responsible for coding all sketches. However, by taking a number of precautions during testing and analysis we can ensure that each of these disadvantages doesn't mitigate the potential value of administering such tests. For example, providing a standard, detailed

description to participants about what information to include within their sketch maps, can provide direction and points of focus which can aid recall, reducing task completion times. Furthermore, by conducting all route learning tests in the passenger seat of the instrumented test vehicle ensures participants are protected from adverse weather and have an adequate, comfortable space to complete tests. Additionally, by utilising the well-established methods of Appleyard (1970) and Lynch (1960) by which to structure sketch map analysis and performing a reliability analysis on a number of sketch maps, it can be ensured that the analysis of participant sketch maps follows a structured protocol, with stringent protections from subjective bias.

The complexity of participant sketch maps within this thesis will be classified according to Appleyard's (1970) categorisation scheme, which examines the predominant elements within the sketch, and their level of accuracy. Sketch maps are defined as being either "sequentially dominant" or "spatially dominant "depending on how participants have chosen to represent their main sections. Sequentially dominant maps use a road network as their main framework, building other elements around this structure. Alternatively, spatially dominant maps use individual buildings, landmarks or districts to create clusters which give the map it's arrangement. Once participant maps are categorised as either sequential or spatially dominant they can be sub-categorised according the detail they contain. Below is a summary of the different map types defined by Appleyard (1970) ranging from simple, primitive maps, to complex, integrated illustrations.

Sequential Maps

1. Fragment: The most rudimentary type of sequential map, this contains portions of paths or lists of components disparate from one another which may appear out of sequence.
2. Chain Maps: Equally simple but more schematic map illustrations, pathways are more connected but are oversimplified so that left and right residential turns and road curvature may be represented as a squiggly or straight lane.

3. Branch and Loop: A more developed map than fragment and chain maps, these maps are more laterally developed and include loops and braches as outcrops from the main network. These loops may have illustrated drastically oversimplified portions of a meandering section of a route.
4. Network: The most complete form of sequential map, these illustrate more complete road systems which are rich in detail and demonstrate a true representation of the routes travelled.

Spatial Maps

1. Scatter and Cluster: most primitive form of spatial maps, these illustrate components such as individual buildings or landmarks which may be grouped together at will and sometimes drawn without any associations.
2. Mosaic: separates off perceived districts or routes with drawn boundaries, whilst these maps could be less specific or accurate than scatter maps in landmark or junction type placement, they, instead have the advantage of plotting out major zones or distinct, separate portions of routes.
3. Link: Places or areas are coupled with graphic linkages, which may represent portions of the road network. However, spatial units remain dominant in these maps.
4. Pattern: These are the most comprehensive and exact spatial maps with outlined areas, and main road features as dominant elements.

Independent navigation tasks offer an alternative method to assess individual environmental learning. Rather than assess each of the individual components of spatial knowledge, independent navigation tasks measure the integration of environmental knowledge by studying navigation in situ. Participants who have previously navigated routes with the assistance of a wayfinding aid are required to navigate these same routes, or sections of these routes independently (Baldwin & Reagan, 2009) to determine the level of environmental knowledge acquired during experimental exposure.

Variations of this method have also required pedestrian participants to navigate back to their route start point, or back to a defined earlier section of the route (Gertner and Hiller, 2009; Oomes et al, 2009). Alternatively, researchers have also tasked participants with navigating new routes in previously learned route networks (Adler, 2001). From this, researchers can gather a number of performance measures to determine acquired environmental knowledge including, number of navigational errors, time taken for route completion and the frequency of repeated landmarks or waypoints. Whilst these assessment measures do not directly measure individual route knowledge components, previous authors have used the measures of this integrated approach to provide an indication of underlying landmark knowledge. Oomes et al (2009) was able to assess landmark knowledge within an independent navigation paradigm by tallying the frequency which participants travelled by landmarks or waypoints which had appeared on the original route. Here, participants are able to demonstrate landmark knowledge as an integrated part of their route strategy. Whilst not explicitly testing for landmark knowledge, this can be deduced from the number of matching landmarks incorporated into an individual's route selection which, in turn, is reflected in a higher score, indicating high route selection accuracy. Whilst use of independent navigation tasks reflect what is arguably a more holistic, ecologically valid measure of environmental learning, use of this approach is not always feasible due to time and experimental constraints, or as in the case of on-road navigation, where use of this method may raise safety concerns - where the drivers' main concern should be the safe operation of the vehicle rather than navigating within a potentially unfamiliar, dynamic environment.

Due to the ease of implementation within a field environment, iconic recognition tasks, sequential ordering tasks and sketch map analysis will be used as a means of respectively assessing landmark, route and survey knowledge throughout this thesis. Whilst, the employment of an independent navigation task could provide an ecologically valid method to assess environmental knowledge and promote

understanding of how this knowledge may influence a driver's navigation strategy, it was decided for ethical reasons that this approach would not be employed on busy, public roads where navigation hesitation may bring safety concerns and where safe control of the vehicle should remain the primary concern.

3.3.2 Eye Tracking

Use of Eye-tracking methodologies promote a unique understanding of an individual's visual behaviours and can be used to provide an understanding of underlying attitudes and behaviours. In the context of driving navigation such rich data can provide additional depth and contextual insight to visual search patterns and environmental points of interest. Buswell (1935), in one early definition, described eye movements as "unconscious adjustments to the demands of attention during visual experiences" (pg. 9). Therefore, we can reason that by analysing these unconscious movements we are able to gain a number of insights. Firstly, we can explore what the observer may have found interesting, or the differences in individual search strategies. Similarly, we can study the variations in how participants attend to the experimental task, or how they engage with their wider environment and interact with any navigational devices during the study period. By examining each of these facets we may begin to postulate the predominant search strategies and interaction patterns of individuals.

Various, diverse fields have previously utilised eye-tracking in the study of human attention. For example, eye-tracking technologies have been implemented within sports to analyse complex visual behaviours determining how a batsman hits a ball (Land & McLeod, 2000). Conversely, these technologies have also been used to identify the visual points of focus during everyday activities such as making a cup of tea or a sandwich (Land, 1999; Land & Hayhoe, 2001). Despite the use of eye-tracking methodologies being routinely utilised in a number of far reaching domains, there remains limited research which demonstrates the use of eye-tracking within the context of on-road navigation. However, a plethora of related works can instead be drawn

upon to inform understanding on the merits of its implementation within this field.

A number of works have used eye-tracking methodologies within the field of cartographic and interactive maps to study how differences in expertise and map design can influence individual search strategies and the extraction of information, subsequently demonstrating the value of such an approach within the wayfinding domain (Opach & Nossum, 2011, July). In addition to this, a number of driving studies have employed both fixed-based and mobile eye tracking set ups within simulator and real-world environments to study the visual and cognitive demand of varying driving configurations and in-car systems (Kun, Paek, Medenica, & Memarović, 2009; Jensen, Skov, & Thiruravichandran, 2010). The development of newer technologies such as the mobile eye-tracking systems have therefore made it possible to study an individual's eye movements within the real-world. These systems, unlike their fixed-based counterparts, overlay eye movement data on to a video feed of the participants forward facing view, revealing the continual shifts of visual attention throughout the course of a task (Webber, 2013). Use of these portable eye-tracking systems is something which sports, driving and pedestrian navigation studies have exploited in recent years (Land & McLeod, 2000; Land & Tatler, 2001; Webber, 2013).

Similar to the planned on-road navigation study, previous pedestrian navigation studies have used eye-tracking to explore the underlying cognitive processes involved in outdoor navigation tasks, such as landmark identification and orientation strategies (Webber, 2013). Providing researchers with a plethora of data for analysis which can be interpreted in a number of unique ways, not previously permitted by other methods. Alternative approaches to eye tracking methodologies include the use of observation (video/direct), which is often utilised as a practical alternative to eye-tracking methods due to the basic experimental set-up and the simple, timely data analysis afforded by use of this approach (Holmqvist, et al., 2011). However, although observation can highlight many of the key behaviours of

participants, there are practical issues around detecting subtle behaviours, which mean that use of this method alone may result in crucial acumens being overlooked. Renshaw and Webb (2007) emphasise this point, indicating that use of observation in isolation fails to capture the comprehensive level of information which eye-tracking can provide, such as pinpointing exactly where participants are looking, the number of fixations, their duration and distribution. In the context of on-road navigation, use of mobile eye-tracking permits the study of the distributions of gaze allocation during wayfinding and at navigational decision points. This use of mobile eye-tracking therefore has the potential to add depth to our understanding of how individuals navigate, whilst driving and how this may vary when using different methods of navigation.

Whilst the use of eye-tracking offers additional depth and insight to data interpretation, it also poses a number of challenges for analysis and extraction of meaningful data. In a navigation context, vision has a dual purpose. Firstly, to collect information pertinent to the task and secondly to steer our movement through the environment. This binary role of vision emphasises the potential difficulties presented in subsequent analysis. Task relevant navigational data mush be distinguished from normal driving safety data in order to establish any differences in the contrasting navigational tools used by participants. For example, distinguishing those gaze allocations made after the issue of a navigational prompt, which are key for identifying the correct junction to take on-route, from other gaze allocations made scanning the wider environment for hazards or oncoming traffic. Only one of these examples is key to navigational performance and it is important to distinguish relevant navigational data from other information, which, although key for road safety, fails to offer any additional value in terms of an individual's navigation decision making.

The employment of an eye-tracking methodology in the real-world comes with a number of practical challenges which need to be carefully considered to ensure that the resulting data is reliable. A number of these challenges occur in both stationary lab-based

environments and dynamic real-world environments. These factors include individual differences in pupil size and eyelash length, whether the subject is wearing dark eye make-up, or wearing glasses or contact lenses, all of which can make tracking the subjects gaze more cumbersome (Holmqvist et al., 2011). In a real-world environment however, accurate calibration can present a concern. Although not moving as freely as pedestrians, drivers can often move their heads and upper torsos frequently when performing visual checks, which may affect the accuracy of the subjects' calibration. Although authors of similar works (Kuparinen & Irvankoski, 2010) suggest multiple recalibrations to counteract these issues, this is not always feasible in a real world, on-road environment where negotiating traffic and safe control of the vehicle should always remain the primary concern. In addition, it was key that participants had the most natural navigation experience possible during these road trials, which therefore meant minimal experimenter intervention. To ensure a data set which was as accurate as possible careful piloting was carried out and additional cab facing recordings of participants were made so that observational analyses could be carried out to overcome any potential limitations or omissions in eye-tracking data.

The employment of mobile eye tracking within this thesis will be used to generate quantitative data, from which we can infer driver behaviour. This approach is similar to previous works conducted within the driving field (Kun, Paek, Medenica, & Memarović, 2009; Jensen, Skov, & Thiruravichandran, 2010; Wang, Reimer, Dobres, & Mehler, 2014). That is, eye tracking data generated from each on-road trial will be used to explore how navigational method can impact a driver's visual behaviours on varying junction approaches.

A number of junctions which appear on route will be selected for further analysis on the basis of their difficulty and the presence of 'roadside furniture'. All driver fixations will then be coded from the geographical point of the first navigational prompt issued by the Satnav device (or equivalent point in non-Satnav conditions). From this, gaze allocation and predominant areas of interest can be

interpreted according to the navigational condition assigned to the participant and therefore the information issued to them. However, it is important to utilise a multi-faceted approach before determining underlying processes. Whilst gaze can infer attention, it cannot offer an explanation to a subject's underlying thoughts. As Keifer, Straub and Raubal (2012, April) explain, "mobile eye-tracking data should thus be taken as an indicator for perception, not perception itself" (pg. 316). Considering this, eye tracking data will be used in combination with other methods such as the Tactile Detection Task (TDT) and the National Aeronautics and Space Administration-Task Load Index (NASA-TLX) data to infer a subject's workload (discussed in the next section).

3.3.3 Workload

Driving is a complex and safety critical task that requires both the communication between cognitive, perceptual and psychomotor skills and the ability to respond to often rapidly unfolding, dynamic environments (Groger, 2000). This involves the ability of the driver to attend to stimuli and select actions appropriate to the current driving environment and task goals whilst disregarding other information, this process is more widely referred to as selective attention. Attention can be driven both endogenously (top-down), in an anticipation of expected events, or exogenously (bottom-up), by unexpected factors, external to the driver such as salient stimuli or events (Posner, 1980).

Selective attention can be related to both the driving task and other secondary in-vehicle tasks which are performed whilst driving. For example, driving in a fast-paced, dense, traffic environment or poor weather conditions may mean drivers selectively attend to particular environmental features at the expense of other potentially safety relevant stimuli (Diels, 2011). Additionally, secondary tasks performed whilst driving such as talking over the phone or interacting with in-vehicle systems may result in increased demands on working memory, resulting in the subsequent withdrawal of attention from the roadway, potentially impairing the identification of safety critical events.

Throughout this thesis, the TDT will be used as a means of objectively evaluating how selective attention is influenced by perceptual and/or working memory demands (Engström, 2010). The TDT is an ISO standardised tactile equivalent of the Peripheral Detection Task (PDT) (Martens & Van Winsum, 2000) where subjects are required to respond to intermittent haptic stimuli, issued at random time intervals. Here, drivers fit a small vibro-tactile motor (or 'tactor') above their collar bone, under instruction from the experimenter. Periodically (and seemingly random), with uniformly distributed time periods in-between, the tactor vibrates with a brief low intensity pulse. The task of the participants is to press a button on their index finger against the steering wheel when they notice the pulse, in order to switch it off. Performance is based on the hit rate of subjects, that is, the number of stimuli which subjects actively respond to and their reaction time, defined as the time from the presentation of the stimulus until the subject triggers an acknowledging response. Both of these measures represent the degree to which selective attention is affected by the primary task (driving) and the secondary task (navigating) demand under evaluation (Diels, 2011).

In contrast, the PDT measures a subject's reaction time to either (i) a single LED fixed to the head at a set angle relative to the eye or (ii) a series of LEDS frequently placed on the left-side dash, within the driver's line of sight, in either an instrumented car or driving simulator. In each of these instances the driver is required to respond to an LED lighting up by pressing a button within the steering column (Martens & Van Winsum, 2000). Whilst the PDT has demonstrated sensitivity to visually and cognitively demanding secondary tasks in addition to driving task demand, there are a number of limitations for its use within the driving field. As highlighted by Engstrom (2010) the prominence of the stimuli can be affected by varying light conditions, which is a particular concern during field testing where changeable weather conditions are likely. Secondly, use of the PDT may influence visual scanning behaviours, potentially impacting the subsequent study of participant eye-movement data.

To circumvent such limitations, stimuli will be presented to participants using an alternative sensory channel, i.e. the employment of the haptic-based TDT. This will reduce the visual load placed upon the driver, during what is already a predominantly visual, safety critical task. A number of previous driving studies have also opted to use this methodology to avoid impacting the driving task and other visual based experimental methods (Large, Burnett, Anyasodo, & Skrypchuk, 2016, October).

In addition to recording an objective measure of participant workload, participants will also be asked to provide an indication of their subjective experience of workload during the experiment. There are a number of well established, robust subjective workload measures available including the NASA-TLX, the Subjective Workload Assessment Technique (SWAT) and the Workload Profile (WP). By selectively employing each of these methodologies according to experimental requirements researchers can benefit from the various strengths associated with each test. For example, if the goal is the comparison of mental workload between two or more tasks with varying objective levels of difficulty, researchers should select the workload profile. However, if the aim is to predict the performance of an individual in a task, then the NASA-TLX would be more appropriate. Alternatively, if the purpose is the assessment of the cognitive or attentional demands of a task, the WP or SWAT both provide a well-suited structure (see Rubio, Diaz, Martin, & Puente, 2004 for complete review of subjective workload scales). Whilst each methodology brings its own advantages and imitations, the NASA-TLX will be used throughout this thesis to provide the drivers own subjective assessment of workload. As a long-standing methodology utilised within automotive research the NASA-TLX is a well-established, non-intrusive, robust method, which is quick and simple to implement, able to garner sensitive results which can be reliably related back to performance.

Subjective measures are an increasingly important tool in system evaluations and are now widely used to assess individual workload

across a number of wide-ranging fields including air traffic control, civilian and military cockpit design, within the field of medicine and the automotive industry (Hart, 2006). This frequent utilisation of such subjective procedures may be attributed to their practical advantages (ease of implementation, non-intrusiveness) and their capability to provide sensitive measures of operator load (Rubio, Diaz, Martin, & Puente, 2004). Since its inception in 1978, the National Aeronautics and Space Administration-Task Load Index (NASA-TLX) has become one of the most widely utilised techniques for assessing subjective workload. As a method, it has been extensively tested and frequently implemented in a number of human performance studies. As a result, it is generally considered to be a robust measure of subjective workload (Hart, 2006).

The NASA-TLX is a multi-dimensional assessment tool which provides an overall workload score based on average ratings of six sub-scales: Mental demand, physical demand, temporal demand, own performance, effort and frustration. A definition of each of these subscales is provided below:

TITLE	ENDPOINTS	DESCRIPTIONS
MENTAL DEMAND	Low/High	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	Low/High	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	Low/High	How much time pressure did you feel due to the rate or pace at which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter? How satisfied were you with your performance in accomplishing these goals?
EFFORT	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

Figure 3-1: definitions of the six NASA-TLX subscales. Taken from Hart, 2006

The assumption of the NASA-TLX is that some combination of the six subscales will likely represent an individual's experience of workload, whilst performing most tasks. Each of the six sub scales were derived from initial extensive testing, which aimed to determine the primary factors which define the subjective experience of workload for a variety of people, performing numerous tasks, with tasks ranging from laboratory-based assignments to flying an aircraft (Hart, 2006).

The administration of the NASA-TLX is a two-part procedure. Firstly, the participant is asked to evaluate the contribution of each factor (its weight) to the workload of the task. This consists of presenting the participants with a series of pair-wise comparisons (15 in total) of the six sub scales and asking participants to choose which of the two dimensions presented to them is more relevant to their personal definition of workload (e.g. mental demand/ frustration level). The number of times a dimension is selected as more relevant influences the weighting of that dimension for any given task performed by the participant. The second part of the workload assessment requires participants to provide a numerical rating for each of the sub scales, these reflect the magnitude of that factor in the task. Rather than provide an initial numerical value indicating perceived workload, participants express their experience of a particular factor (e.g. effort, performance) as a position on an equally distributed 20-point scale. In each case, scales are labelled from 'low' to 'high' except in the case of performance where participants must indicate their ability to execute the task on a scale ranging from 'good' to 'poor'. Each of the subscale ratings provided by that participant during the study is then multiplied by the appropriate weight, therefore producing a scale which has been tailored according to participant's personal workload definitions. Advantages of using of this weighting approach can include increased sensitivity to relevant variables and a decrease in between-subject's variability (Rubio, Diaz, Martin, & Puente, 2004).

However, a number of studies have chosen to modify NASA-TLX implementation by eliminating this weighting process altogether (Hart, 2006). This approach is referred to as Raw TLX (RTLX) and has

gained recognition due it is simplistic, speedy application. Here, the numerical ratings of each sub scale are simply added or averaged to create an estimate of overall workload. Whilst the RTLX method drastically simplifies NASA-TLX methodology previous research has demonstrated that utilising this simplified approach can result in the use of a scale which is equally or more sensitive than the original methodology (Byers, Bittner, & Hill, 1989; Hendy, Hamilton, & Landry, 1993). Due to the number of measures within this thesis which will be implemented post-trial, the requirement for a quick, simple and importantly, sensitive subjective workload assessment is paramount. Therefore, the RTLX procedure will be utilised throughout, in line with previous work conducted in the automotive field (Large, Burnett, Anyasodo, & Skrypchuk, 2016, October).

3.4 SUMMARY OF MEASURES UTILISING DURING DATA COLLECTION

Tables 3-1 and 3-2 below summarise those methodologies, discussed within this chapter, which will be utilised within the following data collection chapters (chapters 5 & 6). Tables 3-1 and 3-2 each provide a brief summary of the adopted methodology alongside the associated advantages and disadvantages of each approach, and any precautions which were made to each method to counteract previous criticisms in the literature.

Measure	Detail	Advantages	Criticisms	Precautions Taken
Test Environment:				
Field-Based On-road study	• Conducting the study in a naturalistic on-road environment, ensures that the resultant behaviours exhibited by participants during each of the experimental drives represent their natural interactions and navigational decisions, made when driving and following wayfinding guidance in an unfamiliar environment.	• Increased external and ecological validity	• Reduced experimental control • Complex data collection	• Road trials were conducted outside of rush hour traffic so that some participants did not spend disproportionally longer on route than others.
Environmental engagement measures:				
Landmark Knowledge	**Assessed via Iconic recognition tests**: Target images are presented to participants alongside distractor images. The participant must correctly identify which images are from scene along their route (target images) and which images are non-route scenes (distractor images).	• Simple and speedy to administer and analyse	Potential for images (utilised in post-trial tests) to be taken from a perspective which is incongruent with how the driver experienced the environment on-route	• Images (administered in post-trial tests) were taken from a driver cab perspective • Utilised images were also sensitive to seasonal change
Route Knowledge	**Assessed via a sequential ordering task**: Participants are presented with a number of scene images, taken from a single route. Participants must then order these images in the sequence they believe they encountered them. Therefore, replicating their best memory of the route	• Simple and speedy to administer and analyse	Can be subject to the same perspective issues as iconic recognition tasks (see above)	• Images (administered in post-trial tests) were taken from a driver cab perspective • Utilised images were also sensitive to seasonal change
Survey Knowledge	**Assessed via cued sketch map**: participants are instructed to draw a map of the environment paying attention to a number of key aspects e.g. the inclusion of landmarks, pathways, road names and junction types	• Offers a holistic insight into the structure and completeness of an individual's cognitive map	• Production lies solely on participants memory • Recall of individuals can vary dramatically • Analysis can be lengthy and open to subjective bias	• A standardised, detailed description will be issued to participants regarding what information to include in their sketch maps • Maps will be analysed using well-established methods with a subsequent reliability analysis being performed to prevent subject bias in analysis

Table 3-1 Summary of methodologies utilised within this thesis

Measure	Detail	Advantages	Criticisms	Precautions Taken
Visual Behaviour:				
Eye tracking	• Mobile eye tracking glasses will be worn by participants during on-road trials and eye tracking analysis will be used to explore how navigational method can impact a driver's visual behaviours on varying junction approaches • All driver fixations will be coded from the geographical point of the first navigational prompt issued by a Satnav (or equivalent point in non-Satnav conditions)	• Permits the study of the distributions of gaze allocation during navigation and at navigational decision points • Adds depth to our understanding of how individuals navigate during driving	• Difficult to ensure accurate calibration in a real-world driving environment (when drivers move their head and torso to perform visual checks)	• Careful piloting carried out to ensure calibration is maintained • Cab facing recordings of participants made to overcome any potential limitations or omission in eye tracking data.
Workload:				
Objective Workload	• Measured using the tactile detection task (TDT) (Engström, 2010), • Here, a series of tactile stimuli are presented via a tactor attached to the participant's shoulder. Participants are required to respond to the presence of a new stimulus by triggering a button, attached to their finger, as quickly as possible. The delay between stimuli is varied subtly to ensure that participants are unable to predict stimulus presentation. Detection performance is measured by response time and success-rate (or missed responses).	• The employment of the haptic based TDT will reduce the visual load placed on the driver. [compared to implementing the cross-modal equivalent peripheral detection task (PDT)]	-	-
Subjective Workload	• Measured using the NASA-TLX questionnaire. Here, participants express their experience of a particular workload factor (e.g. effort, performance) as a position on an equally distributed 20-point scale.	• Ease of implementation • Non-intrusiveness • Capable of providing a sensitive measure of operator load	• The inclusion of the 'weighting' procedure can result in a lengthy administration time	• The weighting process was eliminated and numerical ratings of each sub scale were added together to create an estimate of overall workload.

Table 3-2 Summary of methodologies utilised within this thesis

4

CHAPTER 4: EXPERIMENTAL METHOD

The work described in this section of the thesis details a series of on-road studies which were conducted in the Clifton area of Nottingham, aiming to uncover how different navigational methods affect driver wayfinding performance, workload and environmental engagement. In a between-subjects design, a total of 45 experienced drivers completed two experimental drives comprising the same 3 routes (with overlapping sections), staged one week apart. Drivers were provided with the navigational support of either a Satnav device (baseline), an informed passenger (a stranger with expert route knowledge) or a collaborative passenger (an individual with whom they had a close, personal relationship). Participants experienced the same guidance on each of the two drives to explore changes in reported and observed behaviour. The different navigational methods were notable for their varying interactivity and the preponderance of environmental landmark information

Figure 4-1 provides an overview of the experimental set-up which is detailed in this chapter.

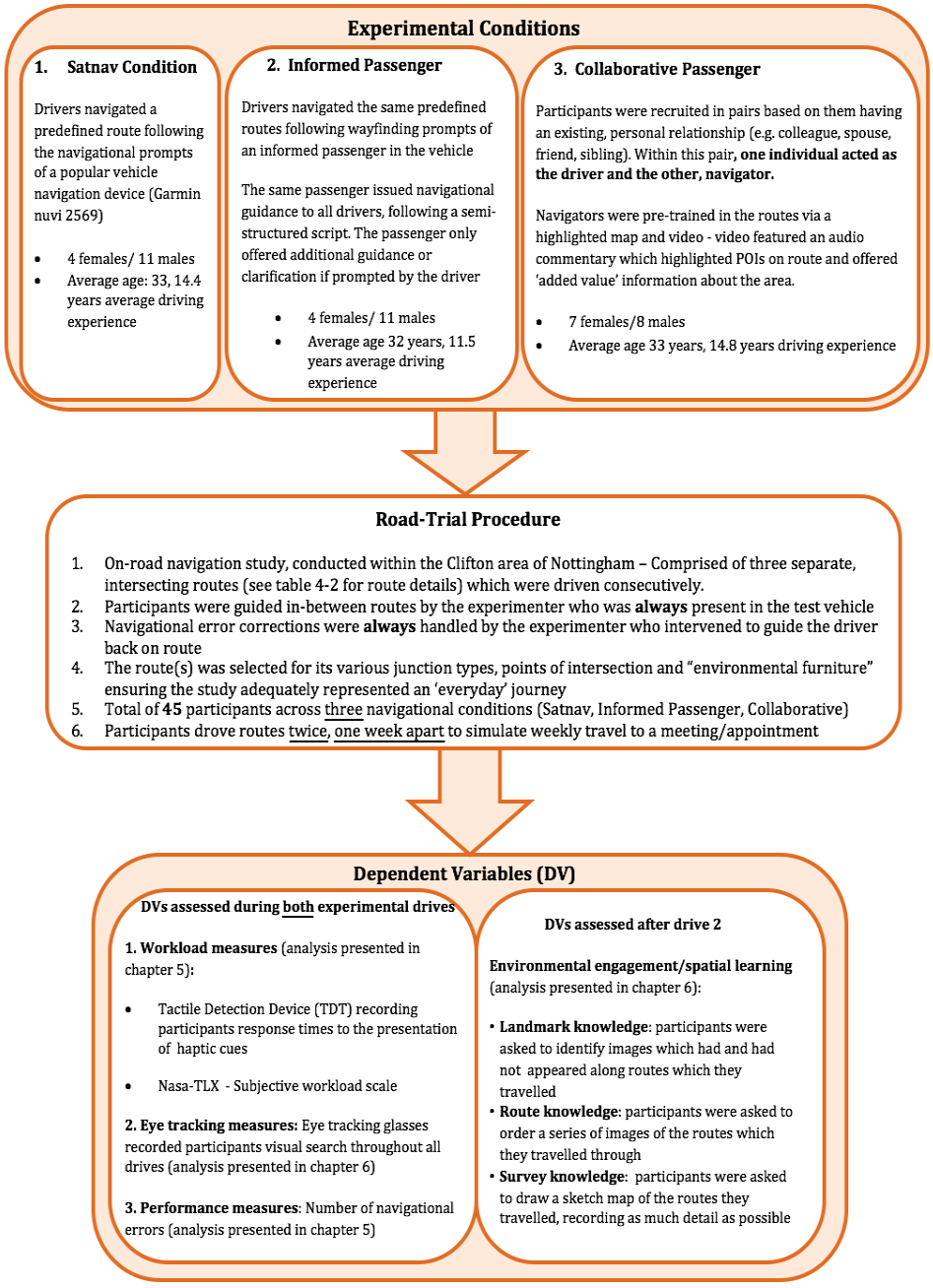


Figure 4-1 Overview of experimental conditions, road-trial procedure and examined dependent variables

Each of following subsections of this chapter provides further detail of each navigational condition in turn, explaining how navigational guidance varied in each setup.

4.1 NAVIGATIONAL METHODS

4.1.1 SatNav

Drivers navigated with the assistance of a Satnav device through three predefined, separate routes that intersected along three points in the Clifton area of Nottingham (points of intersection illustrated in figure 4-7), in a test period which ran from February to March in 2016. In this condition each driver navigated through these routes following the auditory wayfinding prompts and the visual display of a commercially available (non-prototype), nomadic navigation device (Garmin nuvi 2569). Participants were trained in the use of the system prior to commencing the drive, although they were not required to physically interact with the device while driving (i.e. the destination was entered prior to the vehicle moving). Each of the three routes were preprogramed into the device using the Garmin Basecamp ™ application. This process was required as satellite navigation devices often configure routes on the basis of shortest distance, or fastest journey time. As each of the three routes were neither the 'fastest' or 'shortest' route to the final destination the addition of navigation waypoints ensured that navigational guidance and route selection remained consistent for each participant, allowing results to be comparable across experimental conditions. Prior to the road-trial commencing the experimenter installed the navigation device in the test vehicle according to manufacturer's instructions, in the far-right hand corner of the driver's cab, ensuring that the participants were comfortable with the device in that location.

The 'SatNav' condition comprised a total of 15 participants (11 male, 4 female), with an average age of 33 years (SD = 11.5). These participants, with an average of 14.4 years driving experience, identified dedicated SatNav devices as their preferred navigation tool in a pre-trial questionnaire (closely followed by smartphone map applications {i.e. Google maps}), with 12 out of the 15 participants professing to 'always' using such navigational aids when travelling in unknown areas (3 out of 15 participants continued to use such devices in areas which were familiar to them).

Ethical permission to conduct this study was granted by the University of Nottingham, School of Engineering ethics committee on the 3rd of November, 2015. Full details of ethics application and approval can be found in Appendix A.



Figure 4-2: the Garmin nuvi 2569 Satellite navigation device which issued wayfinding guidance to participants in the SatNav condition

4.1.2 Informed Passenger

In this condition drivers navigated along the same three, predefined, intersecting routes, from February to March in 2016, instead following the fixed navigational guidance of an 'Informed Passenger' (an individual unfamiliar to participants/ with whom they had no prior relationship). Here, the experimenter, acting as the 'informed passenger', sat next to the driver and issued navigational guidance to all participants, following a semi-structured navigational script. The passenger offered additional guidance or provided navigational clarification, only when prompted by the driver. The navigational script utilised by the informed passenger referenced the world around the driver by identifying landmarks at each navigational choice point (junction) on route (e.g. turn right after the leisure centre), utilising hand gestures to support this verbal guidance and assist the driver in the identification of the correct roadway. Additionally, landmarks were also utilised at four predefined points, which were not essential to accurate navigational performance. Here, the same four landmarks were highlighted as the driver travelled past them on route (Clifton university campus, Fairham pub, Clifton Market place, Clifton flower garden). This was done to provide the driver with enhanced information about the surrounding route environment.

The 'informed passenger' condition comprised a total of 15 participants (11 male, 4 female), with an average age of 32 years (SD = 9.8). These participants, had an average of 11.5 years driving experience and identified dedicated SatNav devices as their preferred navigation tool in a pre-trial questionnaire (closely followed by smartphone map, and route planner applications {i.e. Google maps, AA route planner}), with 10 out of 15 participants professing to 'always' using such navigational aids when travelling in unknown areas (2 out of 15 participants continued to use such devices in areas which were familiar to them).

Ethical permission to conduct this study was granted by the University of Nottingham, School of Engineering ethics committee on the 3rd of November, 2015. Full details of the ethics application and approvals can be found in Appendix A.



Figure 4-3: an interior view of the vehicle during the Informed passenger navigation condition

4.1.3 Collaborative

Here, prospective participants were asked to sign up in pairs. Members of each partnership were required to have an existing, close personal relationship with one another, which had required them to navigate together on previous occasions (colleague, spouse, friend, sibling). Within these pairs, participants self-selected the roles of 'driver' and 'navigator'. Here, in a testing period from September to October in 2016, the driver was required to navigate through the same three intersecting routes as the previous iterations of the trial

following the guidance of the passenger (termed the collaborative passenger). Prior to commencing the on-road trial, collaborative passengers were trained in the routes and told to make navigational notes to help them guide their driver, training was performed and note taking was recommended to passengers so that they were able to issue accurate, timely guidance to drivers. Training consisted of issuing participants with a highlighted map (see Figure 4-7, pg. 127), which marked route start and end points (as well points of route intersection) and a video which was filmed from the driver cab perspective (see Appendix C for how to access route learning materials). This video featured an audio commentary, which used the same navigational script as the 'informed passenger' trials, with the addition of 'point of interest' and 'added value' information about the area (e.g. highlighting churches, university campuses, market days, names of parks on route). Whilst navigator training was not formally assessed, navigators were asked to confirm that they had utilised the available training materials, prior to the first experimental drive. Navigator notes were also examined by the experimenter to ensure that they were sufficient to guide each driver through the three experimental routes.

The 'collaborative' condition comprised a total of 15 participants (10 male, 5 female), with an average age of 33 years (SD = 9.8). These participants, had an average of 14.8 years driving experience and identified dedicated SatNav devices as their preferred navigation tool in a pretrial questionnaire (closely followed by smartphone map, and route planner applications {i.e. Google maps, AA route planner}), with 7 out of 15 participants professing to 'always' using such navigational aids when travelling in unknown areas (only 1 out of 15 participants continued to use such devices in areas which were familiar to them).

Ethical permission to conduct this study was granted by the University of Nottingham, School of Engineering ethics committee on the 25th of August, 2016. Full details of the ethics application and approvals can be found in Appendix A.



Figure 4-4: interior view of the vehicle in the Collaborative navigation condition

4.2 PARTICIPANTS

Participants who took part in the studies were primarily employees or students at the University of Nottingham and participated voluntarily by responding to advertisements and blanket emails. Participants were reimbursed for their time with a £30 shopping voucher, presented to participants on completion of the final, second drive. The only prerequisites to participation in the road trial were that drivers held a university driving permit which meant they were insured to drive the university owned vehicle and that they had no prior knowledge of the Clifton area of Nottingham where the study took place (details of how participants obtained a university driving permit can be found in Appendix A). Additionally, to ensure that prior experience did not influence the driver's environmental knowledge, participants were only permitted to take part in one of the

experimental conditions. A total of 45 participants (15 SatNav drivers, 15 informed passenger drivers, 15 collaborative drivers) with no known health-related problems took part in the trial.

4.3 APPARATUS AND MATERIALS

An instrumented Ford focus, owned and insured by the University of Nottingham was used for the study (Figure 4-5). The vehicle was fitted with forward facing cameras to capture the road view, providing context to the directions being given by the navigator. Cameras that faced into the driving cab also captured the driver's interactions with either the navigation device, informed passenger or collaborative passenger along with any gestures and facial expressions which were made throughout the driving task.



Figure 4-5: the instrumented Ford Focus used within all on-road trials

Throughout all drives, participants wore a TDT (Tactile detection Task) device (Figure 4-6) to provide an objective measure of workload. The TDT (Engström, 2010) is an ISO standardised method in which drivers wear a small vibro-tactile motor attached to the shoulder/neck. Periodically (and seemingly random) according to the standard, the motor makes a brief low intensity pulse (<1 sec). The task of participants is to press a button on their index finger when they notice the pulse. During the on-road trials participants were given the opportunity to fit the motor, under instruction from the experimenter.

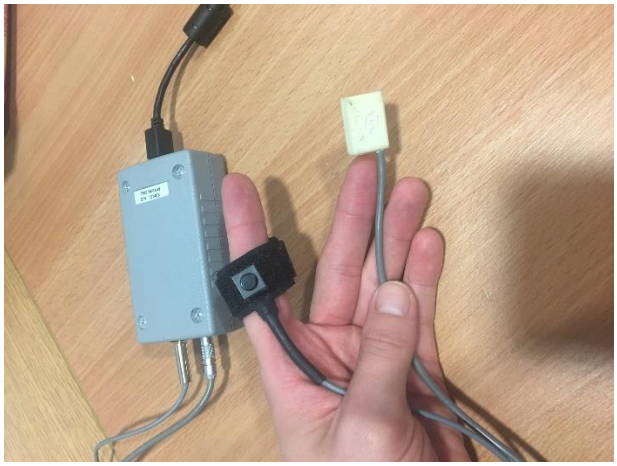


Figure 4-6 The TDT device depicting the white rectangular vibro-tactile motor, and the black response push-button

4.4 DESIGN OF EXPERIMENT

The study adopted a between subject's design with one Independent Variable (IV) namely the navigational aid which assisted the driver in navigating through the routes. This comprised three levels of measurement: whether the driver was assisted in way-finding by a satellite navigation device, an informed passenger who issued semi-structured navigational guidance or a collaborative partner with whom the driver already had an established personal relationship. The Dependent Variables were the level of environmental knowledge acquired by drivers (landmark, route, and survey), driver workload (objective TDT and subjective NASA-TLX measures), performance measures (number of navigational errors) and eye tracking measures.

4.5 PROCEDURE

For each condition the session commenced with a briefing where the details of each study were apprised to participants. They were not informed that their spatial knowledge would be assessed at a later date – to avoid drivers explicitly attempting to learn the routes/area. Upon giving their informed consent participants were asked to drive, following guidance from the experimenter, to the start of the first of the three predefined routes (5-10 minutes duration). This pre-trial drive period was used so that participants could become accustomed

to vehicle controls before the trial began, reducing the impact that the lack of familiarity with the test vehicle had on driving technique and performance.

All three routes incorporated a variety of different road and junction types and each took participants around ten minutes to complete in clear traffic (Table 4-1 provides additional detail of junctions by experimental route). Traffic density was controlled as much as was possible by conducting each road-trial out of peak rush-hour traffic (between a 10am and 4pm window), and during periods when each of the experimental routes were free from any planned road works. Throughout all drives the experimenter clearly defined each route's start and end point by asking the driver to pull over, verbally informing them when the route was finished or about to begin. Each of the three routes intersected at three points, though these periods of overlap were not explicitly mentioned to participants. Upon completing each route, the experimenter directed all participants to their next start point in the same way, clearly informing them that these sections were not part of the defined routes which the study was focused on.

The experimenter was always present in the test vehicle during experimental drives, sitting in the front passenger seat in the Satnav and informed passenger conditions and in the rear of the car during the collaborative condition. On each of these drives the experimenter remained silent (unless they were acting as the informed passenger), observing participant interactions (with the SatNav device or their collaborative passenger). Within the informed passenger condition, the experimenter (seated in the in the front passenger position), issued drivers with navigational guidance, from a set of standard prompts, only deviating from this standard guidance when prompted by the driver for additional information or clarification. Additionally, within all conditions the experimenter always intervened if drivers veered off route. Here, the experimenter, informed the driver of the mistake and directed them back onto the correct path. The only time drivers were prevented from making a navigational error was when

the performance of that action may have put their safety at risk or meant performing an illegal manoeuvre. Each participant travelled routes twice, approximately one week apart to attempt to replicate weekly travel to a meeting or appointment.

	Experimental route					
Experimental Condition	**Route 1** ➢ 2 roundabouts ➢ 4 side turns (2 across traffic) ➢ 1 T-junction ➢ Route length: 2.4 miles		**Route 2** ➢ 3 roundabouts ➢ 2 side turns (1 across traffic) ➢ 1 traffic light junction ➢ 3 T-junctions ➢ Route length: 2.5 miles		**Route 3** ➢ 2 T-junctions ➢ 2 Side turns (1 across traffic) ➢ 2 traffic lights junctions ➢ Route length: 2.1 miles	
	Travelled by participants on:					
	Drive 1	**Drive 2**	**Drive 1**	**Drive 2**	**Drive 1**	**Drive 2**
Satnav	✓	✓	✓	✓	✓	✓
Informed Passenger	✓	✓	✓	✓	✓	✓
Collaborative	✓	✓	✓	✓	✓	✓

Table 4-1 Navigational junctions featured within experimental routes and frequency of participant travel

After the second, final drive participants were asked to complete a landmark and route recognition exercise - a common approach in the spatial cognition and navigation literature (Galea & Kimura, 1993) (Head & Isom, 2010). In the first landmark knowledge test, participants were given a set of 12 images and were asked to identify those images which had appeared across the three routes and those which had not. For the second route learning test, participants were given a set of images for each of the three routes travelled, each image was a view of a junction encountered on route. Participants were asked to put these images in the order which they had appeared on route. Additionally, drivers were asked to draw a sketch map of the routes travelled, incorporating as much detail as possible. They were specifically asked to represent any landmarks which they might have experienced on route, specific junction types and were instructed to illustrate any overlap they might have experienced on route (Appleyard, 1970; Forbes & Burnett, 2007).

4.5.1 Workload

Participant objective workload was captured by the TDT device software. Each route was monitored separately to ensure that only the workload experienced by the participants during the predefined routes was captured. The TDT device software produced an output

after each monitoring period which captured workload using two measurements: The average reaction time, measured in milliseconds in which the driver responded to the TDT impulse and the percentage of impulses which were missed. This second value was derived from the total number of impulses which were issued and the number of these impulses which were not acknowledged by participants (i.e. participants did not depress the response button on their index finger in acknowledgement of the vibration). The total number of impulses issued across the three drives were combined alongside the number of impulses missed by participants. From this, a percentage was calculated illustrating the total number of missed impulses on route. This number, along with the participant's average reaction time across the three routes represented their objective workload. This same process was repeated for both drives so that any changes in workload experienced by participants could be detected from the first-time participants travelled the route and their second experience of the journey.

Participant subjective workload was recorded using the NASA-TLX subjective rating scale. NASA-TLX questionnaires were administered to participants after completion of experimental drives one and two. Here, participants were asked to reflect upon the earlier driving and navigation task and use the questionnaires rating scales to provide an indication of their workload across the three experimental routes.

Cumulative NASA-TLX scores were then used to make assessments on each participant's subjective workload. Cumulative scores were calculated by combining the six, twenty-point ratings scales which feature in the NASA-TLX questionnaire. This means that each participant could have a possible subjective workload score ranging from 0 to 120. Cumulative subjective workload scores were then compared from experimental drives one and two for each participant.

4.5.2 Route Learning

Route learning data was analysed using a method developed by Webber (2013) based on other well-established approaches (Burnett & Lee, 2005; Golledge, Ruggles, & Pellegrino, 1993). This approach provided two scores: a percentage score for the landmark knowledge test and a total error score for the route knowledge task.

To mark the landmark knowledge test, the number of images which participants believed to have appeared on route were separated into two piles, 'on route' and 'off route'. The number of incorrectly placed images were subtracted from the number of correctly placed images which yielded a percentage score of images correctly placed. Therefore, participants could score a minimum of 0 and a maximum of 100% correct for each route. Landmark knowledge was calculated in this way to deter participants from placing all 12 images in the 'on route' pile, guaranteeing that they would have correctly placed the 6 on route images. However, in doing this they would have also placed the same number of images incorrectly so a scoring system which didn't account for this could incorrectly indicate a superior landmark knowledge where there perhaps wasn't one.

The route knowledge test used the same approach to calculate route error across the three routes. However, as each route had a varying number of junctions, participants were asked to order a different number of images according to the specific route. This in turn meant that each route produced route error scores which were not directly comparable to one another. Therefore, final, calculated route error scores were then scaled. The initial approach to calculate route error scores used absolute error as a base index of error. The position of each image was scored relative to its actual position on route. To account for the differences at average levels of performance (where using the absolute error score alone would not provide adequate sensitivity), a 'sequencing value' was also generated. This was the number of the longest string of images which were placed together without error. Final total error values were calculated by subtracting an individual's sequencing score from their error score.

So that route error values could be compared between routes and combined to create an average route error score, all values needed to work from the same scale. Therefore, once a participant's route error score was calculated it was scaled by calculating the position where a participant's route error score was located from the number of available options, giving a route error score of between 0 and 1.

4.5.3 Survey Knowledge

Survey knowledge was tested by asking participants to draw a sketch map (on a blank sheet of A4 paper) of what they remembered from the route environment. They were asked to include any roads, buildings or landmarks which they remembered seeing whilst on each of the three routes. Participants were asked to carefully consider the placement of roads and buildings within in their sketch maps, placing landmarks and roads as accurately as possible in relation to one another as best as they could remember. Additionally, participants were asked to illustrate any route overlap which they believe they had experienced whilst driving. This approach was similar to previous work which had used participant sketch maps to examine participant survey knowledge (Appleyard, 1970; Rovine & Weisman, 1989; Oliver & Burnett, 2008).

A range of analyses were performed on participant sketch maps which provided an indication of participant's acquired survey knowledge. Firstly, the complexity of participant sketch maps were classified using the categorisation scheme first proposed by Appleyard (1970) and utilised in later research (Rovine & Weisman, 1989; Burnett & Lee, 2005). In this approach, maps are considered to be either 'sequentially dominant' (primarily roads) or 'spatially dominant' (primarily landmarks) (see section 3.3.1.1 for a more detailed overview). These broad categories are then further broken down into sub-categories in which the increasing complexity of maps is identified. Maps which range from simplistic sketches with no integration of elements (e.g. spatial scattered) are placed at the lowest end of the complexity scale, sitting at the opposite end of this scale are holistic, integrated maps which marry landmarks and road sequences into a whole view.

In addition to identifying sketch map complexity, the individual elements illustrated within participant sketch maps were assessed using methods adapted from those proposed by Rovine and Weisman (1989) and utilised in later research (Forbes & Burnett, 2007). Here, an assessment of the following map characteristics was conducted:

1. Absolute number of landmarks illustrated in the map
2. Absolute number of path segments (groupings of roads and junctions within the test area)
3. The accuracy of the placement of landmarks – number of landmarks illustrated in the sketch map which were placed correctly either in relation to other landmarks or to a path segment
4. Number of route intersections correctly identified and illustrated by participants (participants experienced a total of three route intersections during experimental drives)

Appropriate statistical analyses were then performed on resulting data to determine if the number of individual components contained within sketch map illustrations differed significantly amongst conditions.

Finally, to ensure that the reliability of the experimenter's subjective ratings of participant sketch map characteristics, a Cohens Kappa analysis was performed on a selection of participant maps. This involved another Human Factors specialist independently analysing a random selection of participant maps from each experimental condition (5 out of 15 maps, in each experimental condition were selected for a secondary, independent analysis). The subsequent result provides an indication of the level of agreement between the two raters, providing some reassurance that the results obtained from the analysis of participant sketch maps were reliable, and made accurate determinations of the sketch maps various components.

4.6 THE ROUTE

The test area which was selected was a large village and housing/residential estate within Nottingham, UK, called Clifton. The Clifton area was chosen for a number of pragmatic and methodological

reasons. Firstly, the area is located close to the University of Nottingham, which enabled easy access to and from the main campus for both the participants and researcher. Secondly, as Clifton is home to a competing universities' large campus and the University of Nottingham does not have any campuses within this area, and it was anticipated that it would reduce the likelihood of prospective participants being familiar with the area (although participants were pre-screened to ensure this), thus increasing the number of potentially available participants. Additionally, the area allowed for the development of three routes within a particular set of constraints. These constraints were based on considerations from earlier literature (Webber, 2013), and the aims of the study:

- All three routes should have a minimum of six decision points (defined as a navigational point or junction which presented the opportunity to change heading)
- Each of the routes must intersect one another at three disparate points
- The three routes should be similar in terms of the number of salient landmarks or features
- The three routes should be completed within approximately 45 minutes driving time

The first constraint was decided upon following a review of the adopted methodologies in earlier, related literature concerning navigation and environmental learning. In prior research the number of decision points ranged from two (Furukawa, 2004) to sixteen (Kruger, Aslan, & Zimmer, 2004), which varied dependent on the methodology adopted (i.e. if participants were completing single or multiple routes) and the research questions being addressed. As a number of studies utilised a high number of decision points within routes and were designed to study pedestrian navigation, it was decided that an increased number of decision points would ensure routes were not too simplistic and would guarantee that routes were an adequate length for use within a driving navigation methodology. Environmental limitations meant that a minimum of six decision

points could be encountered on route, whilst ensuring the other three constraints were satisfied.

To satisfy all constraints, the three finally selected routes each consisted of between six and nine decision points, and are shown in Figure 4-7

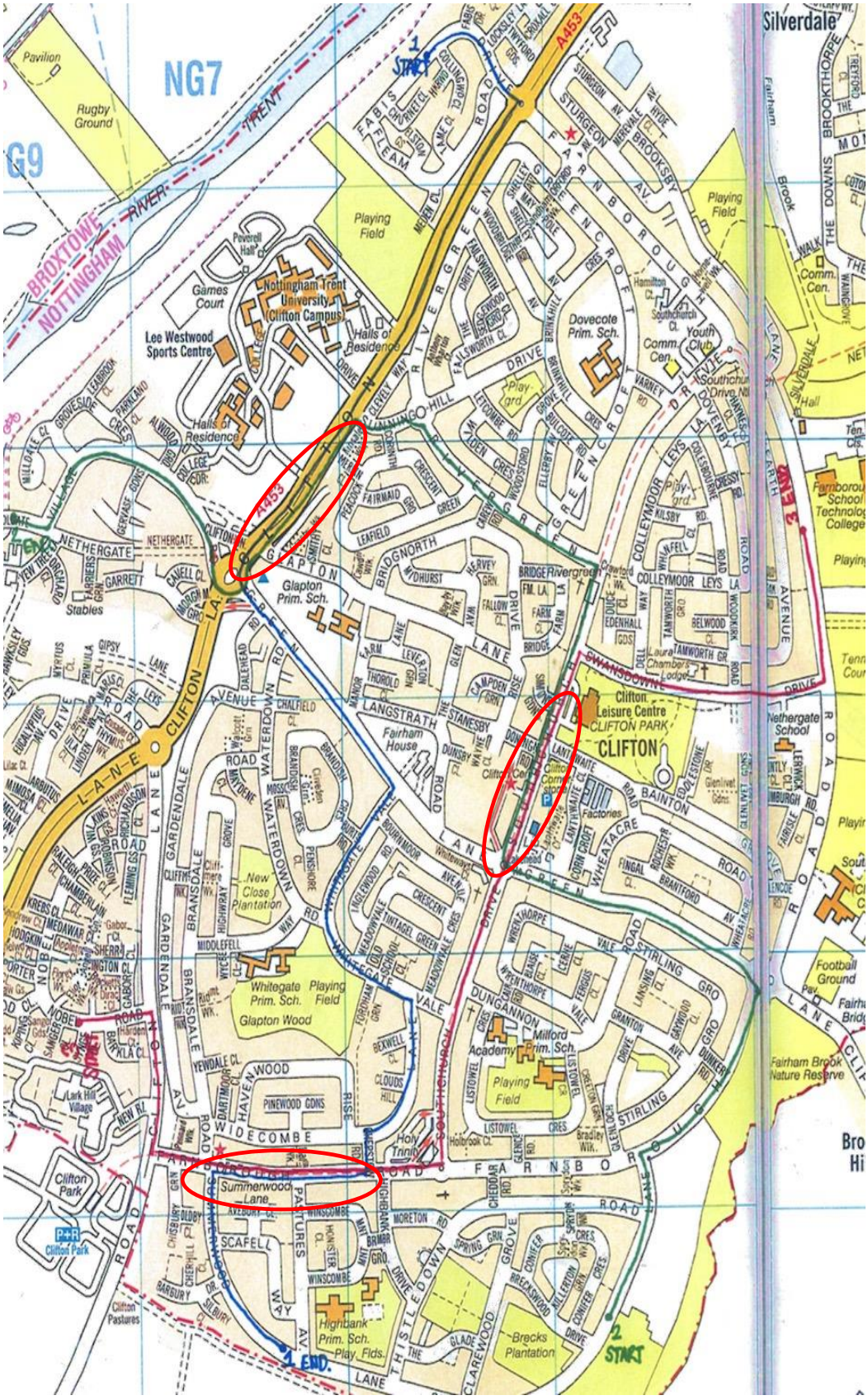


Figure 4-7: a highlighted map depicting route 1 (in blue), route 2 (in green) and route 3 (in red), highlighting the three separate points of intersect with red eclipses

So that the four constraints were satisfied, the components of the three, final routes were similar, though not identical in nature. Table 4-2 below details the components of each of the three experimental routes.

Route 1	Number of Junctions on route	Route Length (miles)
1	7	2.4
2	9	2.5
3	6	2.1

Table 4-2 Components of experimental routes

Whilst the routes were close to one another in proximity it was ensured that there was a separating distance between each routes end and the next route start point, ensuring that each route was perceived as distinct.

4.7 TIMELINE

As each of the four studies detailed within this thesis were conducted during varying seasons over a three-year period between 2014 and 2017, a number of measures were taken to ensure that post trial tests adequately reflected the changing on-road environment. Images used for post-trial landmark and route knowledge tests were changed according to the season in which the on-road trial was conducted. Figure 4-8 on the following page displays examples of the images presented to participants after winter and summer on-road trials and reflects how junction imagery was affected by seasonal change. To prevent experimental bias and facilitate participants correctly identifying and ordering route imagery, it was important that these images adequately represented the environment which they had travelled through. To ensure that images were consistent across experimental condition, care was taken to ensure that both winter and

summer images presented to participants during post-trial tests were taken at the same road position, therefore offering all participants the same junction view and angle.



Figure 4-8 Displays a number of images utilised within post-trial landmark and route knowledge tests. With images utilised during winter road trials shown on the left and summer images on the right

5

CHAPTER 5: RESULTS: PERFORMANCE, WORKLOAD MEASURES & VISUAL BEHAVIOUR

This chapter will compare the navigational performance, workload and visual search (on junction approaches) of participants across the three experimental conditions (Satnav; informed passenger; collaborative navigation). Results for driver engagement will be reported in Chapter 6. Navigational performance is indicated by the average number of route errors made by participants combined across drives one and two. Objective and subjective measurements of participants' workload were taken using a tactile detection device and NASA-TLX questionnaires respectively. Finally, participants' visual search strategies on the approach to a navigational junction were analysed and compared across experimental conditions.

Table 5-1 on the following page presents a summary of each of the navigational conditions which are examined within this chapter:

Navigational Condition	Characteristics
Satnav (11 male, 4 female)	• Participants navigated following the guidance of a commercially available, nomadic navigation device (Garmin nuvi 2569) • Drivers were presented with turn-by-turn navigational guidance and corresponding visual information • Routes were pre-programmed by the experimenter prior to commencing the drive • Satnav device was installed in the far-right hand side of the drivers cab
Informed Passenger (11 male, 4 female)	• Experimenter (sat in the passenger's seat of the vehicle) issued navigational guidance to the passenger from a semi-structured navigational script • Route guidance referenced landmarks at navigational choice points and pin pointed each junction using hand gestures • Drivers could prompt the informed passenger for additional guidance or information at any point on route
Collaborative Passenger (10 male, 5 female)	• Participants were recruited in pairs on the basis of them having a pre-existing, close personal relationship (e.g. spouse, friend, sibling) • Within this pair one acted as the driver, the other navigator • Navigators were pre-trained in experimental routes using a video (with audio commentary) and highlighted map • They were encouraged to make navigational notes so that they could confidently guide their driver through experimental routes • Drivers were encouraged to question guidance when they were unsure, treating the drive as if they were navigating with a friend.

Table 5-1 Summary of experimental conditions examined within this chapter

5.1 NAVIGATIONAL PERFORMANCE

The total number of navigational errors made by participants across experimental drives one and two were recorded and compared across navigational conditions. Normality tests revealed navigational error data followed a non-normal distribution, therefore non-parametric tests were performed.

	Satnav	Informed Passenger	Collaborative
Mean	1.13	0.13	0.47
Min	0	0	0
Q1	0	0	0
Median	1	0	0
Q3	2	0	1
Max	3	1	2
IQR	2	0	1
Upper Outliers	0	2	0
Lower Outliers	0	0	0

Table 5-2 Navigational error breakdown across experimental conditions

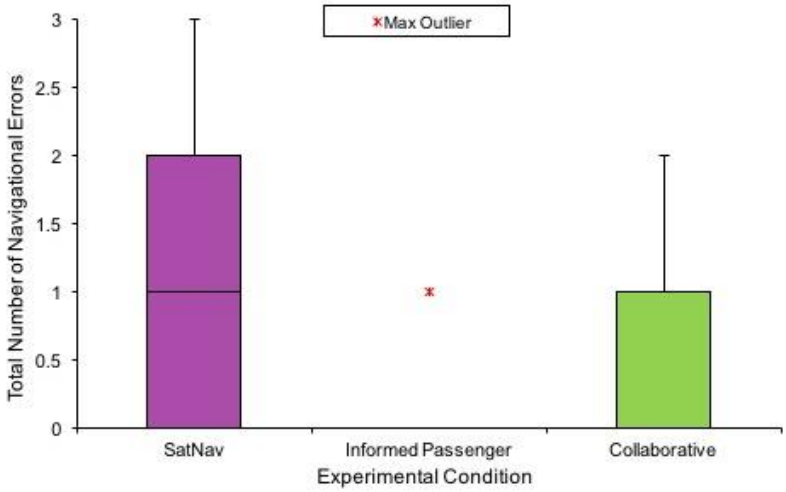


Figure 5-1: Average number of navigational errors (wrongs turnings) made by participants on experimental drives one and two.

- A Kruskal Wallis H test was run to determine if there were differences in the average number of navigational errors made by drivers in the Satnav, Informed Passenger and Collaborative navigation conditions. Distributions of navigation error scores were not similar for all experimental conditions as assessed by visual inspection of a boxplot. Values are mean ranks unless otherwise stated. The mean ranks of the number of navigational errors scores were statistically significantly different between groups, χ^2 (2)= 8.88, p = 0.012.
- Pairwise comparisons were performed using Dunns (1964) procedure with a Bonferroni correction for multiple comparisons. Adjusted p-values are presented. Values are mean ranks unless otherwise stated. This post hoc analysis revealed statistically significant differences in the number of navigational errors made by drivers in the SatNav condition (29.35) compared to drivers following informed passenger guidance (17.03) (p = 0.009).
- Pairwise comparisons revealed no statistically significant differences across any further combinations of experimental conditions.

5.2 NASA TLX MEASURES

NASA TLX questionnaires were administered after participants had completed their first and second drives, this provided a subjective measure of driver workload (average cumulative scores presented in Figure 5-2 below). Normality tests revealed normally distributed data.

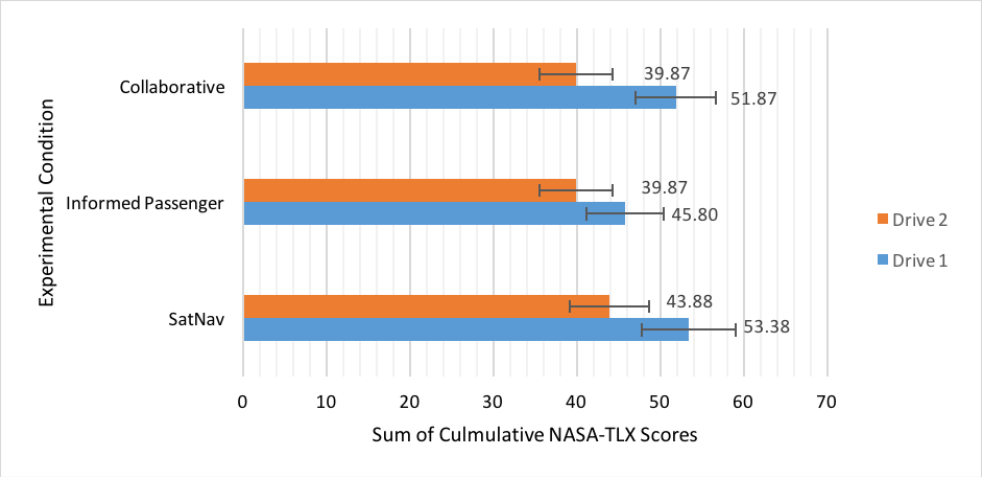


Figure 5-2: Average cumulative NASA TLX scores illustrating the perceived workload scores of SatNav, Informed Passenger and Collaborative participants after Drive 1 and Drive 2

- A between subjects (one-way) ANOVA confirmed that there were no significant differences between the experimental conditions on drive one; F (3,57) = 1.100, p=0.36, demonstrating that perceived workload was statistically similar across experimental conditions on drive one.
- Similarly, for drive two, a between subjects (one-way) ANOVA confirmed that there were no significant differences across experimental conditions on drive two; F (3,57) = 0.538, p=0.66. Again, demonstrating that perceived workload was statistically similar across all experimental conditions on the second, final drive.
- However, paired samples *t* tests revealed a significant drop in perceived workload from drive 1 (M = 56.93, SD = 18.95) to drive 2 (M = 46.80, SD = 16.47) in the SatNav condition; t(14) = 3.22, p= 0.006. Demonstrating a statistically significant reduction in the perceived

workload of participants in the SatNav condition from drive one to drive two.

- Likewise, paired samples *t* tests revealed a significant drop in the perceived workload of Collaborative participants from drive one (M = 51.87, SD = 19.42) to drive two (M = 39.87, SD = 17.60); t(14) = 4.19, p = 0.001. Highlighting that Collaborative participants perceived their workload to be significantly lower on their second, final drive.
- Whilst the perceived workload of Informed Passenger participants did drop from drive one (M = 45.8, SD = 18.45) to drive two (M = 39.87, SD = 17.47). A paired samples *t* test confirmed that this reduction is workload was not statistically significant; t (14) = 1.45, p = 0.17. Meaning that informed passenger participants had statistically similar levels of perceived workload on both experimental drives.

5.3 TDT MEASURES

Throughout both experimental drives participants were required to respond to the impulses issued by the TDT device. The percentage of missed impulses and reaction time in response to impulses provided an objective measure of driver workload. Normality tests revealed that TDT data was not normally distributed therefore non-parametric tests were performed.

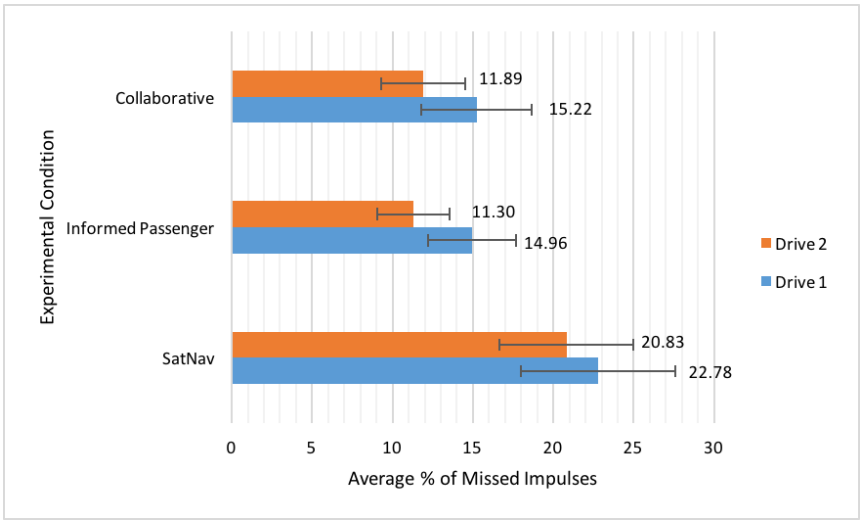


Figure 5-3: Average percentage of TDT impulses missed by SatNav, Informed Passenger and Collaborative participants. Illustrating the average number (expressed as a percentage) of TDT impulses which participants failed to respond to on-drive.

- A Kruskal Wallis test confirmed that there were no significant differences in the percentage of impulses missed by SatNav, Informed Passenger and Collaborative participants in drive one; $H(2) = 1.59$, $p = 0.45$. Demonstrating that the number of TDT impulses which participants responded to was statistically equivalent across conditions on drive one.
- Likewise, a Kruskal Wallis test confirmed that there were no significant differences in the percentage of impulses missed by SatNav, Informed Passenger and Collaborative participants in drive two; $H(2) = 2.93$, $p = 0.23$. Demonstrating that the number of TDT impulses which participants responded to was statistically equivalent across conditions on drive two.
- A Wilcoxon Signed-Ranks test indicted that Informed Passenger drivers missed more TDT impulses on drive one (Mdn = 14.35) compared to drive two Mdn = 11.15); z-2.45, $p<0.014$. Demonstrating that informed passenger drivers experienced a significant drop in objective workload from drive one to drive two, resulting in them responding to significantly more haptic stimuli on their second drive.
- Similarly, a Wilcoxon Signed-Ranks test indicated that Collaborative drivers missed significantly more TDT impulses on drive one (Mdn = 7.8) compared to drive two (Mdn = 6.9); $z = -2.04$, $p<0.041$. Demonstrating that Collaborative drivers experienced a significant drop in objective workload from drive one to drive two, resulting in them responding to significantly more haptic stimuli on their second drive.
- Between subjects' comparisons revealed no statistically significant differences across any further combinations of experimental conditions

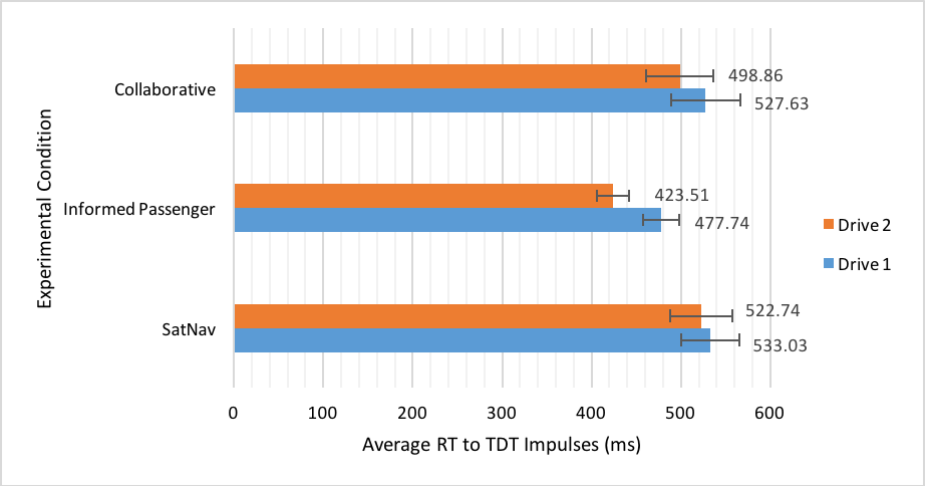


Figure 5-4: Average reaction time data of SatNav, Informed Passenger and Collaborative participants. Illustrating the average amount of time (reported in milliseconds) participants took to respond to the onset of a TDT impulse

- A Kruskal Wallis test confirmed that there were no significant differences in the reaction times of SatNav, Informed Passenger and Collaborative participants toward the onset of a TDT impulses in drive one; $H(2) = 3.41$, $p = 0.33$. Demonstrating that the time it took participants to respond to the onset of TDT impulses in drive one was statistically equivalent across conditions.
- Similarly, a Kruskal Wallis test confirmed that there were no significant differences in the reaction times of SatNav, Informed Passenger and Collaborative participants toward the onset of TDT impulses in drive two; $H(2) = 4.24$, $p = 0.12$. Demonstrating that the time it took participants to respond to the onset of TDT impulses in drive two was statistically equivalent across conditions.
- A Wilcoxon Signed-Ranks test indicted that Informed Passenger drivers had significantly slower reaction times towards the onset of a TDT impulses on drive one compared to drive two; $z = -2.79$, $p < 0.005$. Demonstrating that informed passenger drivers experienced a significant drop in objective workload from drive one to drive two which resulting in them responding significantly quicker to haptic stimuli on their second drive.
- Between subjects' comparisons revealed no statistically significant differences across any further combinations of experimental conditions

5.4 EYE TRACKING MEASURES - SPREAD OF SEARCH AT DECISION POINTS

Throughout all drives participants wore a pair of SensoMotoric Instruments (SMI) eye tracking glasses which collected binocular gaze data at 30 frames per second (FPS). This data was then used to assess participants' visual behaviours on approach to navigational junctions. The five junctions selected for further analysis were representative of the routes as a whole and included side turns (turning left or right off a straight path road), roundabouts and a T-Junction. All fixations were coded from the geographical point of the first navigational prompt issued by the SatNav (or equivalent point in non-Satnav conditions), to ensure a fair comparison across conditions. 'Semantic gaze mapping' with pre-defined areas of interest was performed in the SMI eye tracking analysis software 'BeGaze 3.6' and involved identifying participants' fixations within each junction's schematic representation (as shown in figure 5-5). Participants' total dwell times and mean fixation times within the specific areas of interest were then compared across experimental conditions.

Areas of interest which were examined for each experimental condition are listed in table 5-3 in the following page. Here, landmarks situated to the left, right and forward of the driver are detailed under the appropriate columns, providing detail of the changing roadside environment at each navigational junction. Whilst these landmarks varied in form and function from junction to junction, each was investigated according to it placement at the roadside as a left, right or forward landmark or area of interest.

Junction	Examined areas of interest									
	Passenger	Left wing	Left landmark	Rear-view mirror	Forward Landmark	Roadway	Right landmark	Satnav	Right wing	Dash
Route 1 Junction 4	✓	✓	House/ Church spire	✓	Houses	✓	House/ Hedge	✓	✓	✓
Route 1 Junction 6	✓	✓	Residential home	✓	Houses	✓	Lamppost/ Tree	✓	✓	✓
Route 2 Junction 2	✓	✓	Pub	✓	Tree	✓	Signs	✓	✓	✓
Route 2 Junction 4	✓	✓	Signs & Traffic lights	✓	✗	✓	Flats	✓	✓	✓
Route 2 Junction 7	✓	✓	Petrol station	✓	Roundabout/ Tree	✓	Clifton village	✓	✓	✓

Table 5-3 Areas of Interest (AOI) examined during eye tracking analysis at navigational decision points (listed by navigational junction)

5.5.1 Route 1 -Junction 4

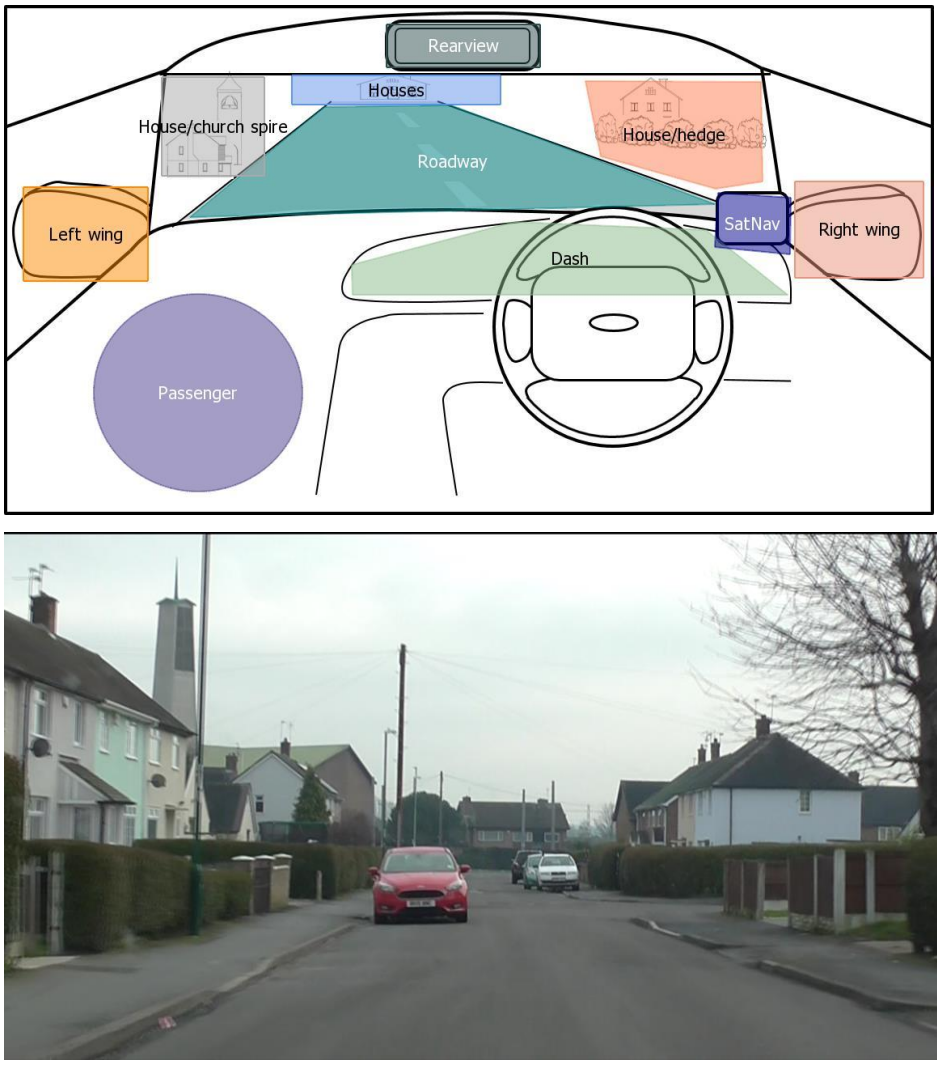


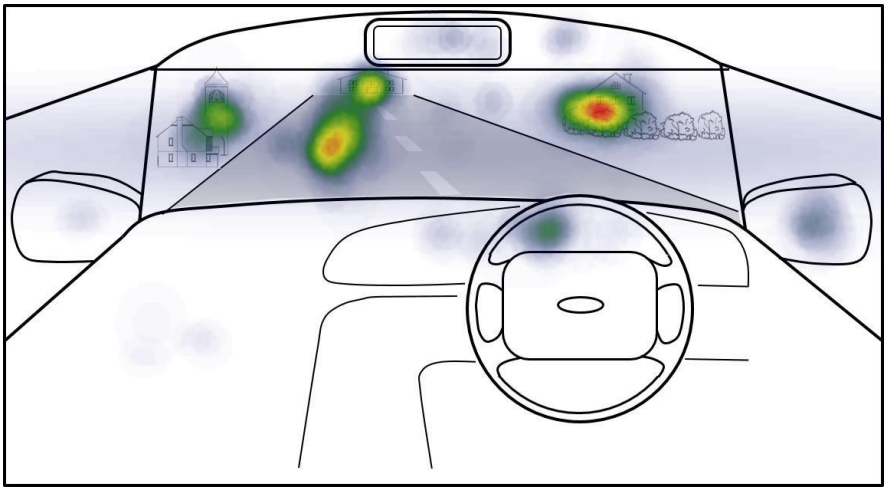
Figure 5-5: Representative image of on-route junction, displaying pre-defined AOIs. On-route image of junction displayed below.

Areas of interest were defined for each navigation junction (displayed in Table 5-3) prior to commencing eye-tracking analysis. Pre-defined areas of interest (AOI) for route 1, junction 4 consisted of the in-car passenger, left wing mirror, house/church spire (on left), rear-view mirror, houses (directly ahead of the driver), roadway, houses/hedge (on right), right wing mirror, Satnav, in-vehicle dash. Participant dwell and mean fixation times within each of these areas of interest were then compared across experimental conditions.

Satnav



Informed Passenger



Collaborative

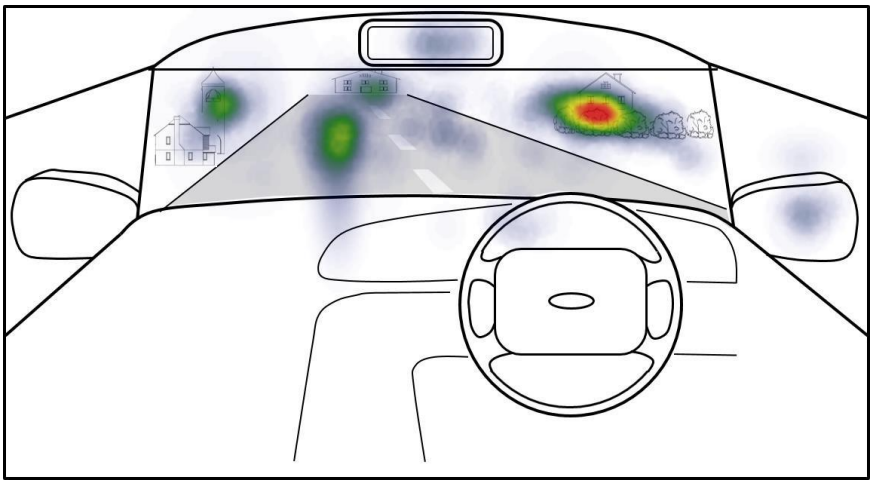


Figure 5-6 Heat map representations of the average fixation times of Satnav, Informed Passenger and Collaborative participants at Route 1 Junction 4

A Kruskal-Wallis test was conducted to see if there were any differences across experimental conditions (SatNav, Informed Passenger, Collaborative) in the dwell and mean fixation times of participants, within the pre-defined AOIs. Distributions of dwell and mean fixation times were not similar for all experimental conditions, as assessed by visual inspection of a boxplot. Participant dwell times were statistically significantly different between experimental conditions within the hedge $\chi^2(2) = 26.42$, $p = <.001$, church spire $\chi^2(2) = 17.66$, $p = <.001$, and house $\chi^2(2) = 9.48$, $p = <.001$ AOIs. Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. This post hoc analysis revealed the following statistically significant differences:

- **Area of interest: Hedge** – Statistically significant differences were found between the dwell times of participants (within the hedge AOI) in the Collaborative (29.45) and SatNav (6.50) (P = <.001) condition and the informed passenger (22.6) and SatNav condition (P = .001), but not between the collaborative and informed passenger conditions.
- **Area of interest: Church spire** - Statistically significant differences were found between the dwell times of participants (within the church spire AOI) in the Collaborative (22.27) and SatNav (8.67) (P = .009) conditions and the informed passenger (26.13) and SatNav conditions (P < .001), but not between the collaborative and informed passenger conditions.
- **Area of interest: Houses** - Statistically significant differences were found between the dwell times of participants (within the houses AOI) in the Informed Passenger (24.70) and SatNav (12.09) (P = .007) conditions, but not between any other group combination.

A Kruskal-Wallis test also revealed that participant mean fixation times were statistically significantly different between experimental conditions within the hedge $\chi^2(2) = 9.42$, $p = .009$ and church spire $\chi^2(2) = 11.73$, $p = .003$ AOIs. Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni

correction for multiple comparisons. This post hoc analysis revealed the following statistically significant differences:

- **Area of interest: Hedge** – Statistically significant differences were found between the mean fixation times of participants (within the hedge AOI) in the Collaborative (26.82) and SatNav (12.73) ($P = .008$) conditions, but not between any other group combination.
- **Area of interest: Church spire** - Statistically significant differences were found between the mean fixation times of participants (within the church spire AOI) in the Collaborative (25.18) and SatNav (11.27) ($P = .008$) conditions and the informed passenger (23.77) and SatNav conditions ($P < .011$), but not between the collaborative and informed passenger conditions.

5.5.2 Route 1 – Junction 6

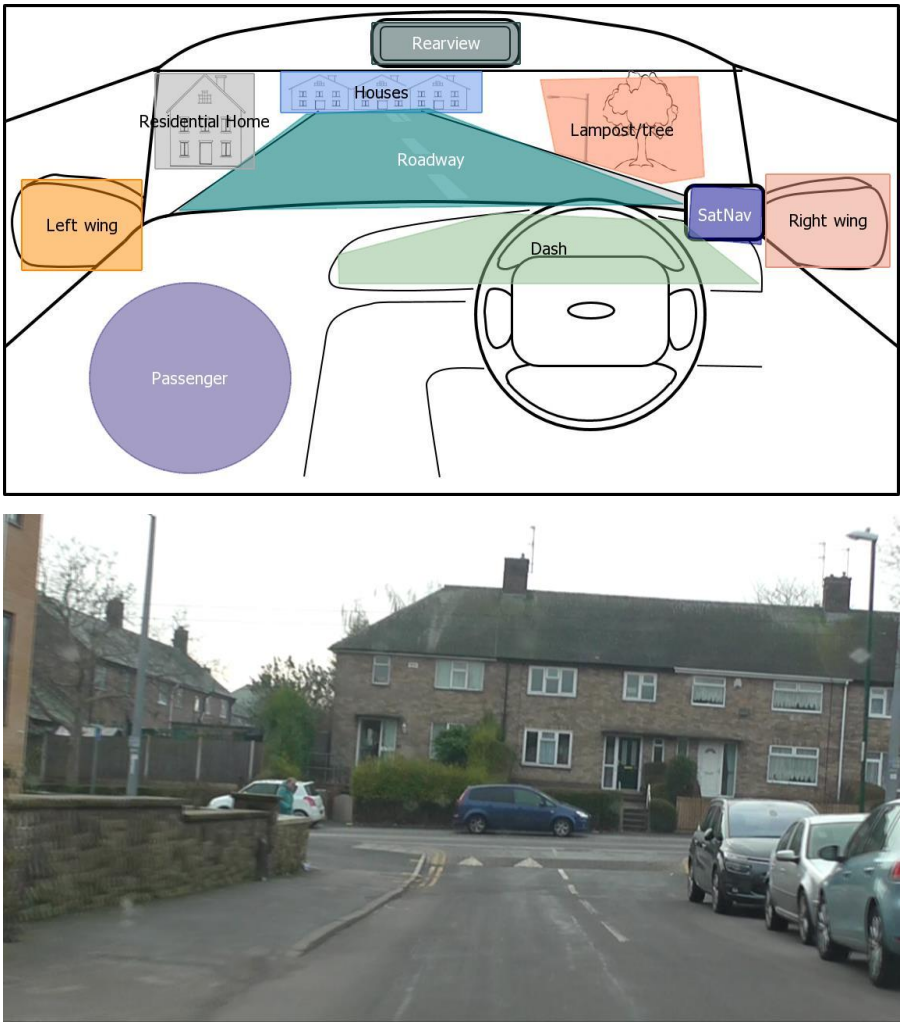


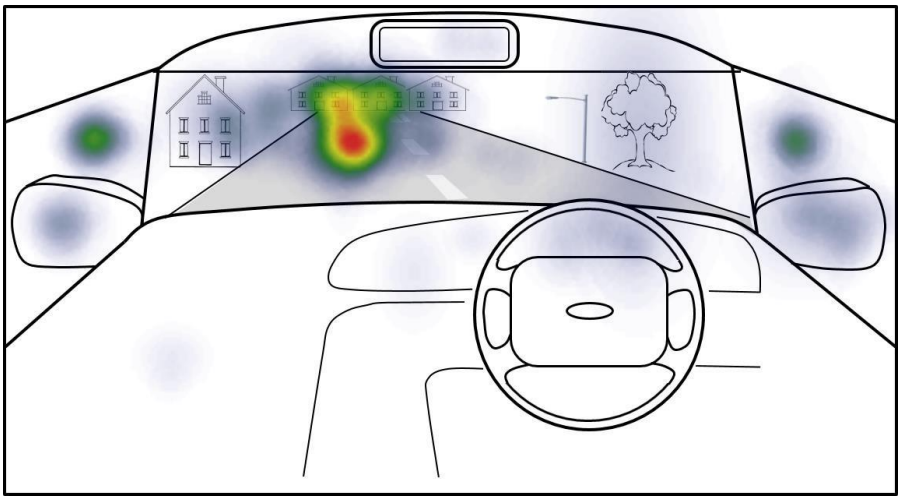
Figure 5-7: Representative image of on-route junction, displaying pre-defined AOIs. On-route image of junction displayed below.

Pre-defined areas of interest (AOI) for route 1, junction 6 consisted of: the in-car passenger, left wing mirror, residential home (on left), rear-view mirror, houses (directly ahead of the driver), roadway, lamppost/tree (on right), right wing mirror, Satnav, in-vehicle dash. Participant dwell and mean fixation times within each of these areas of interest were compared across experimental condition (SatNav, Informed Passenger, Collaborative).

Satnav



Informed Passenger



Collaborative

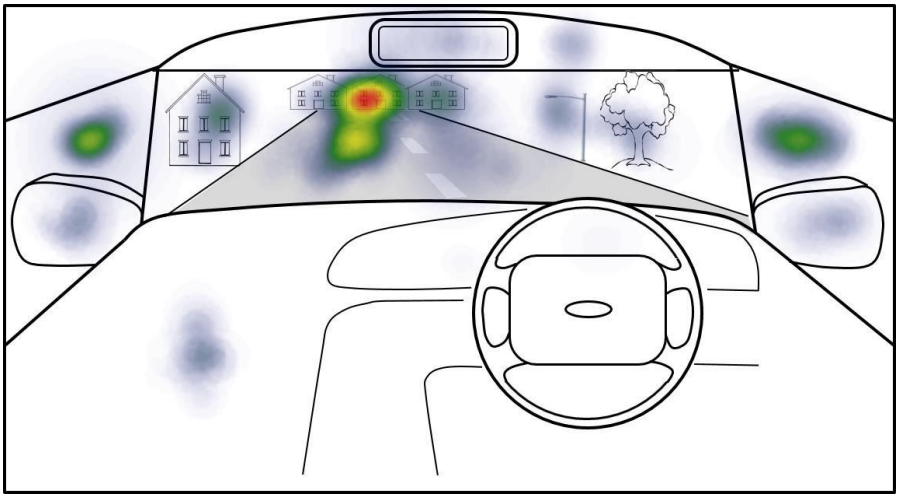


Figure 5-8 Heat map representations of the average fixation times of Satnav, Informed Passenger and Collaborative participants at Route 1 Junction 6

A Kruskal-Wallis test was conducted to see if there were any differences across experimental conditions (SatNav, Informed Passenger, and Collaborative) in the dwell and mean fixation times of participants, within the pre-defined AOIs. Distributions of dwell and mean fixation times were not similar for all experimental conditions, as assessed by visual inspection of a boxplot. Participant dwell times were statistically significantly different between experimental conditions within the lamppost $\chi^2(2) = 6.52$, $p = .038$, passenger $\chi^2(2) = 9.64$, $p = .008$, Dash $\chi^2(2) = 6.66$, $p = .036$, and houses $\chi^2(2) = 11.43$, $p = .003$ AOIs. Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. This post hoc analysis revealed the following statistically significant differences:

- **Area of interest: lamppost** – Statistically significant differences were found between the dwell times of participants (within the lamppost AOI) in the Collaborative (25.18) and SatNav (17.31) (P = .050) conditions but not between any other group combination.
- **Area of interest: Passenger** - Statistically significant differences were found between the dwell times of participants (within the passenger AOI) in the Collaborative (26.14) and SatNav (15.50) (P = .006) conditions but not between any other group combination.
- **Area of interest: Dash** - Statistically significant differences were found between the dwell times of participants (within the dash AOI) in the Informed Passenger (24.23) and Collaborative (13.68) (P = .030) conditions, but not between any other group combination.
- **Area of interest: Houses** - Statistically significant differences were found between the dwell times of participants (within the houses AOI) in the Collaborative (26.14) and SatNav (11.50) (P = .005) conditions and Informed Passenger (22.87) and SatNav (P = .025) conditions, but not between any other group combination.

A Kruskal-Wallis test also revealed that participant mean fixation times were statistically significantly different between experimental conditions within the passenger $\chi^2(2) = 8.91$, $p = .012$ and dash $\chi^2(2) = 6.77$, $p = .034$ AOIs. Subsequently, pairwise comparisons were

performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. This post hoc analysis revealed the following statistically significant differences:

- **Area of interest: Passenger** – Statistically significant differences were found between the mean fixation times of participants (within the passenger AOI) in the Collaborative (25.77) and SatNav (15.50) (P = .009) conditions, but not between any other group combination.
- **Area of interest: Dash** - Statistically significant differences were found between the mean fixation times of participants (within the dash AOI) in the Informed Passenger (24.33) and Collaborative (13.68) (P = .028) conditions, but not between any other group combination.

5.5.3 Route 2 – Junction 2

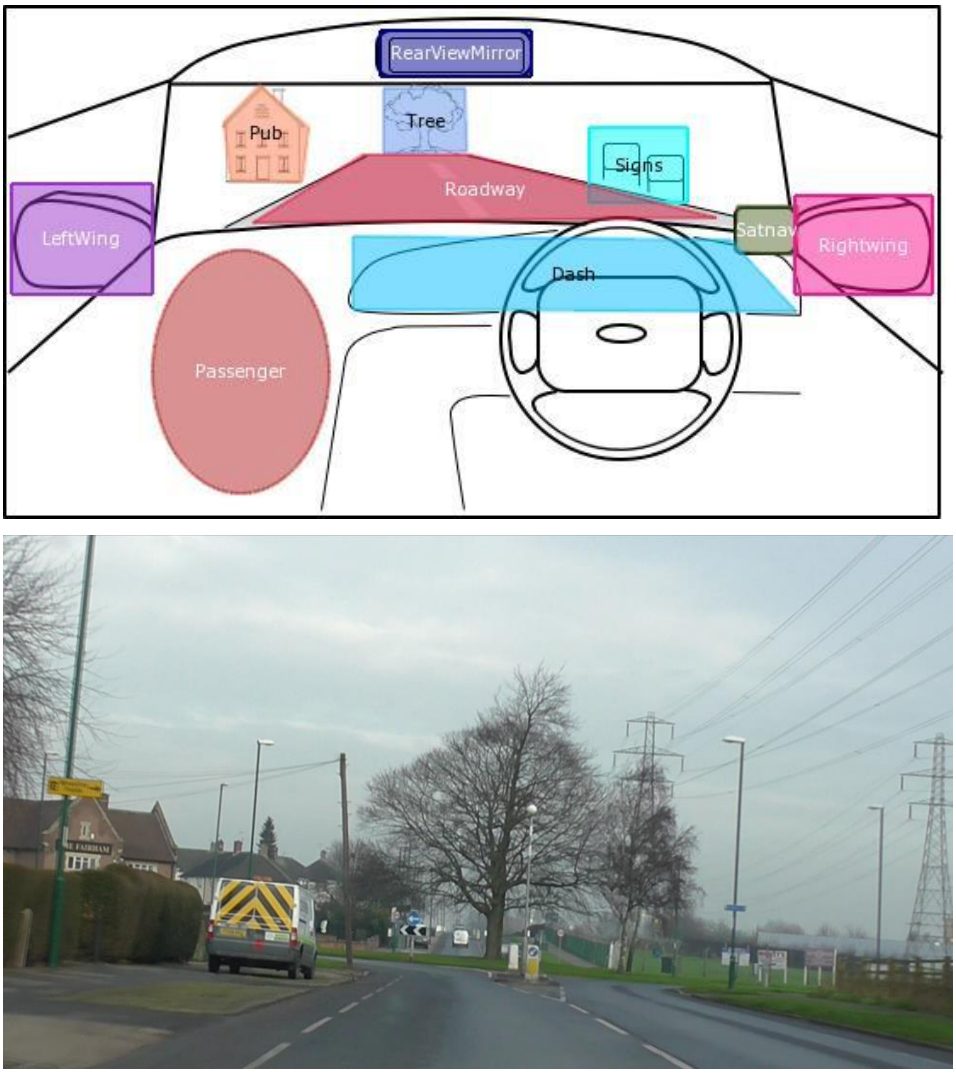
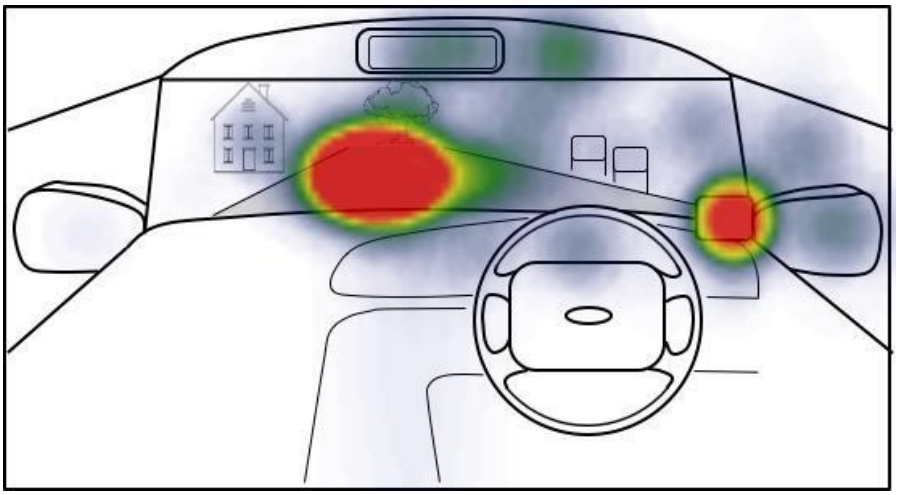


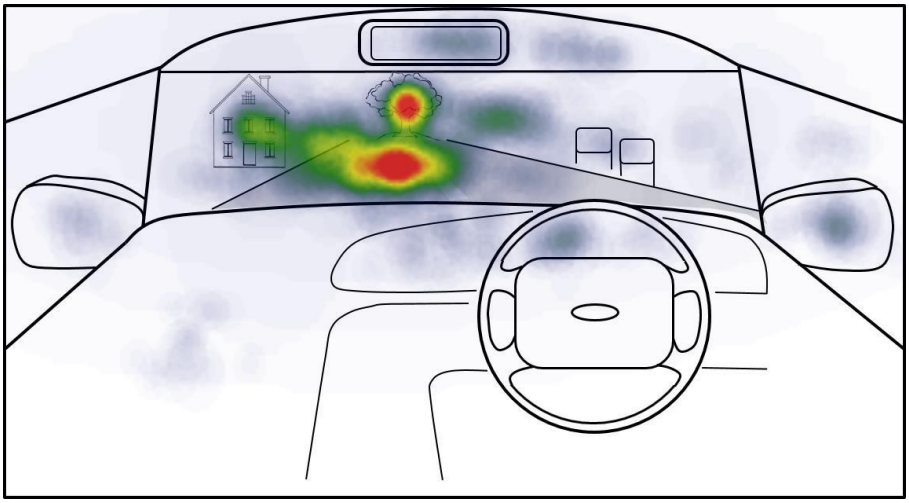
Figure 5-9: Representative image of on-route junction, displaying pre-defined AOIs. On-route image of junction displayed below.

Pre-defined areas of interest (AOI) for route 2, junction 2 consisted of: the in-car passenger, left wing mirror, pub (on left), rear-view mirror, roundabout/tree (directly ahead of the driver), signs (on right), right wing mirror, Satnav, in-vehicle dash. Participant dwell and mean fixation times within each of these areas of interest were compared across experimental conditions (SatNav, Informed Passenger, and Collaborative).

Satnav



Informed Passenger



Collaborative

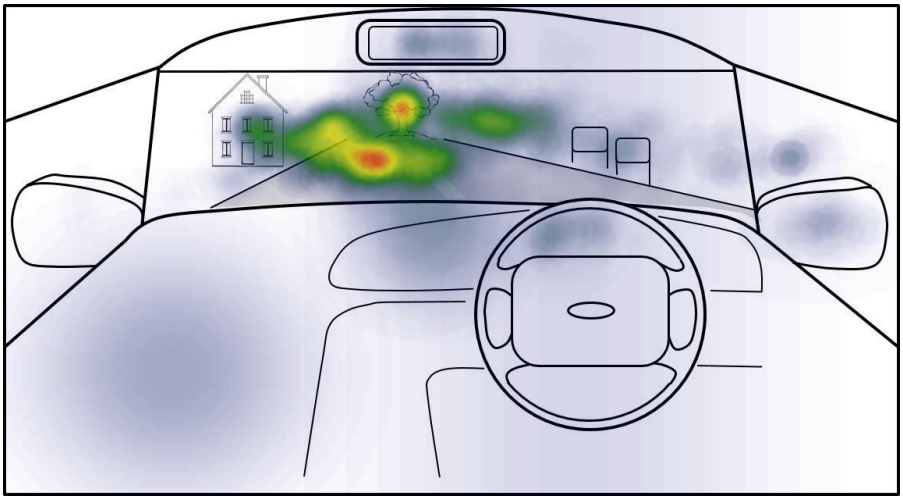


Figure 5-10 Heat map representations of the average fixation times of Satnav, Informed Passenger and Collaborative participants at Route 2 Junction 2

A Kruskal-Wallis test was conducted to see if there were any differences across experimental conditions (SatNav, Informed Passenger, Collaborative) in the dwell and mean fixation times of participants, within the pre-defined AOIs. Distributions of dwell and mean fixation times were not similar for all experimental conditions, as assessed by visual inspection of a boxplot. Participant dwell times were statistically significantly different between experimental conditions within the roadway $\chi^2(2) = 17.40$, $p = <.001$, signs $\chi^2(2) = 6.51$, $p = .039$, tree $\chi^2(2) = 20.92$, $p = <.001$, and pub $\chi^2(2) = 21.55$, $p = <.001$ AOIs. Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. This post hoc analysis revealed the following statistically significant differences:

- **Area of interest: Roadway** – Statistically significant differences were found between the dwell times of participants (within the roadway AOI) in the SatNav (29.54) and Collaborative (11.20) (P = <0.01) conditions and the SatNav and Informed Passenger (16.33) (P = .005) conditions, but not between any other group combination.
- **Area of interest: Signs** - Statistically significant differences were found between the dwell times of participants (within the signs AOI) in the Collaborative (26.60) and SatNav (15.77) (P = .043) conditions but not between any other group combination.
- **Area of interest: Tree** - Statistically significant differences were found between the dwell times of participants (within the tree AOI) in the Collaborative (26.30) and SatNav (8.12) conditions (P = <.001) conditions, and Informed Passenger (24.83) and SatNav conditions (P = <.001) but not between any other group combination.
- **Area of interest: Pub** - Statistically significant differences were found between the dwell times of participants (within the pub AOI) in the Collaborative (24.40) and SatNav (7.96) (P = .001) conditions and Informed Passenger (26.23) and SatNav (P = <.001) conditions, but not between any other group combination.

A Kruskal-Wallis test was also run to determine if there were differences in the mean fixation times of participants between

experimental conditions (SatNav, Informed Passenger, and Collaborative). Distributions of mean fixation scores were not similar for all groups, as assessed by visual inspection of a boxplot. The mean rank of mean fixation scores was not statistically significantly different between groups, for all pre-defined AOIs.

5.5.4 Route 2 – Junction 4

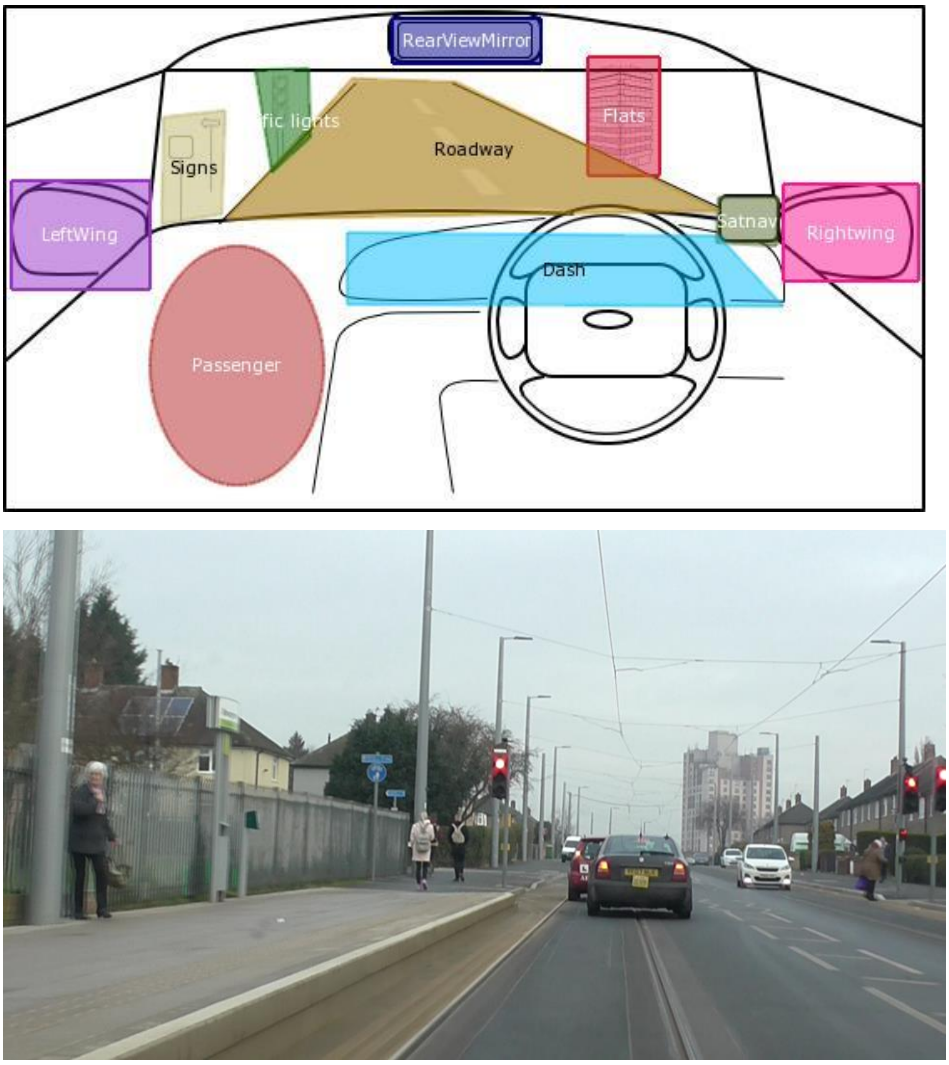
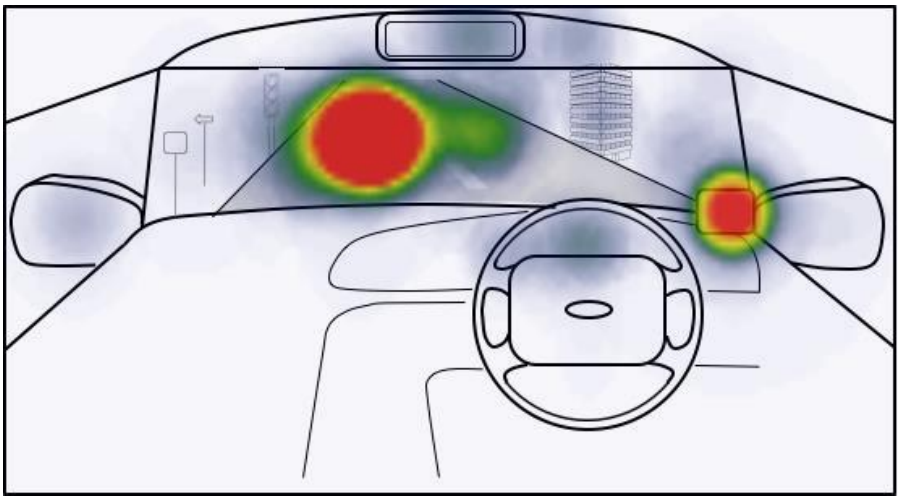


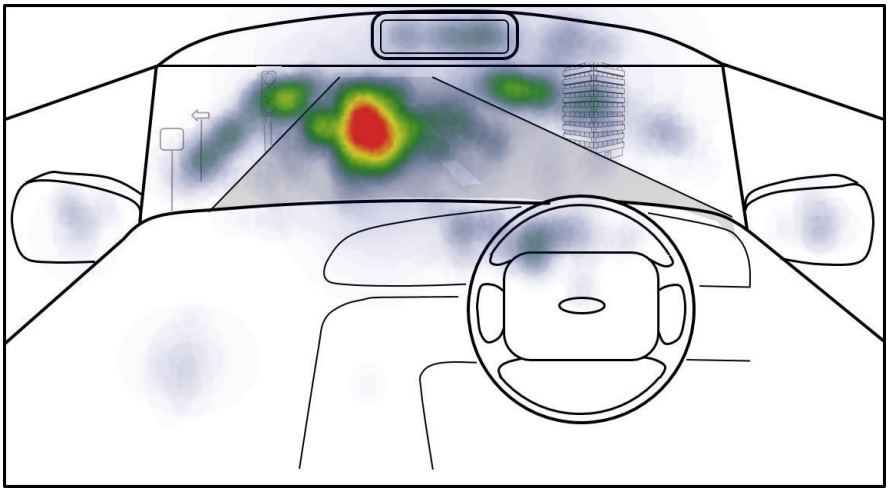
Figure 5-11: Representative image of on-route junction, displaying pre-defined AOIs. On-route image of junction displayed below.

Pre-defined areas of interest (AOI) for route 2, junction 4 consisted of: the in-car passenger, left wing mirror, signs (on left), traffic lights (on left), rear-view mirror, roadway, block of flats (on right), right wing mirror, Satnav, in-vehicle dash. Participant dwell and mean fixation times within each of these areas of interest were compared across experimental conditions (SatNav, Informed Passenger, Collaborative).

Satnav



Informed Passenger



Collaborative

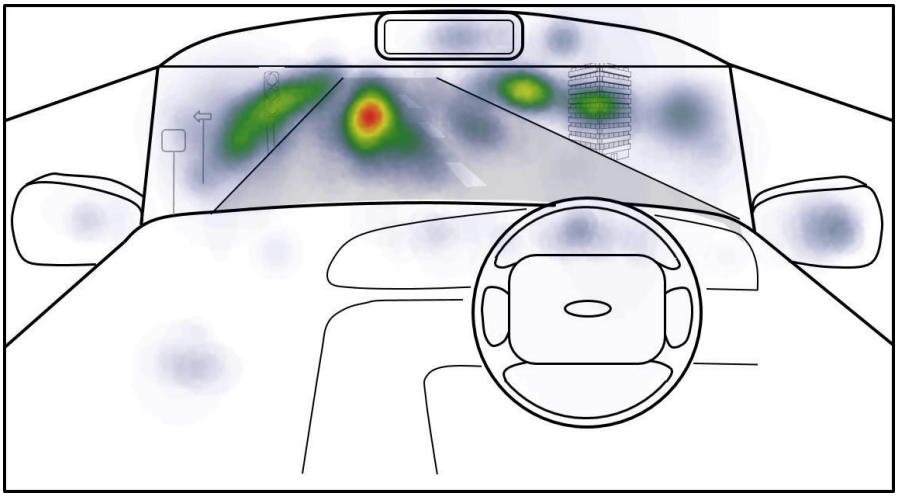


Figure 5-12 Heat map representations of the average fixation times of Satnav, Informed Passenger and Collaborative participants at Route 2 Junction 4

A Kruskal-Wallis test was conducted to see if there were any differences across experimental conditions (SatNav, Informed Passenger, and Collaborative) in the dwell and mean fixation times of participants, within the pre-defined AOIs. Distributions of dwell and mean fixation times were not similar for all experimental conditions, as assessed by visual inspection of a boxplot. Participant dwell times were statistically significantly different between experimental conditions within the traffic lights $\chi^2(2) = 9.46$, $p = .009$, roadway $\chi^2(2) = 9.42$, $p = .009$, flats $\chi^2(2) = 10.91$, $p = .004$ and right wing $\chi^2(2) = 7.16$, $p = .028$ AOIs. Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. This post hoc analysis revealed the following statistically significant differences:

- **Area of interest: Traffic lights** – Statistically significant differences were found between the dwell times of participants (within the traffic lights AOI) in the Collaborative (25.08) and SatNav (12.23) (P = .014) conditions and the Informed Passenger (22.86) SatNav (P = .044) conditions, but not between any other group combination.
- **Area of interest: Roadway** - Statistically significant differences were found between the dwell times of participants (within the roadway AOI) in the SatNav (25.00) and Collaborative (11.75) (P = .011) conditions but not between any other group combination.
- **Area of interest: Flats**- Statistically significant differences were found between the dwell times of participants (within the flats AOI) in the Collaborative (25.75) and SatNav (11.92) conditions (P = .005) conditions, and Informed Passenger (22.57) and SatNav conditions (P = .038) but not between any other group combination.
- **Area of interest: Right-wing** - Statistically significant differences were found between the dwell times of participants (within the right-wing AOI) in the Collaborative (23.33) and SatNav (13.85) (P = .050) conditions, but not between any other group combination.

A Kruskal-Wallis test also revealed that participant mean fixation times were statistically significantly different between experimental

conditions within the flats $\chi^2(2) = 7.51$, $p = .023$, Dash $\chi^2(2) = 7.80$, $p = .020$, and right-wing $\chi^2(2) = 6.89$, $p = .032$ AOIs. Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. This post hoc analysis revealed the following statistically significant differences:

- **Area of interest: Flats** – Statistically significant differences were found between the mean fixation times of participants (within the flats AOI) in the Collaborative (25.42) and SatNav (13.54) (P = .022) conditions, but not between any other group combination.
- **Area of interest: Dash** - Statistically significant differences were found between the mean fixation times of participants (within the dash AOI) in the Informed Passenger (26.54) and Collaborative (15.12) (P = .028) conditions, but not between any other group combination.
- **Area of interest: Right wing** - Statistically significant differences were found between the mean fixation times of participants (within the right wing AOI) in the collaborative (22.33) and SatNav (14.00) and (P = .044) conditions, but not between any other group combination.

5.5.5 Route 2 – Junction 7

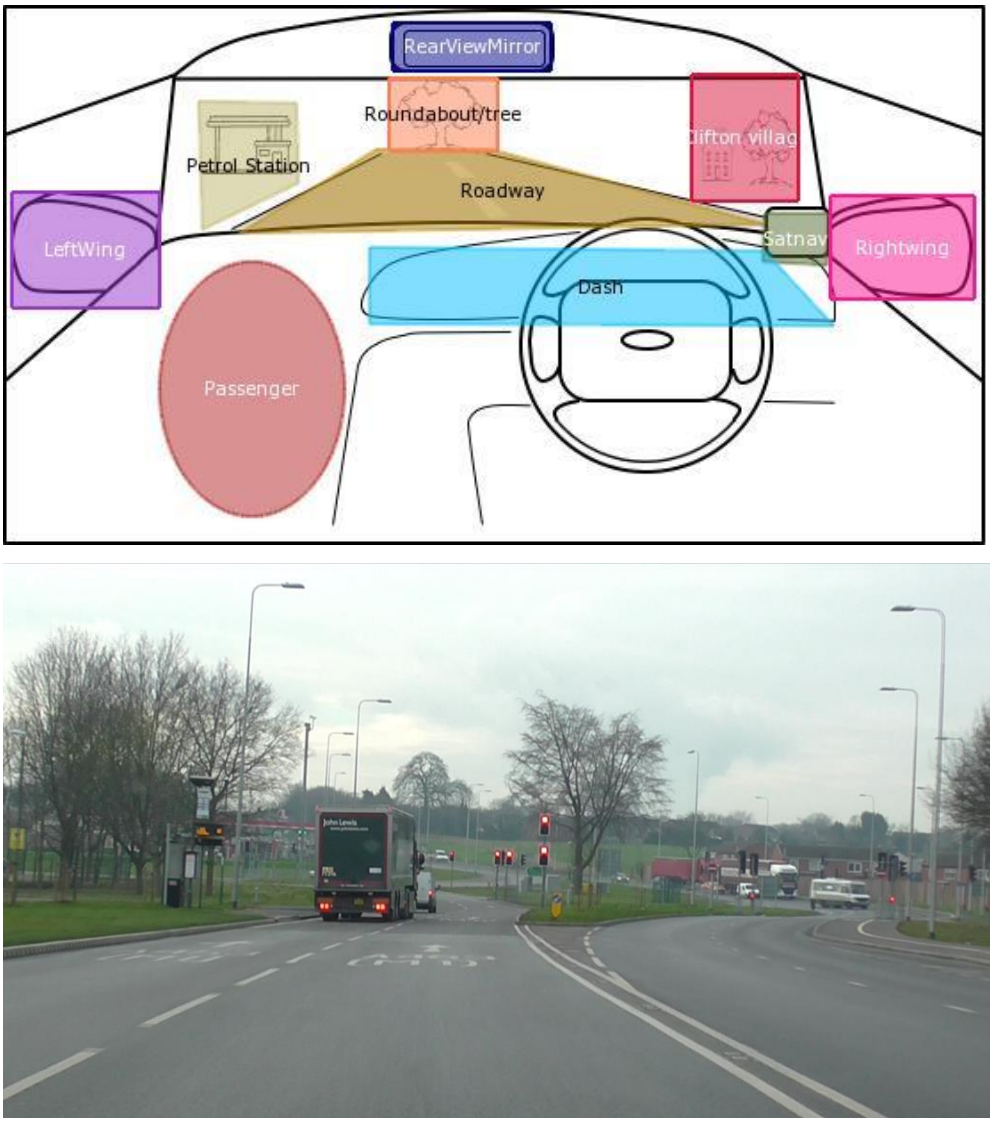
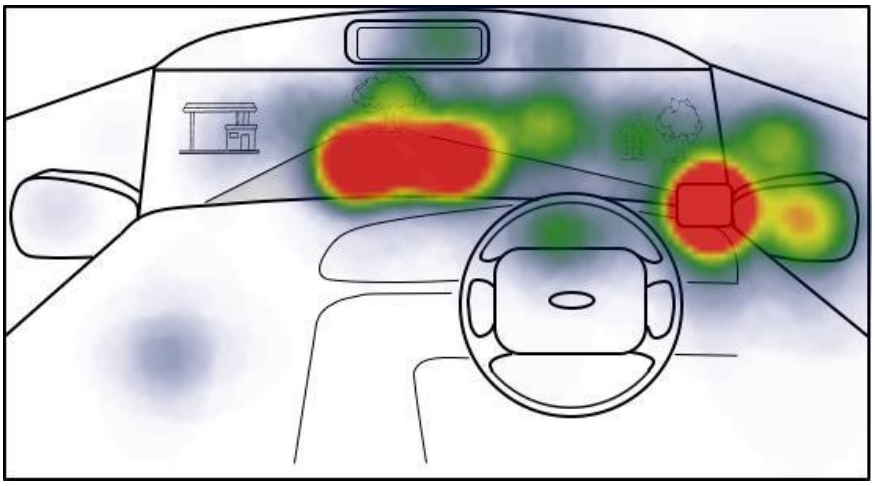


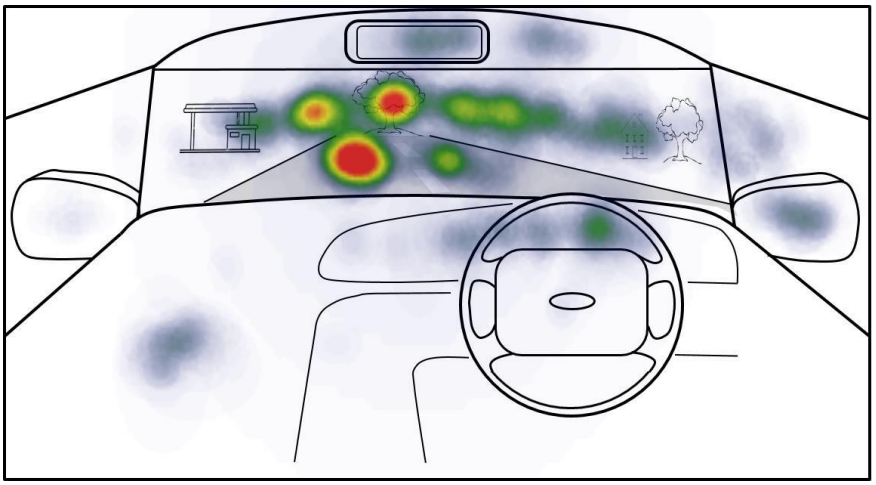
Figure 5-13: Representative image of on-route junction, displaying pre-defined AOIs. On-route image of junction displayed below.

Pre-defined areas of interest (AOI) for route 2, junction 7 consisted of: the in-car passenger, left wing mirror, petrol station (on left), rear-view mirror, roundabout/tree (directly ahead of the driver), rear-view mirror, roadway, Clifton village (on right), right wing mirror, Satnav, in-vehicle dash. Participant dwell and mean fixation times within each of these areas of interest were compared across experimental conditions (SatNav, Informed Passenger, Collaborative).

Satnav



Informed Passenger



Collaborative

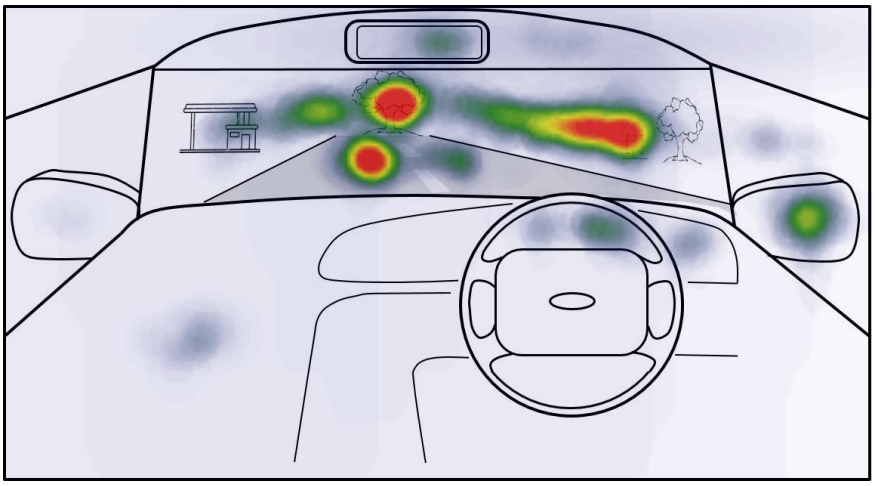


Figure 5-14 Heat map representations of the average fixation times of Satnav, Informed Passenger and Collaborative participants at Route 2 Junction 7

A Kruskal-Wallis test was conducted to see if there were any differences across experimental conditions (SatNav, Informed Passenger, Collaborative) in the dwell and mean fixation times of participants, within the pre-defined AOIs. Distributions of dwell and mean fixation times were not similar for all experimental conditions, as assessed by visual inspection of a boxplot. Participant dwell times were statistically significantly different between experimental conditions within the Clifton Village $\chi^2(2) = 20.73$, $p = <.001$, roundabout $\chi^2(2) = 19.47$, $p = <.001$ AOIs. Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. This post hoc analysis revealed the following statistically significant differences:

- **Area of interest: Clifton village** – Statistically significant differences were found between the dwell times of participants (within the Clifton village AOI) in the Collaborative (31.36) and SatNav (10.85) (P = <.001) conditions and the Collaborative and Informed Passenger (18.21) (P = .010) conditions, but not between any other group combination.
- **Area of interest: Roundabout** - Statistically significant differences were found between the dwell times of participants (within the roundabout AOI) in the Collaborative (27.91) and the SatNav (8.85) (P = <.001) conditions and the Informed passenger (22.79) and SatNav conditions (P = .003) but not between any other group combination.

A Kruskal-Wallis test also revealed that participant mean fixation times were statistically significantly different between experimental conditions within the Clifton village $\chi^2(2) = 7.031$, $p = .030$ AOI. Subsequently, pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. This post hoc analysis revealed the following statistically significant differences:

- **Area of interest: Clifton village** – Statistically significant differences were found between the mean fixation times of participants (within

the Clifton village AOI) in the Collaborative (26.91) and SatNav (15.77) (P = .042) conditions, but not between any other group combination.

5.6 SUMMARY OF PERFORMANCE AND WORKLOAD DATA

5.6.1 Navigational errors

Participants in the informed passenger condition made significantly fewer navigational errors, across drives one and two, than participants in the SatNav condition. Whilst there was a trend for fewer errors in the collaborative condition (compared to SatNav participants) there were no statistically significant differences across any further combinations of experimental conditions.

5.6.2 Nasa TLX measures

Statistical analyses revealed no significant differences in the perceived workload of participants. This was true across experimental conditions, on both drives one and two.

However, statistical analyses revealed a significant drop in participant perceived workload within experimental condition, from drive one to drive two in the SatNav and Collaborative condition. This means that participants in the SatNav and Collaborative conditions, perceived their workload to be significantly less on their second, final drive.

5.6.3 TDT Measures

Statistical analyses revealed no significant differences in the percentage of missed TDT impulses across experimental condition, on both experimental drives. Therefore, participants missed a statistically similar number of TDT impulses across SatNav, informed Passenger and Collaborative conditions.

Similarly, statistical analyses revealed no significant differences in the reaction time of participants towards the onset of a TDT impulse, on both experimental drives. Therefore, participants reaction time towards the onset of TDT impulses was statistically similar across SatNav, informed Passenger and Collaborative conditions.

However, statistical analyses revealed a significant drop in participant objective workload within experimental condition, from drive one to drive two in the Informed passenger and Collaborative conditions. This means that participants in the Informed Passenger and Collaborative conditions, experienced a significant reduction in objective workload on their second, final drive. This reduction in workload allowed participants to respond to significantly more haptic stimuli (informed passenger & collaborative participants) and also meant that their responses toward haptic TDT stimuli were significantly quicker (informed passenger participants) on their second experimental drive.

5.6.4 Eye tracking measures

Eye tracking measures are presented in table 5-5 on the following page, a significant result is denoted by an asterisk. With the direction of the result indicted along the row which was found to have the significantly longer dwell or mean fixation time. For example, within table 5-4 below, on route 1, junction 6, and collaborative participants were found, on average to have significantly longer dwell and mean fixation times (in the passenger AOI) than participants in the Satnav condition.

Junction/Experi-mental condition		Passenger	
		Dwell	MF
Route 1 Junction 4	Satnav	-	-
	IP	-	-
	Collab	-	-
Route 1 Junction 6	Satnav	-	-
	IP	-	-
	Collab	*SN	*SN

Table 5-4 Example table of significant results within eye tracking data

Junction/Experimental condition		Area of interest																	
		Passenger		Left wing		Left landmark		Rear-view mirror		Forward landmark		Roadway		Right landmark		Right wing		Dash	
		Dwell	MF	Dwell	MF	Dwell	MF	Dwell	MF	Dwell	MF	Dwell	MF	Dwell	MF	Dwell	MF	Dwell	MF
Route 1 Junction 4	Satnav	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	IP	-	-	-	-	*SN	*SN	-	-	*SN	-	-	-	*SN	-	-	-	-	-
	Collab	-	-	-	-	*SN	*SN	-	-	-	-	-	-	*SN	*SN	-	-	-	-
Route 1 Junction 6	Satnav	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	IP	-	-	-	-	-	-	-	-	*SN	-	-	-	-	-	-	-	*CP	*CP
	Collab	*SN	*SN	-	-	*SN	-	-	-	*SN	-	-	-	-	-	-	-	-	-
Route 2 Junction 2	Satnav	-	-	-	-	-	-	-	-	-	-	*CP& IP	-	-	-	-	-	-	-
	IP	-	-	-	-	*SN	-	-	-	*SN	-	-	-	*SN	-	-	-	-	-
	Collab	-	-	-	-	*SN	-	-	-	*SN	-	-	-	*SN	-	-	-	-	-
Route 2 Junction 4	Satnav	-	-	-	-	-	-	-	-	-	-	*CP	-	-	-	-	-	-	-
	IP	-	-	-	-	*SN	-	-	-	-	-	-	-	*SN	-	-	-	-	*CP
	Collab	-	-	-	-	*SN	-	-	-	-	-	-	-	*SN	*SN	*SN	*SN	-	-
Route 2 Junction 7	Satnav	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	IP	-	-	-	-	-	-	-	-	*SN	-	-	-	-	-	-	-	-	-
	Collab	-	-	-	-	-	-	-	-	*SN	-	-	-	*SN & IP	*SN	-	-	-	-

Table 5-5 Eye tracking results by navigational junction. Significant result indicted by an * , with the direction of result provided along the row with the significantly longer Dwell or mean fixation time

6

CHAPTER 6: RESULTS: DRIVER ENGAGEMENT MEASURES

6.1 INTRODUCTION

A corpus of environmental engagement tests were administered to participants upon completion of the final, second drive – based on previous research (as discussed in chapter 3). Here, participants completed image sorting and ordering tasks in addition to drawing a sketch of the on-road environment which they had traversed on-route. The results of these tests provided an indication of the participants' acquired landmark, route and survey knowledge respectively. A summary of each of the environmental knowledge assessment methods utilised within this thesis is provided in table 6-1 on the following page:

Environmental knowledge Component	Method	Assessment
Landmark (see section 4.5.2 for extended methodology)	➢ Participants were given a set of 12 images and were asked to identify which of those images had appeared across the three routes and which hadn't. ➢ Of the 12 images, 6 were 'target' images (images of scenes on route) and 6 were 'distractor' images (images of environments not experienced on route), though participants were not informed of this split.	➢ The images presented to participants were separated into, 'on route' and 'off route' piles. ➢ The number of incorrectly placed images was subtracted from the number of correctly placed images ➢ This yielded a percentage score of images correctly placed
Route (see section 4.5.2 for extended methodology)	➢ Participants were given a set of images for each of the three routes travelled, ➢ Each image was a view of a junction encountered on route. ➢ Participants were asked to put these images in the order which they had appeared on route	➢ The position of each image was scored relative to its actual position on route. ➢ A 'sequencing value' was then generated to account for the differences at average levels of performance. ➢ A sequencing value was the longest number of images which were placed together without error. ➢ Total error values were calculated by subtracting an individual's sequencing score from their error score. ➢ Final, calculated route error scores were then scaled to account for each route having a varying number of junctions
Survey (see section 4.5.3 for extended methodology)	➢ Drivers were asked to draw a sketch map of the routes travelled, incorporating as much detail as possible. ➢ Specifically, they were asked to represent any landmarks which they might have experienced on route, specific junction types and were instructed to illustrate any route overlap they might have experienced on route	➢ Analysis of participant sketch maps provided an indication of a participant's acquired survey knowledge. ➢ Participant sketch maps were scored by recording the number of elements incorporated as below: 1. Landmarks – number drawn which occurred on route 2. Nodes – road junctions drawn and correctly related to a landmark or path segment 3. Path segment - segments of the map drawn correctly (i.e. which link two locations with a correct road layout) 4. Landmark orientation - accurate placement of a particular landmark with respect to other landmarks 5. Route Intersections – number of route intersections illustrated

Table 6-1 Summary of the environmental knowledge assessments utilised as part of this thesis

6.2 LANDMARK KNOWLEDGE

Landmark identification tasks were administered after participants had completed their second, final drive. Here, participants were presented with 12 images and were asked to identify which of the environments represented in these images had appeared on the three routes which they had travelled. To ensure participants' scores best reflected their landmark knowledge, the number of inaccurately placed images was deducted from the total number of accurately placed images. This process yielded a percent correct score which is represented as a decimal in figure 6-1. Normality tests also indicated normally distributed data.

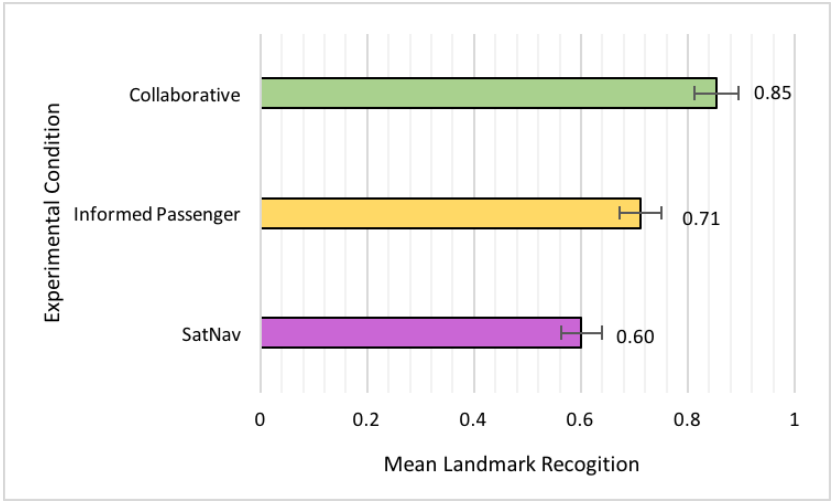


Figure 6-1: Average landmark recognition scores (in decimal format) of participants in the Satnav, Informed Passenger and Collaborative navigation conditions

- A between subjects (one way) ANOVA identified a statistically significant difference in landmark identification between navigational conditions; $F(2,42) = 9.46$, $p=0.000$.
- A Tukey HSD post hoc test revealed that participants in the collaborative navigation condition ($M = 0.85$, $SD = 0.17$) were able to identify significantly more landmarks than participants in the SatNav condition ($M= 0.60$, $SD = 0.15$, $p = 0.000$) and the informed passenger condition ($M= 0.71$, $SD = 0.16$, $p = 0.049$)
- However, Tukey HSD post hoc tests revealed that there was no statistically significant difference between the landmark identification

scores of SatNav and Informed passenger participants. Indicating that participants navigating with the assistance of a SatNav identified a statistically similar number of landmark as participants navigating with an informed passenger ($p = 0.15$).

6.3 ROUTE KNOWLEDGE

Part of the battery of environmental knowledge tests included a number of route knowledge tasks. Here, participants were given a set of photographs for each route. Images depicted each junction which participants had encountered on route. Participants were required to place these images in the order which they believed they had encountered them on route. This task was completed separately for routes 1, 2 and 3, in turn. With participants being informed prior to the ordering task which route the images corresponded to. The placement of images by participants was scored using an established method (detailed in section 3.3.1.1) which evaluated the veracity of participant route knowledge based on the number of errors they made when ordering route images. Route knowledge is therefore represented by a route error score – signifying the number of placement errors made by participants. The error score scale moves from 0 to 1, with lower scores representing fewer placement errors and therefore superior route knowledge. Tests of normality indicated normally distributed data.

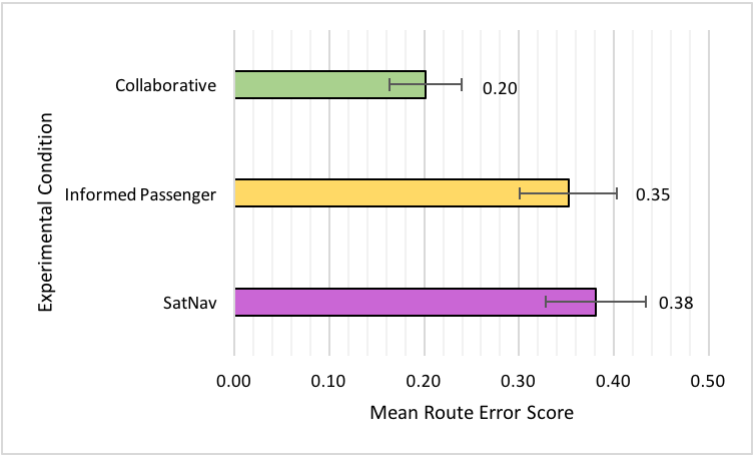


Figure 6-2: displaying the average route error scores from routes 1, 2 & 3 of participants in the SatNav, Informed Passenger and Collaborative navigation conditions

- A between subjects (one way) ANOVA revealed a statistically significant difference in the route error scores of participants between navigational conditions; F (2,42) = 3.85, p=0.029. Indicating that navigational condition had a statistically significant effect on the route knowledge acquired by participants
- A Tukey HSD post hoc test revealed that participants in the collaborative navigation condition (M = 0.20, SD = 0.15) had significantly lower route error scores than participants in the SatNav condition (M= 0.38, SD = 0.21, p = 0.026). Meaning collaborative participants were able to order route images with significantly higher accuracy than participants in the SatNav condition.
- However, Tukey HSD post hoc tests revealed that there were no statistically significant differences between the route error scores of collaborative and informed passenger (M = 0.33, SD = 0.46, p= 0.16) participants. Indicating that participants in the collaborative condition made a statistically similar number of errors when ordering route images as participants in the informed passenger condition.
- Tukey HSD post hoc tests also indicated that there were no statistically significant differences in the route error scores of those participants navigating with the assistance of a SatNav and Informed passenger. Indicating that the number of errors made by participants when ordering route images was statistically equivalent across conditions (p = 0.69)

6.4 SURVEY KNOWLEDGE

To evaluate acquired survey knowledge participants were required to draw a sketch map of the routes travelled. Here, they were asked to incorporate as many landmarks as they could remember, placing the landmarks accurately within their sketched environment, they were also asked to include road names, points of route overlap and sections of pathway and junctions. The number of components detailed within each participant sketch map for the three experimental conditions are detailed across tables 6-2 to 6-7, split by information type (e.g. number of landmarks, landmark orientation, no of road names etc.). Accompanying boxplots (figures 6-3 to 6-7) support the data presented within these tables, providing an illustration of how the

number of components detailed in participants sketch maps differed within and between experimental conditions.

Sketch maps were then assessed by the experimenter on the basis of the various components they contained (e.g. landmarks, accuracy of landmark placement, navigational junctions, pathways). To ensure that this subjective assessment of participant sketch maps was an accurate reflection of the components contained within participants sketches, a portion of maps (5 out of 15 in each of the 3 experimental conditions [15 in total]) were assessed by another human factors specialist who acted as second reviewer. Cohens Kappa was then run to determine if there was agreement between both reviewers on the selection of maps assessed. The subsequent results indicated there was very good agreement between the two rater's judgements, k = .845 (95% CI, .759 to .931), p<.0005.

This section will therefore use the experimenter's assessments of participants sketch maps to quantitatively determine whether the individual components contained within participants sketches differed significantly across conditions. Sketch maps will then be assessed on the basis of their overall structure and detail using an establish method developed by Appleyard (1970). Representative examples of participant sketch maps for the Satnav, Informed Passenger and Collaborative condition are provided in figure 6-8 and figure 6-9.

Participant No	Number of Landmarks drawn		
	SN	IP	CP
1	7	12	11
2	5	6	11
3	5	11	9
4	5	8	6
5	5	5	11
6	3	9	8
7	2	4	16
8	8	8	15
9	0	8	8
10	0	12	4
11	8	12	7
12	3	5	11
13	3	8	7
14	3	9	11
15	6	9	5

Table 6-2 Number of landmarks contained within Satnav, Informed Passenger and Collaborative Passenger sketch maps

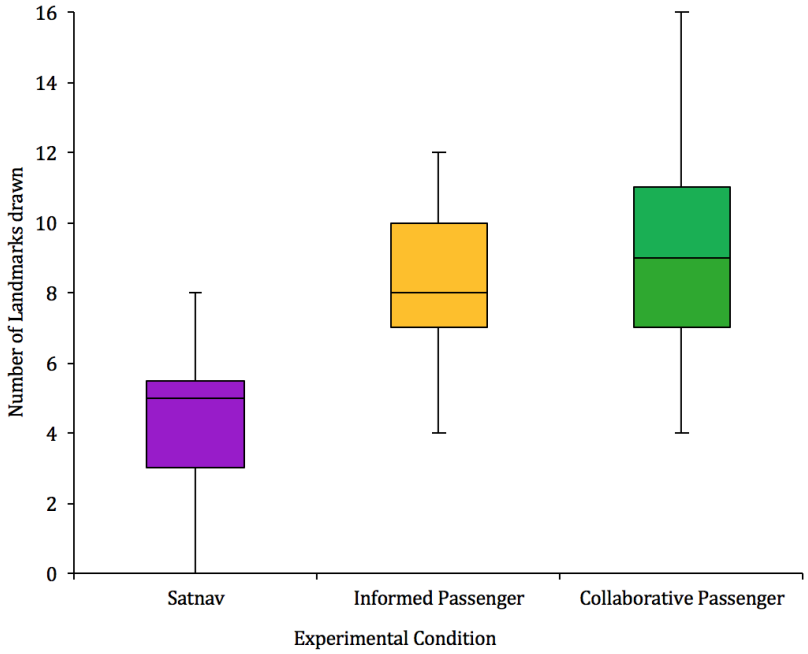


Figure 6-3 Boxplot illustrating the number of landmarks incorporated into Satnav, Informed Passenger and Collaborative Passenger participant sketch maps

Participant No	Landmarks Orientation		
	SN	IP	CP
1	0.43	1.00	0.64
2	0.20	0.17	0.91
3	0.60	0.91	0.89
4	0.00	0.00	0.00
5	0.40	0.00	0.00
6	0.00	0.78	0.63
7	0.00	0.00	0.81
8	0.75	0.13	0.00
9	0.00	1.00	0.63
10	0.00	0.50	0.75
11	0.00	0.58	0.71
12	0.00	0.00	0.00
13	0.00	0.00	0.29
14	0.67	1.00	0.82
15	0.00	0.00	0.00

Table 6-3 Landmark Orientation scores of environmental features contained within Satnav, Informed Passenger and Collaborative Passenger sketch maps

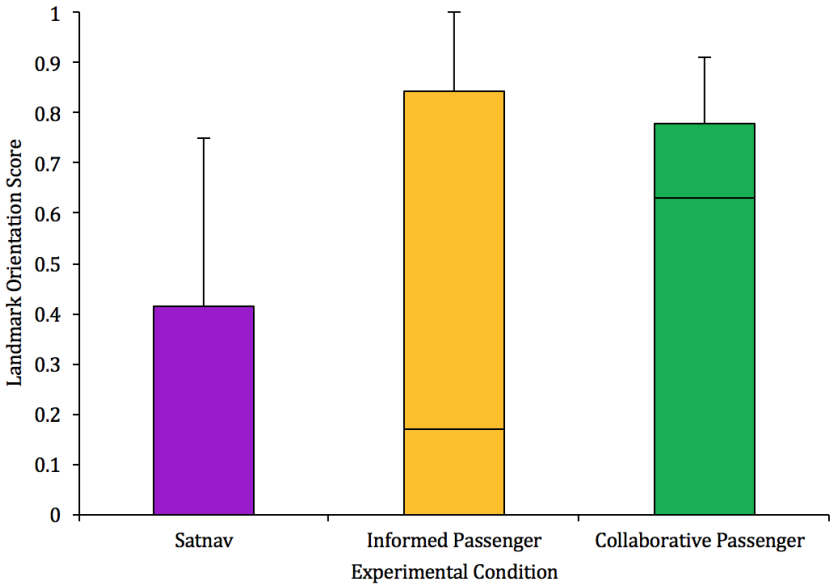


Figure 6-4 Boxplot illustrating the landmark orientation scores of environmental features incorporated into Satnav, Informed Passenger and Collaborative Passenger sketch maps

Participant No	Number of Pathways drawn		
	SN	IP	CP
1	3	8	5
2	3	3	6
3	2	6	6
4	2	0	2
5	2	3	3
6	2	5	4
7	3	2	6
8	3	3	5
9	2	6	4
10	2	6	1
11	3	6	5
12	2	3	3
13	3	4	2
14	5	8	6
15	4	4	2

Table 6-4 Number of pathways depicted within Satnav, Informed Passenger and Collaborative Passenger sketch maps

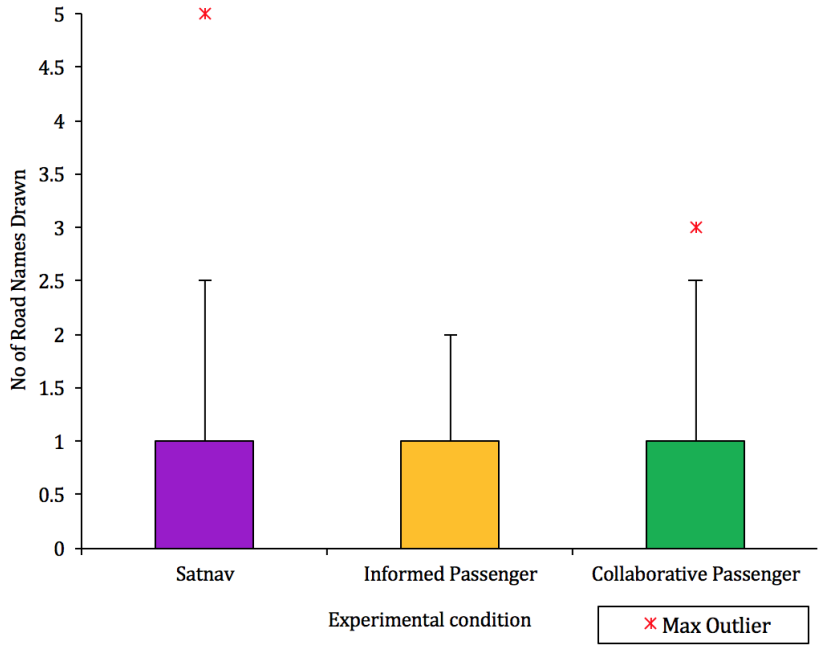


Figure 6-5 Boxplot illustrating the number of pathways depicted within Satnav, Informed Passenger and Collaborative Passenger sketch maps

Participant No	Point of intersect Illustrated		
	SN	IP	CP
1	0	1	2
2	1	2	3
3	1	3	2
4	1	0	0
5	0	1	1
6	0	1	2
7	0	0	2
8	0	1	0
9	0	2	1
10	0	0	1
11	0	1	3
12	0	0	1
13	0	0	0
14	2	0	3
15	0	1	1

Table 6-5 Points of route intersect depicted within Satnav, Informed Passenger and Collaborative Passenger sketch maps

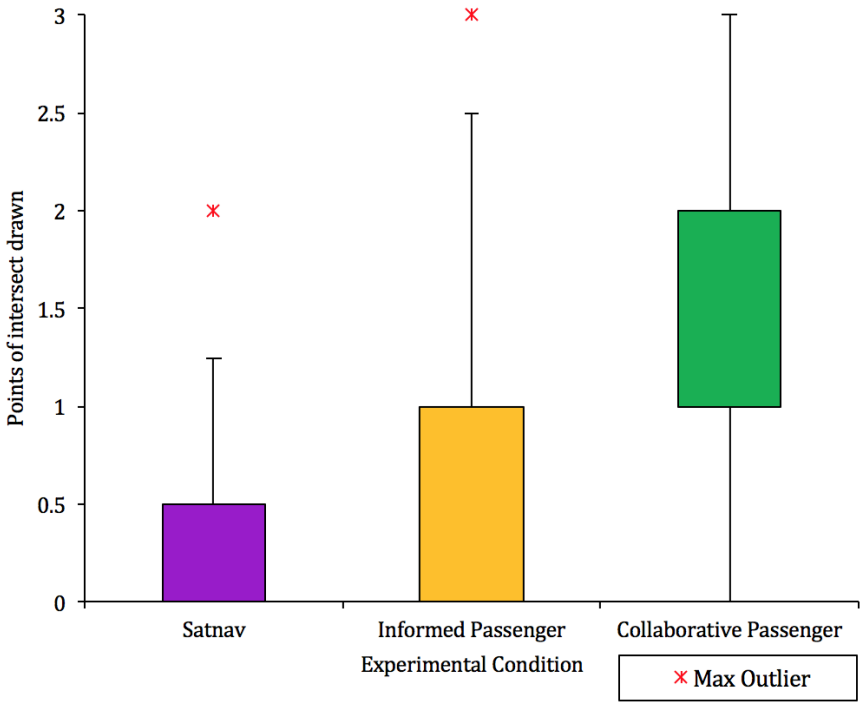


Figure 6-6 Boxplot illustrating the points of route intersect depicted within Satnav, Informed Passenger and Collaborative Passenger sketch maps

Participant No	Number of Road names drawn		
	SN	IP	CP
1	3	0	1
2	0	0	0
3	0	2	0
4	0	0	0
5	0	1	0
6	0	0	2
7	2	1	3
8	0	1	1
9	0	0	1
10	0	0	0
11	0	2	0
12	0	0	0
13	2	0	0
14	0	2	3
15	5	0	0

Table 6-6 Number of road names depicted within Satnav, Informed Passenger and Collaborative Passenger sketch maps

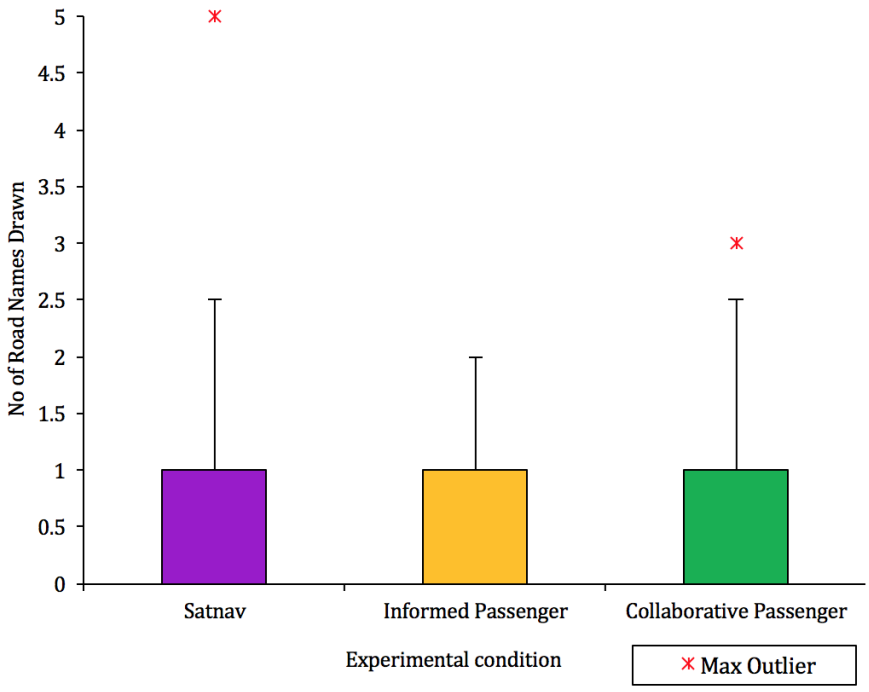
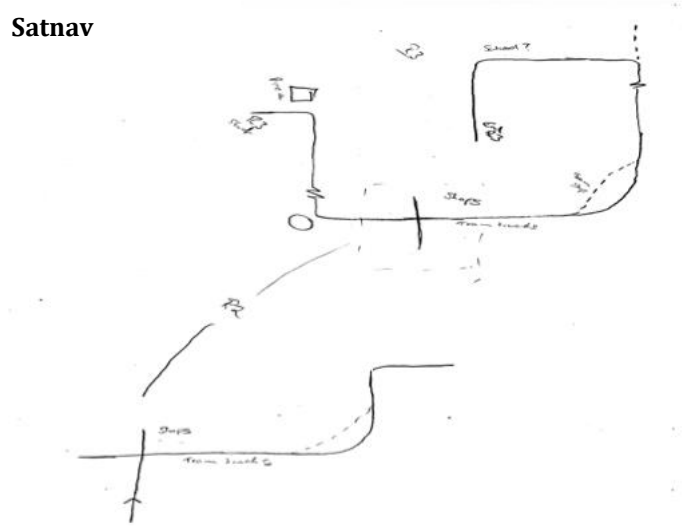


Figure 6-7 Boxplot illustrating the number of road names depicted within Satnav, Informed Passenger and Collaborative Passenger sketch maps

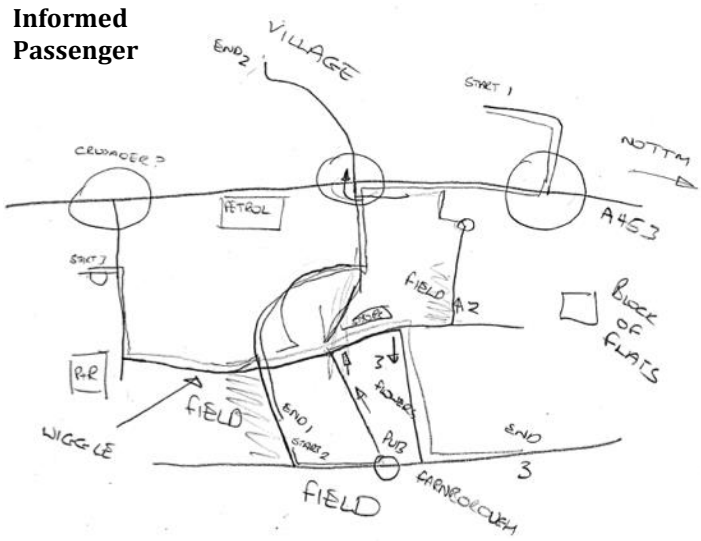
Map type	Satnav	Informed Passenger	Collaborative
Spatial (landmark based)			
Scatter & Cluster	-	-	-
Mosaic	-	-	-
Link	-	-	-
Pattern	-	-	-
Sequential (road based)			
Fragmented	**5**	**2**	**4**
Chain	**1**	**5**	**3**
Branch & Loop	**9**	**2**	**3**
Netted	-	**6**	**4**
Total:	**15**	**15**	**15**
Dominant map type:	**Chain**	**Chain/Netted**	**Even spread**

Table 6-7 Illustrates the varying/dominant map types drawn by Satnav, Informed Passenger and Collaborative Passenger participants

Satnav



Informed Passenger



Collaborative Passenger

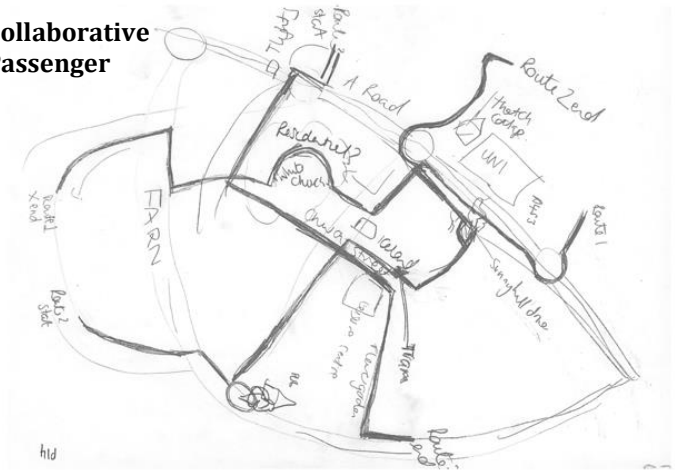
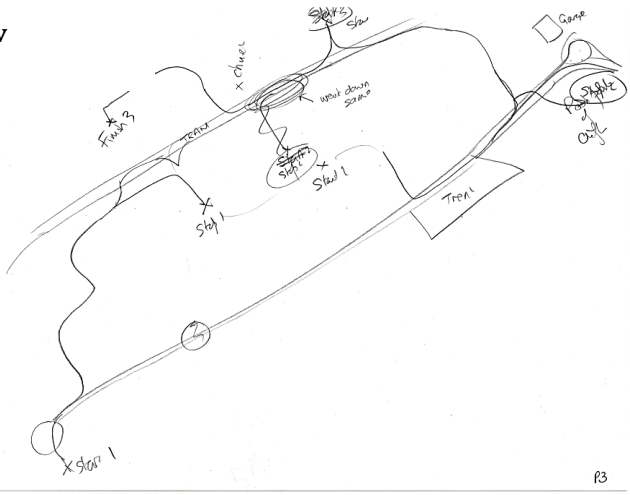
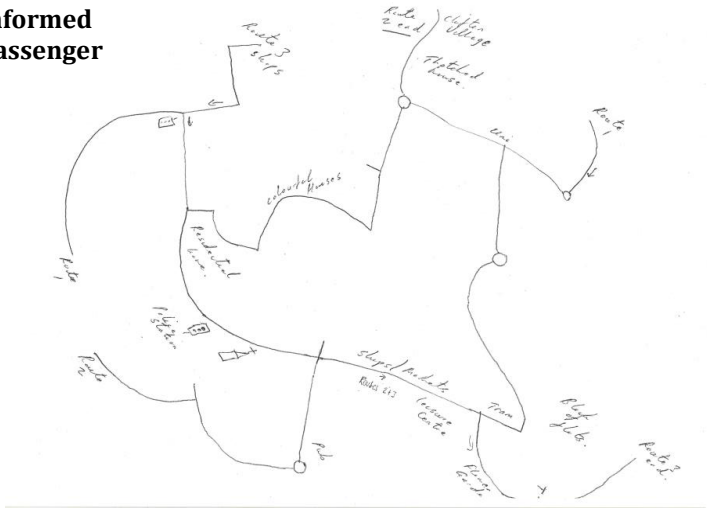


Figure 6-8 Representative examples of participant sketch maps from the Satnav, Informed Passenger & Collaborative Passenger navigation conditions

Satnav



Informed Passenger



Collaborative Passenger

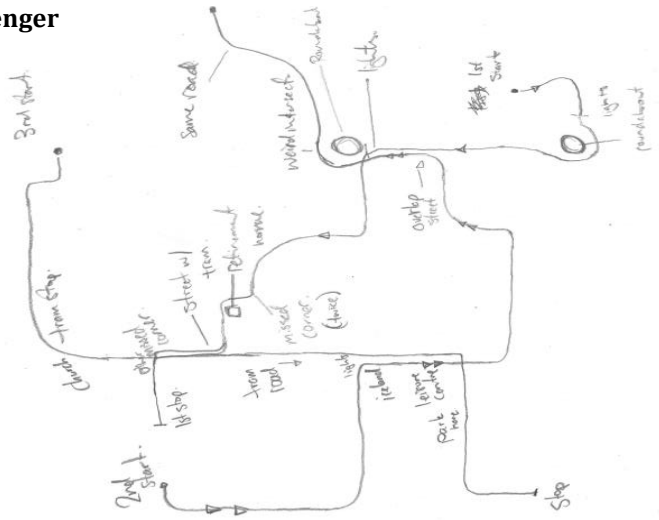


Figure 6-9 Representative examples of participant sketch maps from the Satnav, Informed Passenger & Collaborative Passenger navigation conditions

6.4.1 Quantitative analysis of Participant Sketch map components

The section below examines the total number of landmarks contained within participant sketch maps, assessing the variations across experimental conditions. Normality tests indicated normally distributed data.

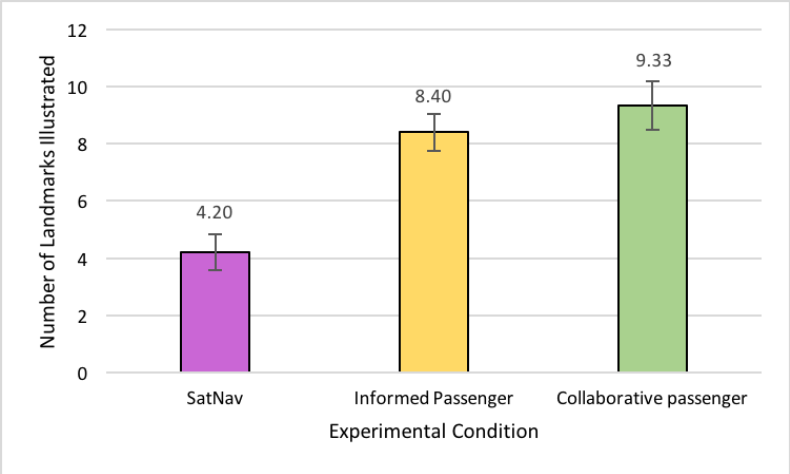


Figure 6-10: mean number of landmarks illustrated in participant sketch maps in the SatNav, Informed passenger and Collaborative condition

- A between subjects (one way) ANOVA revealed a statistically significant difference in the number of landmarks drawn by participants between navigational conditions; F (2,42) = 13.56, p=0.000. Indicating that navigational condition had a statistically significant effect on the number of landmarks remembered by participants.
- A Tukey HSD post hoc test revealed that participants in the collaborative navigation condition (M = 9.33, SD = 3.42) incorporated significantly more landmarks within their sketch maps than participants in the SatNav condition (M= 4.2, SD = 2.51, p = 0.000). Meaning collaborative participants were able to remember significantly more landmarks than SatNav participants.
- Similarly, a Tukey HSD post hoc test revealed that participants in the informed passenger condition (M= 8.4, SD = 2.6) also incorporated significantly more landmarks within their sketch maps than SatNav participants (p= 0.001). Indicating that Informed passenger

participants were also able to remember significantly more landmarks than SatNav participants.

- Tukey HSD post hoc tests also indicated that there were no statistically significant differences in the number of landmarks drawn by Collaborative and Informed Passenger participants (p= 0.65). Indicating that the number of landmarks remembered and incorporated into sketch maps was statistically equivalent across conditions.

As normality tests on the remainder of the sketch map components indicated non-normal data, Kruskal Wallis tests were used to examine if there were any statistically significant differences between experimental conditions and the remainder of the sketch map elements including: landmark orientation, number of pathways, number of route intersections and the number of road names illustrated. Figure 6-6 illustrates landmark orientation scores of participants, scores were derived by determining the placement accuracy of landmarks within the sketch map environment drawn by the participants. The resulting output was a decimal number, in which total placement accuracy is illustrated by a score of 1 (see section 3.3.1.1 for more detail).

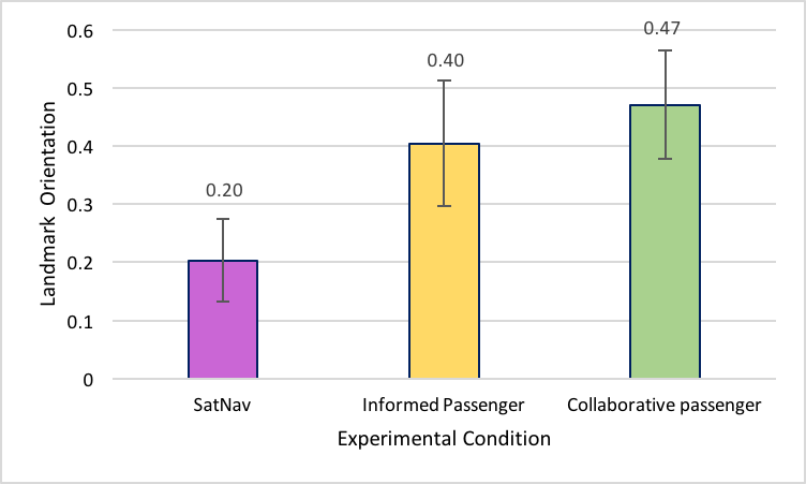


Figure 6-11: Mean landmark orientation score of SatNav, Informed passenger and Collaborative participants indicating the accuracy of landmark placement within participant sketch maps

- A Kruskal Wallis test confirmed that there were no significant differences in the landmark orientation of SatNav, Informed Passenger

and Collaborative participants in sketch map illustrations. H(2) = 4.11, p = 0.13. Demonstrating that the accuracy with which participants placed landmarks illustrated within their sketch maps was statistically similar across conditions.

In addition to analysing the landmark information contained with participant sketch maps. The number of path segments (pre-defined groupings of roads and junctions within the on-road test area) which were depicted within participant sketches were also analysed and compared across conditions.

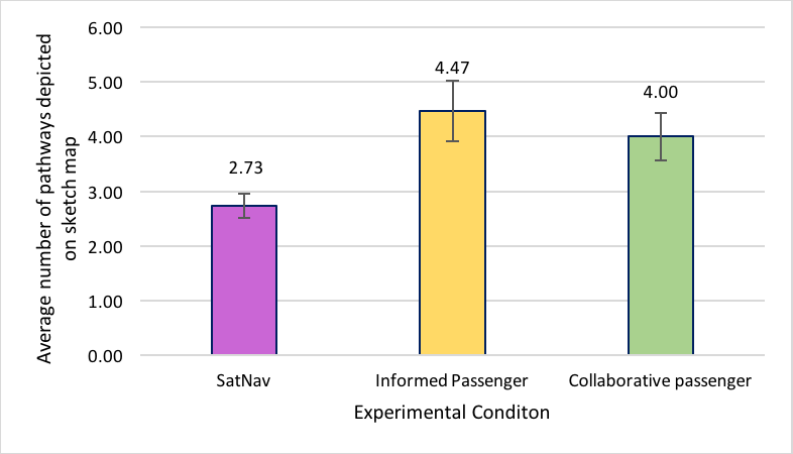


Figure 6-12 Mean number of pathways illustrated by SatNav, Informed passenger and Collaborative participants within sketch map illustrations

- A Kruskal Wallis test indicated that there was a statistically significant difference in the number of pathways depicted in sketch map illustrations and participant experimental condition H(2) = 7.86, p = 0.020. Demonstrating that the number of pathways participants were able to remember and incorporate within sketch maps illustrations differed significantly according to experimental condition.
- Dunn's post-hoc pairwise comparisons indicated that informed passenger participants (M = 4.47, Mean Rank= 28.2) incorporated significantly more pathways within sketch map illustrations than SatNav participants (M = 2.73, Mean Rank= 15.6, p= 0.022, adjusted using the Bonferroni correction). Indicating that participants receiving navigational guidance from an informed passenger were able to

remember significantly more road sections of the routes travelled than participants receiving guidance from a SatNav device.

- Dunn's Post-hoc pairwise comparisons also indicated that there were no significant differences in the number of pathways incorporated into sketch maps by Informed passenger and Collaborative Passenger participants (M= 4, Mean Rank= 25.2, p=1.0). Indicating that the number of pathways which participants incorporated within their sketch maps was statistically equivalent across these conditions.
- Similarly, post-hoc pairwise comparisons also indicated that there were no statistically significant differences in the number of pathways incorporated into sketch maps by SatNav and Collaborative participants (p= 0.12). Indicating that the number of pathways which participants incorporated within their sketch maps was statistically equivalent across conditions.

The three experimental routes which participants traversed, intersected at three, separate points (see figure 4-6 for highlighted points of route intersect). Participants were asked to incorporate any route intersections they remembered within their sketch maps. Sketch maps which contained accurate references to these route intersections were analysed and compared across conditions.

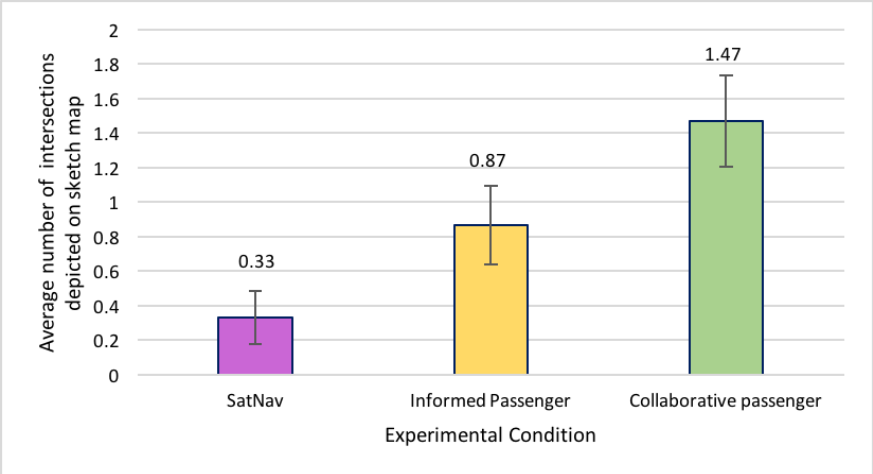


Figure 6-13: Mean number of route intersections depicted in the sketch maps of SatNav, Informed Passenger and Collaborative participants

- A Kruskal Wallis test indicated that there was a statistically significant difference in the number of route intersections depicted in sketch map

illustrations and participant experimental condition, H(2) = 10.22, p = 0.006. Demonstrating that the number of pathways participants were able to remember and incorporate within sketch map illustrations differed significantly according to experimental condition.

- Dunn's post-hoc pairwise comparisons indicated that Collaborative participants (M = 1.47, Mean Rank= 30.1) identified significantly more route intersections within their sketch map illustrations than SatNav participants (M = 0.33, Mean Rank= 15.73, p= 0.004, adjusted using the Bonferroni correction). Indicating that participants receiving navigational guidance from a collaborative passenger were able to remember significantly more route intersections than participants receiving guidance from a SatNav device.
- Dunn's Post-hoc pairwise comparisons also indicated that there were no significant differences in the number of route intersections incorporated into sketch maps by Informed passenger (M= 0.87, Mean rank= 23.17) and Collaborative Passenger participants (p=0.37). Indicating that the number of route intersections which participants identified and subsequently incorporated within their sketch maps were statistically equivalent across conditions.
- Similarly, Dunn's post-hoc pairwise comparisons also indicated that there were no statistically significant differences in the number of intersections incorporated into sketch maps by SatNav and Informed passenger participants (p= 0.29). Indicating that the number of route intersections which participants incorporated within their sketch maps was statistically equivalent across conditions.

Finally, participants were asked to incorporate any road names they remembered from the three experimental routes into their sketch maps. Accurate references to road names were then analysed and compared across conditions.

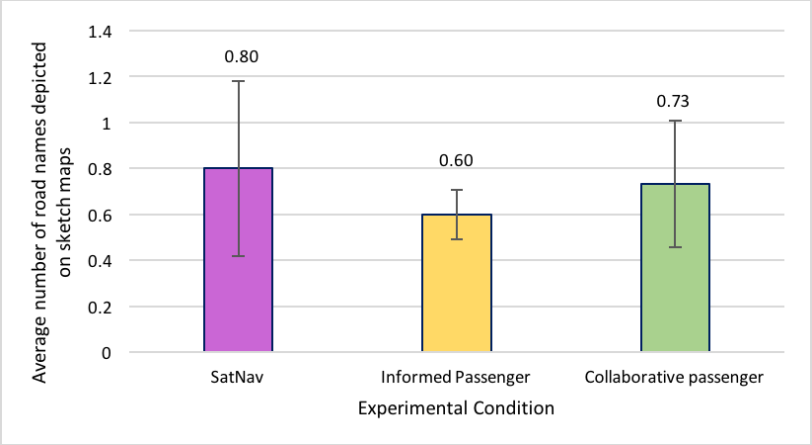


Figure 6-14: mean number of road names illustrated in the Sketch maps of SatNav, Informed Passenger and Collaborative participants

- A Kruskal Wallis test confirmed that there were no significant differences in the number of road names identified within the sketch maps of SatNav (M= 0.80, Mean rank = 22) Informed Passenger (M= 0.60, Mean rank= 23.20) and Collaborative participants (M =0.73 , Mean rank= 23.8). H(2) = 0.20, p = 0.90. Demonstrating that the number of road names remembered and subsequently incorporated within participant sketch maps were statistically similar across conditions.

6.4.2 Subjective assessment of Sketch map structure

In addition to the quantative assessment of sketch map components the complexity of participant sketch maps were classified under the categorisation scheme first proposed by Appleyard (1970) and used in the later research of Burnett and Lee (2005). In this approach, maps are considered to be either 'sequentially dominant' (primarily roads) or 'spatially dominant' (primarily landmarks). These broad categories are then further broken down into sub-categories in which the increasing complexity of maps is identified (see Figure 6-10). Maps which range from simplistic sketches with no integration of elements (e.g. spatial scattered) are placed at the lowest end of the complexity

scale, sitting at the opposite end of this scale are holistic, integrated maps which marry landmarks and road sequences into a whole view (e.g. sequential netted).

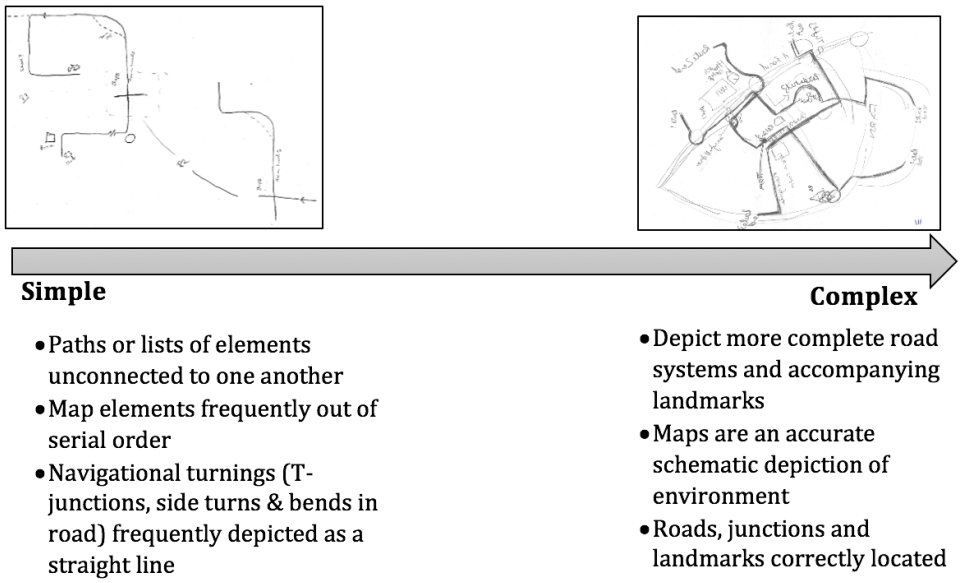


Figure 6-15 Complexity of participant sketch maps and elements depicted

Table 6-3 shows the categories of maps drawn by participants in the Satnav, Informed Passenger and Collaborative navigation conditions, and reveals that, in the Satnav condition, one third of participants (five out of fifteen) drew the simplest category maps (i.e. sequential fragmented) with the predominant number of maps within this condition (nine out of fifteen) being *chain* maps. Whilst chain map structures are more schematic in their appearance than fragmented maps they are equally simple representations, with turns and intersections frequently represented as a straight line. Indeed, some of these maps were no more than lists of places or components remembered off route.

Increasing complexity ↓

Map Type	Experimental condition					
	Satnav		Informed Passenger		Collaborative Passenger	
	Spatially dominant	Sequentially dominant	Spatially dominant	Sequentially dominant	Spatially dominant	Sequentially dominant
Fragmented	-	5	-	2	-	4
Chain	-	9	-	5	-	3
Branch & Loop	-	1	-	2	-	4
Netted	-	-	-	6	-	4

Table 6-8 Number of participants who drew particular categories of map

However, analysis of informed passenger and collaborative passenger sketch maps revealed that a wider range of map types were drawn with a large proportion of these maps being the more sophisticated *Branch and Loop* and *Netted* structures which depicted more laterally developed illustrations of which a number were accurate representations of the experimental routes and their interaction with one another.

6.5 SUMMARY OF ENVIRONMENTAL ENGAGEMENT DATA

6.5.1 Landmark Knowledge

- Participants in the Collaborative Navigation condition demonstrated superior landmark knowledge over SatNav and Informed Passenger participants. Here, Collaborative participants accurately identified significantly more landmarks which had appeared along experimental routes than participants in the SatNav condition and the informed passenger conditions.

6.5.2 Route Knowledge

- Participants in the Collaborative Navigation condition demonstrated superior route knowledge over SatNav and Informed Passenger participants. Here, participants in the collaborative navigation conditions were able to order route images with significantly higher accuracy, resulting in significantly lower route error scores than participants in the SatNav and informed passenger condition.

6.5.2 Survey Knowledge

- Collaborative and Informed Passenger participants incorporated significantly more landmarks than SatNav participants within their sketch maps. Meaning participants in the collaborative and informed passengers' conditions were able to remember significantly more landmarks than their SatNav counterparts. However, no further statistically significant differences (in the number of landmarks incorporated into sketch maps) were found in any other combination of experimental conditions

- No significant differences were found in the landmark orientation of SatNav, Informed Passenger and Collaborative participants in sketch map illustrations. Demonstrating that the accuracy with which participants placed landmarks illustrated within their sketch maps was statistically similar across conditions.
- Informed passenger participants accurately incorporated significantly more pathways within sketch map illustrations than SatNav participants. Indicating that participants receiving navigational guidance from an informed passenger were able to remember significantly more road sections of the routes travelled than participants receiving guidance from a SatNav device. No further significant differences in the number of accurately depicted pathways were found in any other combination of experimental conditions.
- Collaborative participants accurately highlighted significantly more instances of route intersection within their sketch map illustrations than SatNav participants. Indicating that participants receiving navigational guidance from a collaborative passenger were able to remember significantly more route intersections than participants receiving guidance from a SatNav device.
- No significant differences were observed between conditions in the number of road names remembered and subsequently incorporated in participant sketch maps.
- Participants in the Satnav condition predominantly draw simplistic sketch maps (fragmented & chain) compared to participants in the Informed passenger and Collaborative passenger conditions. Here, informed passenger and collaborative participants drew a wider variety of map types with over half of the participants in each of these conditions (eight out of fifteen participants, in both conditions) drawing more sophisticated *branch and loop* and *netted* maps, offering more accurate representations of experimental routes.

7

CHAPTER 7: PRELIMINARY DISCUSSION OF RESULTS FROM CHAPTERS 5 & 6

7.1 INTRODUCTION

This chapter will discuss the results related to navigational performance, participant workload (objective and subjective), visual behaviour and environmental engagement measures, presented in chapters five and six. Results will be discussed in the context of previous literature and the impact of study design on experimental outcomes will be considered. The chapter goes on to discuss the fundamental differences in the content and presentation style of route guidance information issued by a Satnav device compared to guidance issued from an in-car passenger (informed passenger and collaborative passenger guidance) and how these different navigational methods can impact upon a driver's environmental engagement and subsequent cognitive map formation.

Results are then reflected upon in the context of recent navigation literature which has proposed using the driver-passenger model as a basis for future navigation system design. Building on this literature this thesis examines the verbal navigational interactions between driver and passenger to create a natural language, navigation transcript which will be issued to drivers, in place of traditional verbal turn-by-turn navigation instructions, in a final on-road trial. In this final study, detailed in chapter 9, drivers will be informed that they are receiving guidance from a natural language navigation system, which is able to issue context sensitive, landmark based navigation. This

system (implemented using a Wizard-Of-Oz approach), using voice-based guidance as its sole interaction method, encourages driver interaction through the use of route progress checks and prompts to receive enhanced environmental information (at designated points). Thus, mimicking the interactions observed amongst previous driver-passenger pairings.

7.2 RESULTS

Results from the on-road trials, detailed in chapters five and six, showed that participants receiving guidance from an informed passenger made significantly fewer navigational errors than those participants navigating with the assistance of a Satnav. These differences in driving performance may be attributed to those participants in the informed passenger condition having the ability to clarify their understanding of instructions with the informed passenger, checking the location of turnings and questioning lane placement in order for the correct turning to be accessed with ease. Additionally, a proportion of these differences may be ascribed to difficulties interpreting the navigational interface within the SatNav condition. Previous literature has suggested that misinterpretations of the interface can lead to navigational uncertainty or inappropriate path selection (Forlizzi, Barley, & Seder, 2010).

Whilst there was a trend for fewer navigational errors in the Collaborative condition, compared to SatNav participants, these differences failed to reach levels of significance. This may be ascribed to the perceived level of expertise of the navigator. Whilst collaborative navigators were trained in routes prior to the on-road trial, they lacked the same level of familiarity as the informed-passenger, which may have impacted on the conciseness and timing of route descriptions and information delivery. Resulting in navigational information being issued too late or lacking the clarity required for drivers to take timely action.

Previous literature has postulated that the use of electronic navigation devices when wayfinding fails to prompt workload at a level which

encourages environmental learning (Burnett, 2000). Within this thesis, there were no significant differences in the objective workload experienced by participants, across both experimental drives, when using a SatNav device compared to the use of instructions from an informed or collaborative passenger - although there were some trends for lower workload in the informed passenger condition. Such results nevertheless can provide insight into possible decision-making processes which may occur during different forms of navigation. Participants in the Satnav condition may have shown trends toward higher objective workload values as they were required to navigate the route alone, only following the guidance of the device and were unable to check their understanding with anyone, the navigational outcome of the journey depended solely on themselves – i.e. one-way interaction. Comparatively, the trend toward lower objective workload values in participants in the informed passenger and Collaborative conditions could be attributed to their ability to check their understanding of navigation instructions throughout their journey, asking for additional information or clarification of instructions. Thus, allowing them to be confident in their navigational decisions before selecting a course of action – i.e. two-way interaction.

Furthermore, analysis of objective TDT workload data illustrated that those participants navigating with the assistance of an Informed passenger and Collaborative passenger benefitted from a significantly lower workload on their second drive. These results may be related to increased route familiarity making the navigational process less challenging. On the contrary, drivers navigating with a Satnav demonstrated no such drop in objective workload on their second journey, indicating that Satnav participants had to work at similar levels on their second drive to navigate the route successfully, and therefore did not benefit from the same levels of familiarity as those navigating with the assistance of an Informed passenger or a Collaborative passenger.

Subjective scores of participant workload, from the completion of NASA-TLX questionnaires, largely reflected trends for equivalent

workload across conditions. With no significant differences being found between experimental conditions, across both drives – although trends did illustrate that Satnav participants perceived their workload to be higher than other conditions, on both drives. However, within-subject analysis of subjective workload data illustrated that those participants navigating with the assistance of a Satnav and a Collaborative passenger, perceived their workload to be significantly lower on their second, final drive. These results may be related to increased route familiarity making the navigational process less challenging. Alternatively, this reduction in perceived workload may be attributed to participant familiarity with the experimental procedure and test vehicle which may have influenced driver expectations and perceived competence.

Semantic gaze mapping revealed that on four out of five junction approaches both Collaborative and Informed passenger participants spent significantly longer looking at roadside and forward landmarks than their Satnav counterparts. These findings may be attributed to the content of route instructions, within the Collaborative and Informed passenger conditions, which drew the driver's attention to the outside environment, through the use of landmark information to indicate points where reorientation was required. In addition to this, landmark information was frequently utilised at points on route which were not essential to route navigation. Here, landmarks served as 'points of interest', encouraging driver interaction with the physical environment outside the vehicle. Comparatively, drivers in the Satnav condition looked toward roadside and forward landmarks infrequently. Leshed et al (2008) suggests that the tendency of drivers utilising a Satnav to disregard the wider environmental space can be attributed to the visual interface of the Satnav presenting drivers with an alternative, virtual representation of their environment. Interaction with a Satnav then "creates some blurring of the physical environment with the virtual environment, as the virtual environment becomes the primary environment with which the user engages and in response decontextualizes the physical space" (Leshed et al, 2008, p.1680).

This predilection for drivers, navigating with a Satnav, to inspect this virtual environment, over their immediate physical environment, represents a shift in human navigation behaviour, where an individual's inspection of the physical geography and characteristics of an environment influences how we choose to move through space and the subsequent development of our cognitive maps. Indeed, semantic gaze mapping revealed that drivers navigating with a Satnav, on approach to navigational junctions, predominantly focused their visual attention toward the device and the forward roadway. Indeed, on two junction approaches Satnav drivers spent significantly longer looking toward the roadway than Collaborative and Informed passenger participants. These visual behaviours may be attributed to a driver's cognitive capture as a result of being presented with visual navigation information in a predominately visual task environment such as driving. Cognitive capture is the phenomenon, discussed in relation to head up display use in previous literature, where drivers begin to focus on the forward visual field, relying on the information presented on the Satnav and spending less time monitoring the peripheral visual field or the internal vehicle cabin, as a result of the attentional switching costs of moving between tasks (Gish & Staplin, 1995).

In addition, environmental engagement measures indicate enhanced landmark recognition, route learning and survey knowledge associated with the more active navigational methods, in particular, within the Collaborative Passenger condition, compared to the Satnav. Navigational instructions provided by the satnav (representing the least 'active' method) commonly take the form of turn-by-turn prompts utilising distance-to-turn information, alongside directional (left, right, straight on) instructions. However, this information is issued unilaterally (from system to driver), thereby preventing interactivity and route collaboration. Moreover, the emphasis on distance descriptors diverges from how humans naturally convey spatial information to one another (Denis, Space and spatial cognition: A multidisciplinary perspective, 2017). As such, Satnav guidance can only support the construction of a fragmented cognitive map, even though there is scope for the driver to draw additional information

from the environment (such as relevant landmarks), independently from the system. Consequently, drivers using the satnav performed more poorly on environmental engagement measures.

In contrast, navigational guidance provided by the informed and collaborative passenger frequently contained landmarks in place of distance-to-turn information, with familiar driver-passenger couplings commonly drawing upon previous experiences to situate route guidance. This is likely to support the formation of more comprehensive route knowledge, which was clearly evident in the environmental engagement measures. In particular, the sketch maps associated with the more 'active' methods of navigation were typically far more comprehensive, displaying a larger number of integrated elements and populated with significantly more, accurately-placed landmarks.

Even so, it is interesting to note that drivers provided with the informed passenger questioned route guidance information less frequently than those in collaborative pairings. This is likely to reflect the level of confidence the driver placed in the navigator – the informed passenger was presented to drivers as an 'expert navigator' who had prior experience with the experimental routes. Thus, drivers may have placed more trust and confidence in the guidance issued to them, rendering navigational checks redundant. Alternatively, the pre-existing relationship between driver and passenger in the collaborative condition may have introduced more social dynamism into the car environment, effectively reducing the formality between driver and navigator. This may have increased the driver's willingness to engage with their passenger, for example, by commenting on environmental features and discussing, or questioning, the route guidance provided to them.

It was also particularly revealing that the sketch maps constructed following the collaborative driving experiences often included landmarks that were not specifically referred to within the navigational instructions, confirming enhanced environmental engagement associated with these approaches.

However, it is clearly unrealistic to expect all drivers to be accompanied by an obliging and knowledgeable passenger during all journeys, and therefore, a further aim of the research was to utilise data collected from the driver-passenger collaborations (specifically, the linguistic interactions), and use this to create a 'natural language' navigational aid that actively engages the driver in the navigation task, even in the absence of a passenger. This was subsequently evaluated over the same routes (detailed within chapter 9). Route guidance within this final on-road trial was informed using the interactions between drivers and passengers during the collaborative condition which resulted in the development of a context-aware, interactive navigational script that was subsequently delivered to drivers using a natural language interface (NLI).

The NLI issued information to drivers in a similar fashion to previous collaborative pairings. That is, by referencing roadside landmarks at navigational choice points (rather than traditional distance-to-turn information), and using these environmental features to draw attention to the external environment, thereby aiming to increase the driver's confidence in their path selection, whilst managing workload. This information was subsequently provided to the driver in a two-way dialogue (delivered using a Wizard-of-Oz approach), allowing the driver to clarify their understanding, or question guidance.

Chapter eight details the process of formulating a natural language navigational transcript from collaborative passenger guidance, with chapter nine detailing the methodology of an additional on-road trial in which drivers received navigational guidance from an NLI. Subsequent results are compared against the earlier Satnav condition and discussed in the context of current navigation technologies.

8

CHAPTER 8: ANALYSIS OF COLLABORATIVE TRANSCRIPTS AND FORMATION OF NATURAL LANGUAGE ROUTE GUIDANCE

This chapter will begin by looking at previous navigation literature for recommendations regarding the structure and content of 'good' route directions. Exploring how route instructions should best utilise descriptive components to encourage environmental engagement and promote successful navigation episodes, where there are fewer errors and an individual retains an awareness of the traversed routes and their wider surroundings. Using these recommendations as a framework, navigational instructions for each of the three experimental routes will be constructed. These navigation instructions will derive their descriptive content from the driver-passenger transcripts of a selection of the collaborative navigation pairings. Transcripts were selected for additional analysis based upon the driver's performance in post-trial environmental knowledge tests, those drivers shown to have superior landmark, route and survey knowledge had their navigational dialogue transcribed and the content analysed for its descriptive components. Using this content and the recommendations of previous literature, route guidance was constructed for use within a final on-road trial. Here, drivers were informed they were receiving navigational guidance from an

interactive natural language system, which issued speech-based navigational guidance.

8.1 ROUTES AND ROUTES DIRECTIONS

Route directions are a "specific type of spatial discourse" (Denis, 2017, p149), which aim to guide a person through an unfamiliar environment to reach a target destination. Such discourse is designed to convey information and, critically, elicit action within the individual who is receiving the navigational instructions. Upon subsequent completion of the individual's 'journey', memory of the traversed environment may remain. Though the literature has frequently suggested this is influenced by the information contained within spatial discourse (Denis, 2017).

Discourse intended to assist individuals with navigation belongs to a more general class of procedural discourse. That is, a discourse which delivers instructions to guide an individual along a specific course of action (Fontaine & Denis, 1999). Other examples of procedural discourse include assembly instructions and cooking recipes. All share the same trait of issuing a number of steps which individuals must follow in order to achieve a goal. Critically, the actions laid out in procedural descriptions follow a chronological directive. That is, in the example of route directions, instructions are consistently issued in the order in which they are expected to be experienced, from the departure point to a destination (Fontaine & Denis, 1999).

A number of authors have put forward recommendations regarding the structure and content of route directions with much of this work being centred around the incorporation of landmarks into route directions. Indeed Denis (1997) proposed that there are two components which are essential in route descriptions: Landmarks and actions. Landmarks are comprised, of predominantly three-dimensional physical structures. Such structures can be natural to the environment (church, bus stop, petrol station), or be designed to

signal directions (signposts, traffic lights), or distinguishable road features where reorientations take place (roundabout, T-Junction). Alternatively, actions are components which prescribe movement (straight on, turn left, go around, etc). It is the combination of these two discourse components which make route descriptions functional. That is, designated actions are to be performed at particular sites within the individual's environment, such sites are determined by identifying a landmark within that environmental space.

Denis (1997) suggests that route directions utilise each of these components in a particular, reoccurring order. This route structure, adapted from Denis (1997) is outlined in the steps listed below:

0. ***Locate and orientate the addressee at the starting point.*** The initial step is to identify to route start point to the addressee. This point should be defined verbally and unambiguously, with checks being performed to ensure that the addressee places themselves accurately at this location. The speaker must then position the addressee in the correct direction, this is typically done by referencing a landmark in the direction of intended travel or referring to an environmental point to walk away from.
1. ***Start progress.*** This is the first prescribed action. Though, this initial statement frequently refers to the direction of travel for the addressee to proceed (e.g. walk straight on). As the environmental scene around the addressee changes with their movement along the route, new landmarks appear in their visual field which may be used to define approaching navigational actions. The addressee's progress continues until such a landmark is reached
2. ***Announce landmark.*** As the addressee move through the environment and reaches a designated landmark. This point is either used as a conclusion to the subject's path of movement or as a reference point for reorienting the subject. Additionally, mention of the landmark at a junction can be used to provide the subject with a local view, providing them with a conformation that they are on the

right path ("when you reach the T junction, you will see a post office to your right and a park straight ahead")

3. ***Re-orientate addressee.*** Here, the subject is directed to change the angle of their path of progress. However, angular quantities are rarely referred to when directing subjects. Instead, left and right directional turn instructions are frequently issued alongside additional landmark information. Here, the landmark just encountered by the subject is mentioned alongside another landmark which features on the subjects' upcoming path of movement ("turn left at the pub and head straight toward the blocks of flats ahead").
4. ***Start further progress.*** Once the preceding manoeuvre has been completed the cyclical process of route instructions begins again for the next navigational manoeuvre (see step 1)
5. Announce further landmark etc. (see step 2)

Denis (1997) subsequently analysed a number of students' descriptions of familiar routes around their university campus, for their adherence to these proposed set of route instruction guidelines. Whilst there did appear to be some examples of this guideline sequence in participant route descriptions, there were no cases where the protocol was used in its 'purest' form. Participants tended to deviate from these guidelines in a number of ways including:

1. ***Use of landmarks to confirm progress along a route***: Participants frequently used landmarks to serve as 'progress checks' along lengthy stretches of pathway. Although, these landmarks were not required for reorientation they acted as 'markers' along a route, providing confirmation that the correct path was being followed.
2. ***Landmarks at critical sites***: Critical sites refer to points in the environment where reorientation is required. At these points Denis (1997) found participants' route descriptions incorporated a larger number of landmarks to ensure correct reorientation.

These findings are echoed in the later work of Burnett (2000) who emphasises that navigation information should support the driver throughout the course of the navigation task, providing supporting

environmental information in additional to the navigational prompts issued at navigational choice points (junctions). In this work Burnett (2000) suggested that navigation should be viewed as a continuous task where assistance is required across of number of different stages, for example, prior to commencing the journey, leading up to a manoeuvre, directly following the manoeuvre or across the whole timeframe of the task.

Burnett (2000)suggested that offering this temporal description of the navigation task, allows the goals of drivers to be assigned to each stage, which in turn can mean that appropriate guidance can be generated which considers the drivers aims and their information requirements. Figure 8-1 provides an illustration of each of the information types drivers may require over the course of the navigation task, a definition of each of each is then provided below:

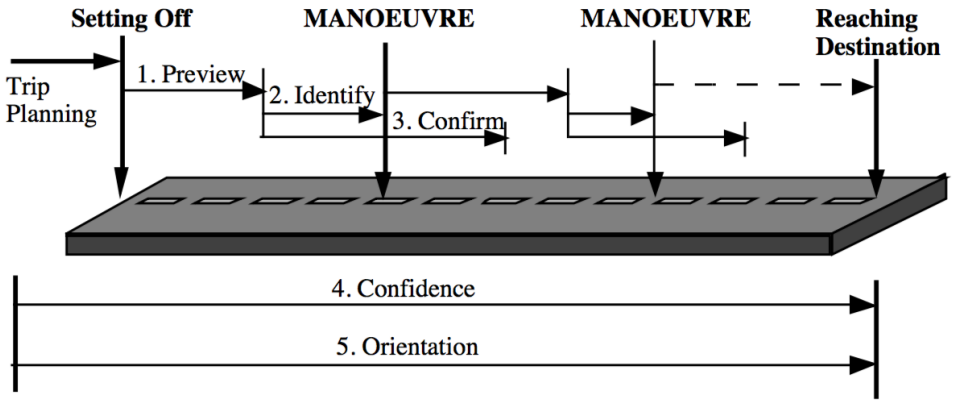


Figure 8-1: The stages of the driver's navigation task (taken from Burnett, 2000)

1. ***Preview:*** Allows the driver to gain a perception of the time or distance to the manoeuvre ahead. This guidance can give the driver a mental picture of the manoeuvre ahead, allowing drivers to gain preparatory knowledge of the required road position for that manoeuvre. Preview guidance should be issued following the completion of the previous manoeuvre up to the final approach of the next manoeuvre.
2. ***Identify:*** Allows drivers to pin point the location of the next manoeuvre within the road environment. This information can help the driver to exercise proper speed control on approach to the

junction and establish the correct on-road positioning to safely perform the manoeuvre. Identify guidance should be issued on the final approach to a manoeuvre.

3. ***Confirm:*** Issued to drivers as affirmation that the correct manoeuvre has been identified/made. This enables drivers to quickly establish whether they are on the correct route or whether a navigational error has been made. Confirm information should be issued to drivers on the final approach, or immediately following a manoeuvre.
4. ***Confidence:*** Issued to drivers to provide reassurance that the correct route is being followed or that the system is working correctly. Confidence information can be issued to drivers prior to them commencing the journey or throughout the course of a drive.
5. ***Orientation:*** Issued so that the driver is able to obtain an awareness of how their current location relates to their wider environment. Orientation information can be issued to drivers prior to commencing their journey and throughout the course of the drive.

The early linguistic work or Grice (1975), whilst not focussed specifically on navigation interactions can go some way to explaining why a number of the principles of 'good' route instructions, put forward by Denis (1997) and Burnett (2000) commonly feature in the navigation instructions which individuals would naturally construct. Grice (1975) suggested that, within a given community or culture, when we talk we operate according to a set of assumptions, these assumptions or 'conversational principles' ensure that the contributions which we make within our conversations are unambiguous, relevant, factual (to the best of our knowledge) and avoid any unnecessary prolixity. These principles can also be applied to the formation and delivery of navigational instructions. For example, individuals overwhelmingly construct a chronological narrative when formulating route directions, ensuring that navigational instructions are issued in the order in which the recipient can expect to experience them on route. Therefore, avoiding any unnecessary confusion and promoting ease of understanding.

Examining the Gricien (1975) conversational maxims can help to explain some of the other regularities which individual's commonly observe during conversational intercourse and why these may also be important to a successful driving navigation exchange:

The maxim of Quantity – The extent to which a contribution is informative, but not overloading.

The dual task nature of a driving navigation scenario means that the avoiding any unnecessary prolixity in verbal navigational instructions is essential in ensuring that drivers, who's primary task is the safe control of the vehicle, are not over loaded by any unnecessary information. Therefore, navigational instructions should be informative enough to allow drivers to confidently make an accurate navigational decision, without containing any redundant information.

The maxim of Quality – The extent to which a contribution is based on truth and how well this is backed by evidence.

The accuracy of information contained within navigational prompts is of particular importance in the driving navigation paradigm. Inaccurate or false information could result in the driver making illegal or risky manoeuvres, putting themselves and other road users at risk. So that drivers can confidently follow navigation instructions that adhere to the rules of the road it is of the utmost importance that drivers are provided with accurate navigation information, based on robust evidence.

The maxim of Relation – The extent to which a contribution is relevant to the task or activity at hand.

Navigational instructions or information which is relayed to the driver should always be relevant to their current driving environment and upcoming navigational manoeuvre, thereby avoiding any unnecessary confusion and reducing the likelihood of navigational error.

The maxim of Manner – Conversational contributions should avoid any obscurity of expression and ambiguity, ensuring inputs are orderly and brief.

Navigation information which is issued to the driver should be clear and unambiguous, allowing the driver to focus on accurate path selection and the safe control of the vehicle, rather than using any of their cognitive capacity to interpret vague statements or abstruse information.

The work of Denis (1997), Burnett (2000) and Grice (1975) was utilised in the analysis of collaborative passenger transcripts. Here, the top 4 rated transcripts (based on participants' environmental knowledge tests) were analysed and their content was used to form the basis of a natural language navigation transcript. Section 8.2 details the process of transcript analysis and natural language script formation.

8.2 ANALYSIS OF COLLABORATIVE TRANSCRIPTS & FORMATION OF NATURAL LANGUAGE ROUTE GUIDANCE

One of the purposes of the collaborative navigation condition within this thesis was to study the language that individuals naturally use when providing navigational assistance to someone with whom they have an established, personal relationship. By exploring the language utilised within navigational prompts and the varying information types used to describe required actions at navigational choice points, it was anticipated that these navigational transcripts could be used to build a descriptive, yet concise version of route descriptions. Such descriptions would contain all essential navigation prescriptions and landmarks useful to drivers when navigating routes, presenting a compromise between some participants' descriptions which were excessive in length or those that contained a dearth of information.

So that a natural language transcript could be generated for use within the final road trial of this thesis, the top four rated transcripts in the collaborative partnership condition were selected for further analysis. That is, the drivers who achieved the highest scores in post-trial, environmental engagement measures (landmark, route and survey knowledge tests) had their driver-passenger navigational dialogue transcribed and analysed. This process was completed for all three routes, on both participant drives, in weeks one and two.

Participants' rankings of acquired environmental knowledge were determined by the experimenter who considered the components of an individual's spatial knowledge holistically (landmark, route and survey knowledge), making a considered subjective assessment of the participants' acquired knowledge based on their performance in landmark and route knowledge tests, and the various components depicted within participant sketch maps.

Table 8-1 displays the order in which Collaborative participants were ranked based upon their overall performance in the battery of environmental engagement measures. The highlighted rows represent the four highest rated participants. The navigational transcripts of these participants and their collaborative passenger were subsequently transcribed and analysed to inform a natural language navigational transcript.

Collaborative condition: Environmental engagement measures								
Participant	Landmark knowledge	Route Error Score	No Landmarks	Landmark Orientation	No Pathways	Points of intersect	No Road names	Map Type
P7	1	0	16	0.81	6	2	3	Branch and Loop
P3	1	0.02	9	0.89	6	2	0	Netted
P14	0.83	0.08	11	0.82	6	3	3	Netted
P12	0.83	0	11	0.00	3	1	0	Chain
P2	0.83	0.07	11	0.91	6	3	0	Netted
P8	0.83	0.16	15	0.00	5	0	1	Branch and Loop
P6	1	0.21	8	0.63	4	2	2	Branch and Loop
P11	1	0.23	7	0.71	5	3	0	Netted
P13	0.83	0.22	7	0.29	2	0	0	Fragmented
P1	0.83	0.38	11	0.64	5	2	1	Branch and Loop
P5	0.83	0.36	11	0.00	1	1	0	Fragmented
P15	1	0.18	5	0	2.00	1.00	0	Chain
P4	0.33	0.28	6	0.00	2	0	0	Fragmented
P9	0.83	0.33	8	0.63	4	1	1	Chain
P10	0.83	0.5	4	0.75	1	1	0	Fragmented

Table 8-1 Collaborative driver environmental engagement scores

This portion of participant transcripts were selected for further examination as the literature has previously pointed to a link between an individuals acquired environmental knowledge and the associated route guidance they are issued (Denis, 2017). On this basis, it was felt that examination of this sub-section of transcripts, where drivers had acquired a superior level of route knowledge, would provide an insight into the descriptive content of successful route descriptions. Such descriptions would subsequently be used to generate an effective navigation dialogue for use within a natural language system. Here, the system would aim to enhance a driver's environmental engagement through its use of environmental references within navigational prompts.

The four navigational transcripts of driver-passenger collaborations were firstly separated according to junction specific guidance for each of the twenty-three junctions which had featured on the three experimental routes. All guidance which collaborative passengers had issued in relation to each junction was listed according to participant, under an image of the associated junction (see figure 8-3). Junction specific guidance was then created by an experimenter led panel of three human factors experts, who utilised the descriptive content (landmarks and environmental references) within collaborative transcripts and worked to a set of guidelines, based on the recommendations and assumptions of Denis (1997), Burnett (2000) and Grice (1975) to formulate route guidance for each of the experimental routes. These guidelines, designated the arrangement of route guidance information and informed the construction of a set of navigational prompts which followed a clear, consistent, fact-checked, informative structure. The process of formulating route guidance information is summarised within figure 8-2.

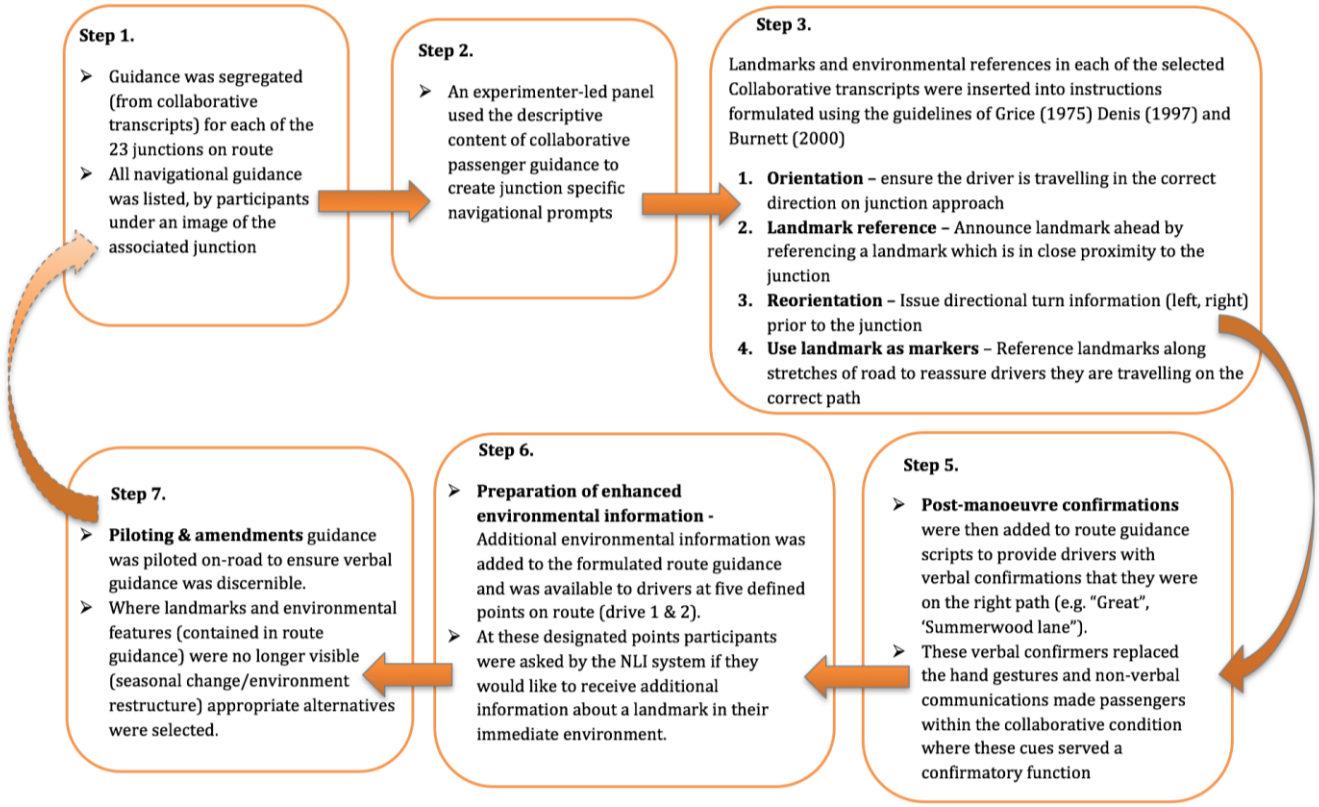


Figure 8-2 Summary of the process utilised to generate an NLI navigation script

8.3 FORMULATING A NAVIGATIONAL SCRIPT

The experimenter-led panel used the information contained within the collaborative navigational guidance to identify a schematic outline followed by all participants and identify a subset of landmarks and prescriptions to formulate a "core" set of concise route instructions which adhered to the Gricean (1975) conversational maxims (discussed in section 8-1). This meant that, where possible, any formulated route instructions should be concise, yet informative (quantity), unambiguous and clear (manner), relevant to driver's immediate environment or upcoming manoeuvre (relation), and supported by adequate evidence (quality).

In addition to adhering to these conversational maxims (Grice, 1975), the experimenter-led panel were also advised that route instructions should follow the same structure for each navigational junction on route. This structure was informed by the previous work of Denis (1997), Burnett (2000), and is summarised below:

1. **Orientation**: ensure that the driver is travelling in the correct direction to approach the junction ahead, issue directional or specific lane information (e.g. carry straight on) to allow the driver to progress accurately onto the next junction.
2. **Landmark reference**: announce junction ahead by referencing a corresponding landmark in close proximity to the junction (the landmark used should assist the driver in identifying the appropriate turn).
3. **Reorientation at junction**: Issue directional turn information prior to the junction to allow driver to re-orientate accurately (e.g. left, right, third exit).
4. **Use of landmarks as markers**: additionally, on long stretches on road where reorientation isn't required consider the use landmarks to confirm the drivers' progress along the correct route.

Using the collaborative guidance as a basis, a set of navigation instructions were created for each of the twenty-three junctions on

route. Once this process had been completed some additional information was added to the route guidance:

i. **Post-manoeuvre confirmation**: confirm information was added to the newly formed navigational information. This was done to provide drivers with reassurance that they were on the correct route.

   The later addition of confirm information was necessary as route instructions had been derived from the content collaborative transcripts where passengers frequently utilised non-verbal forms of confirmation to signify that the driver was on the correct route or had selected the correct turn (for example, gestures). As the final road trial would issue verbal-only guidance to the driver an additional verbal confirmation was required in place of a head nod or a hand gesture given by a passenger. In addition to receiving confirm information, participants were also given the option to receive enhanced environmental information at five separate points on route:

ii. **Enhanced environmental information**: the option of receiving additional environmental information was given to drivers at five defined points on route. At these points, on drives one and two, a landmark on route was highlighted. Here, the driver would be asked if they would like to receive additional information about this landmark.

   Figure 8-3 illustrates how this process transformed Collaborative participant navigational dialogue and informed navigation script design for one of the navigation junctions on route:



Collaborative navigation transcripts:

P3: Keep in this lane, we're going to take a right (Gestures) at the next roundabout. Yeah in this lane. Oh sorry (Gestures) left in this left roundabout.

P7: We're going to stay on this road until the next roundabout where we'll take the first onto green lane, just before the Esso garage.

P12: So we're going to carry on this road until we get to the Esso petrol station and then just before the Esso we're going to turn left onto Green lane, but i will tell you that when we get nearer. Ok so we're going to turn left shortly onto Green Lane, it's not this one but (Gestures) the next one.

P14: Stay in this lane because we go left at the roundabout ahead and we don't want to go dead fast anyway. I think its 40 anyway here. So that's Trent campus (Gestures) you know from Nottingham Trent uni. So we're going down to the roundabout ahead where we're going to take the first left. Onto Green lane. After the traffic lights (Gestures) before the Esso though

Formulated script for same manoeuvre:

- Clifton Road
- The road has a 40mph speed limit in place
- At the roundabout ahead, you'll be taking the first left onto Green lane
- On your right-hand side is Nottingham Trent university, Clifton campus
- Would you like some additional information about Clifton campus?
- The turn is located after the traffic lights, before the petrol station

Figure 8-3: shows the process of navigational script generation for one of the junctions on route (junction displayed in above image)

The formulated navigational script detailed in figure 8-3 was developed following the route guidance structure, described in section 8.3. The structure and information contained within these prepared route instructions and the extent to which this guidance adheres to the Gricien (1975) conversational maxims (detailed in section 8.1) is discussed below:

1. *Clifton Road*

   On completion of the previous manoeuvre and upon turning onto a new roadway, the name of the new roadway was announced with a post-manoeuvre conformation. Post-manoeuvre conformations were commonly concise (quantity), unambiguous (manner) statements which consisted of issuing accurate roadway information (quality) to the driver. Such statements were intended to provide the driver with confidence that they had made an accurate roadway selection and they remained on the correct route.

2. *The road has a 40mph speed limit in place*

   Providing the participant which fact checked information (quality) about the roads which they are travelling on encourages them to maintain a legal speed profile on route.

3. *At the roundabout ahead, you'll be taking the first left onto Green lane*

   Here, the roundabout ahead acts as a landmark reference for the participant, providing them with a visible point ahead where reorientation is required. Following this landmark reference information reorientation information is issued which will allow the driver to reorient accurately. This information was issued to drivers at point on route where the roundabout ahead was visible, but some distance away. Therefore, this navigational prompts was relevant to their current driving scene and their next required action (relation). Additionally, whilst this prompt omits a number of words e.g. "At the roundabout (on the road) ahead, you'll be taking the first left (turn) onto green lane" the required action remains clear and unambiguous (manner) to individuals familiar with a driving

navigation scenario. Omitting this additional information ensures that this navigational prompt contains no more or less information than is required (quantity).

4. On your right-hand side is Nottingham Trent university, Clifton campus

Here, the driver was issued landmark information which acted as a marker on route, whilst this landmark information was not essential for accurate navigation it was anticipated that providing this information on a long stretch of road where reorientation wasn't required would confirm participant's accurate progress along the route. This system output was designed to be clear, concise (quantity), unambiguous (manner) and related to the participants' current driving scene (relation), additionally accurate labelling information (building name/ function) was provided for all referenced landmarks on route, ensuring only accurate environmental information was relayed to the driver (quality).

5. Would you like some additional information about Clifton campus?

This was one of five instances on route where the natural language system asked the participant if they wished to receive enhanced environmental information about a landmark which they had passed on route. Each of five highlighted landmarks were not essential for route navigation but offered the participant additional information about the area through which they were travelling, which was hoped would enhance cognitive map formation. Whilst this additional information may flout the Gricien (1975) maxim of quantity by issuing non-essential navigation information to the driver, the landmarks which the system referred to at each of these points were supported by the maxim of relation as the information which was issued was relevant to the participants' immediate driving environment.

6. The turn is located after the traffic lights, before the petrol station

On the final junction approach an additional landmark reference was issued to the participant to aid accurate roadway selection. This landmarks reference was intended to be as informative as possible without containing any gratuitous information (quantity), such landmarks

references only referenced environmental features which appeared in the drivers' field of view and could assist in the accurate selection of roadway and completion of navigational manoeuvre (relation).

8.4 PILOTING ROUTE GUIDANCE AND TRANSCRIPT AMENDMENTS

To ensure that the formulated route guidance was appropriate for use in the intended experimental setting it was then piloted on-road with verbal route guidance issued to the driver via a Bluetooth-enabled phone call. Following the piloting or route guidance some minor changes were then made to the landmarks which featured in navigational instructions. This variance in landmarks was due to each of the road trials being conducted around six months apart. Therefore, a number of the landmarks highlighted by collaborative passengers within their route guidance, six months prior, either no longer existed in that form (e.g. roadworks) or were no longer visible due to seasonal change and subsequent foliage growth.

Those landmarks which were no longer visible or in place along the experimental route were removed and alternative, salient landmarks which reflected the current environmental scene were used in their place. In order to select an appropriate alternative landmark, the experimenter drove each of the experimental routes and asked two passengers to select an appropriate landmark in close proximity to the required navigational junctions. So that appropriate landmarks were selected, the passengers were asked to base their landmark sections on a number of key features, adapted from the earlier work of Burnett, Smith and May (2001).

1. **Visibility**: a good landmark should be visible to drivers from a distance.
2. **Proximity to junction**: when referencing a landmark to highlight the location of a navigational choice point, landmarks should ideally be situated close to the road and the associated junction.
3. **Permanence**: All landmarks referenced should be relatively permanent

4. **Uniqueness**: Use of distinctive structures within directions allows individuals to quickly discern the landmark from the wider environment.
5. **Brevity**: The description of the landmark should be concise. Environmental features should require a minimal number of words to be discerned

Piloting also highlighted a number of navigational phrases within route instructions which drivers found to be problematic. The sentence structure and phrasing of a number of navigational prompts were not easily discernable when drivers relied solely on verbal prompts to guide them through routes. Interestingly, these same misinterpretations were not observed in the collaborative condition, where the structure and content navigational prompts were remarkably similar to those piloted, the differences in the interpretations in the two conditions may be attributed to the absence of a passenger and their associated non-verbal cues.

When driver and passenger occupy the same physical space and collaborate on a navigation task, the passenger is able to quickly discern (via non-verbal body language cues and facial expressions) when the driver may be confused or have misunderstood a statement. In such instances passengers frequently use secondary physical hand or head-nod gestures to offer additional clarity to navigational statements (to pinpoint turnings etc). Without these non-verbal exchanges, navigational prompts needed to be concise, clear and quickly understood. To address this, minor adjustments were made to the language and sentence structure of verbal prompts to increase the likelihood that route guidance would be quickly and accurately interpreted. An example of this process can be found in figure 8-4 below:



Collaborative passenger guidance: Route 2 – Junction 3

- **P3**: At these traffic lights turning right (Gestures)
- **P7**: So, we're going to continue along this road, through two sets of traffic lights, we're going to go past Iceland and then we'll be taking a right turning on Southchurch drive (Gestures), Clifton leisure centre will be on the right if you need a visual marker
- **P12**: then we're going to keep going on this road until we get to some traffic lights where we're going to turn right. So, at these traffic lights we're turning right (Gestures) onto Southchurch drive
- **P14**: So, at these traffic lights we're going to make a right turn, so go across with Iceland opposite, take a right turn (Gestures) Onto Southchurch drive

Initial NLI verbal guidance: Route 2 – Junction 3:

- Continue straight along this road
- Through two sets of traffic lights
- At second set of traffic lights we'll be turning right onto Southchurch drive
- At traffic lights with Iceland opposite, turn right onto South church drive

Amended NLI verbal guidance: Route 2 – Junction 3:

- Continue along this road to a set of traffic lights
- At the traffic lights turn right onto Southchurch drive
- At the traffic lights, Iceland shop opposite. *Can you see this?*
- Turn right onto Southchurch drive

Figure 8-4: Example of route guidance amendments for NAV system

This finalised route guidance was then utilised in a final on-road trial where navigational information was issued to the driver via a natural language navigation system. The natural language navigation system (shortened to 'NAV' during the study), was conceptualised as a high-functioning, socially enabled artificial intelligence. It was described to participants as a "fully operational, prototype natural language system", but for the purpose of the study was created using Wizard-of-Oz approach (detailed in section 9.1.4).

9

CHAPTER 9: NAV: NATURAL LANGUAGE NAVIGATION ASSISTANT

This chapter details a final on-road trial where participants navigated with the assistance of a natural language navigation system. The natural language system, administered using a wizard-of-Oz technique, guided participants through the same three routes traversed by Satnav, Informed passenger and Collaborative participants. Akin to previous road trials conducted as part of this thesis, routes were travelled by participants twice, one week apart to replicate weekly travel to a meeting and to allow for direct comparison between previous navigational conditions studied within this thesis.

The navigational guidance issued by the natural language navigation system was constructed from a selection of Collaborative passenger and driver transcripts. Transcripts, selected on the basis of driver environmental engagement scores, were analysed according to the landmark information they contained and for the structure of route information on approach to a navigational decision point. Natural language route guidance instructions were then formulated on the basis of this information within transcripts and according to recommendations made in the literature (detailed in chapter eight, section 8.1).

This formulated guidance was then piloted at the time of the final road trial to ensure landmark information contained within navigational prompts was current and to ensure that drivers, receiving verbal navigational guidance over a telephone link could hear the

navigational prompts clearly and discern descriptive information easily.

9.1 METHOD

This final study followed on from the previous on-road trials which investigated how different navigational methods influence environmental engagement and workload. Navigational methods previously studied included:

1. SatNav drivers navigated along a series of predefined intersecting routes within the Clifton area of Nottingham, UK, with the help of a satellite navigation device (conducted February-March, 2016).
2. Informed passenger drivers navigated along these same intersecting routes instead following the fixed navigational guidance of the navigator. The same navigator issued navigational guidance to all drivers, following a semi-structured script. The navigator was able to issue additional guidance or offer clarification if prompted by the driver (conducted February-March, 2016).
3. Collaborative drivers navigated the same three routes as previous trials, this time following the navigational guidance of someone with whom they had an established personal relationship with. Collaborative navigators were trained in the routes prior to the study so that they could give accurate and detailed navigational prompts (conducted September-October, 2016).

However, participants in the final study, conducted between August and September in 2017, followed the navigational guidance of what they were informed was a '*prototype natural-language navigation interface*'. This was created by using a Wizard-of-Oz approach in which an actor mimicked a high-functioning, interactive natural language navigation system. Here the actor issued navigational prompts to drivers over a Bluetooth enabled hands-free phone call. To ensure that navigational prompts were issued accurately, at the correct location WiFi enabled dash cams provided the actor with a live video stream of the road.

9.1.1 Participants

The participants used within the study were employees and students at the University of Nottingham and held a university driver's permit which meant they were insured to drive the university owned test vehicle. All drivers participated in the study on a voluntary basis by answering a blanket email which was sent out. This was typical of other driving studies previously carried out at the university. Participants were reimbursed £30 in amazon vouchers for their participation, which was presented to participants on completion of their second, final drive. The 'NAV' condition comprised a total of 16 participants (11 male, 5 female), with an average age of 29 years (SD = 8.6). These participants, had an average of 8.6 years driving experience and identified smart phone maps as their preferred navigation tool (e.g. Google maps) closely followed by dedicated route planner applications (i.e. AA route planner), with 13 out of 15 participants professing to 'always' use such navigational aids when travelling in unknown areas.

Ethical permission to conduct this study was granted by the University of Nottingham, School of Engineering ethics committee on the 28th of July, 2017. Full details of ethics application and approval can be found in Appendix A.

9.1.2 Apparatus and Materials

As with previous on-road trials within this thesis an instrumented Ford focus, owned and insured by the University of Nottingham was used as the road vehicle for the study. This vehicle was fitted with a number of cameras for the purpose of this trial, the first of which was a WiFi enabled dash cam which provided live stream video footage to the actor who was located in a disparate location. The dash cam provided the actor with a real-time road view ensuring that navigational prompts could be issued to drivers accurately and in a timely manner.

The live dash cam stream was supported by an EE in-car Wi-Fi hub, this provided a WiFi signal using mobile cellular data. To ensure adequate 4G coverage, capable of enabling a live video stream from the

dash cam, the network coverage of a number of network providers was assessed. As EE™ had desirable network coverage in the on-road test area of Clifton, Nottingham, this provider was selected as the supplier of the WiFi in-car hub.

To record the driver/ system interaction a second set of cameras were in place; cameras faced into the driving cab which captured the verbal interaction between the system and driver and any novel gestures and facial expressions that were made by the driver throughout the driving task. As with previous iterations of the study within this thesis, participants wore a Tactile Detection Device (TDT) to provide an objective measure of their workload (for a complete overview of this device see section 3.3.3), and eye tracking glasses so that the visual search patterns of drivers could be analysed and compared across navigational conditions (for a full overview of eye tracking methodology see section 3.3.2 and for its particular application within this thesis see sections 5.4 & 9.2.6).



Figure 9-1: - In-car setup showing the driving facing camera, dash cam, supporting Wi-Fi hub and in-car Bluetooth phone connection for the NAV on road trial

9.1.3 Design of Experiment

The Independent Variable (IV) in this study comprises the natural language navigational aid which assisted drivers in navigating the route. The results from this study are compared the SatNav condition discussed earlier in this condition (within chapters 4 -7), this comparison allows this novel wayfinding approach to be compared against current commercially available navigation systems.

In this final study drivers received navigational guidance from what they believed was a prototype natural language navigation system. Participants were informed that the system, dubbed 'NAV' would provide them with spoken navigational assistance throughout their journey. Participants were assured that NAV was able to understand

natural language. Therefore, they were instructed to question NAV if they were unsure of route directions or indeed if they had any questions about the environment which they were travelling through. NAV was created using a Wizard-of-Oz approach in which an actor mimicked a high-functioning, interactive natural language system. The actor who was previously trained in the experimental routes, issued navigational guidance to participants from a separate location, at predetermined points along the route. The actor was alerted to these points via live stream dash-cam footage which he was able to access via a dedicated system application called Blackvue™ (links to the full navigational transcripts which the actor used to issue navigational prompts to the driver can be found in appendix C).

The Dependent Variables within this study were driver performance, that is, the number of navigational errors made by drivers whilst on route. The level and veracity of environmental knowledge acquired by drivers (landmark, route, and survey). Driver workload was assessed objectively using a Tactile detection device and subjectively using a NASA-TLX questionnaire. Eye tracking glasses also examined driver visual search at a number of junctions on route. Examining these visual search patterns at junctions where there is the potential for navigational uncertainty can provide an indication as to whether navigational method influences visual search strategy. Driver-system interaction was also examined by exploring common themes across participants and the depth and frequency of driver-initiated interactions.

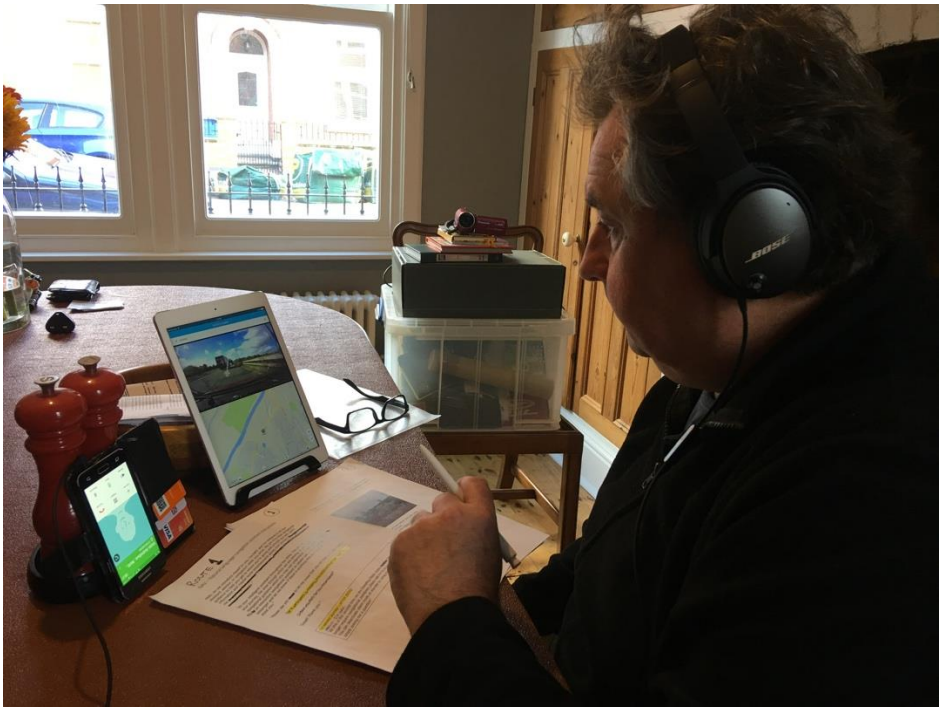


Figure 9-2 Experimental set up illustrating the 'Wizard' acting as the NAV NLI system. Here, the actor observes a real time road view of the driver, issuing guidance at designated points via a phone link

9.1.4 Procedure

The study utilised the same experimental procedure as the other on-road trials described within this thesis (see section 4.5 for extended methodology). However navigational guidance during this study was administered by an actor using a Wizard-of-Oz approach.

As with the previous on-road trials the study commenced with a briefing session where participants were apprised of the study using a participant information sheet. Upon giving their informed consent to take part in the study participants underwent a familiarisation drive where they were directed by the experimenter from the university campus to Fabis drive in Clifton which was the start point of route one. This familiarisation period ensured that participants could become familiar with vehicle controls prior to starting the road trial. During the road trial, each participant drove three routes, which intersected along three separate points. All routes incorporated a variety of different road and junction types and each took participants around

ten minutes to complete in clear traffic (see section 4.6 for detailed route overview).

Participants were guided through routes following the navigational guidance of what they were told was a prototype natural language navigation system called 'NAV'. However, in reality this 'prototype' system was created using a Wizard-of-Oz approach in which an actor issued navigational guidance over a Bluetooth-enabled hands-free phone connection within the vehicle. With the timing of the navigational prompts being informed by a live-video stream from an in-car dash-cam. To ensure that participants believed that the navigational guidance they were receiving was from a system rather than a human, the actor used a prosodic syntax akin to other commercially available voice recognition systems, in that short pauses were incorporated into instructions which wouldn't be associated with human-to-human dialogue. Prior to commencing route one, participants were introduced to NAV and were briefed on its features and capabilities. This was done to promote system engagement and encourage participants to direct questions toward the system instead of looking to the experimenter (who was in the car with them) for a response. In the system introduction NAV presents itself as a travel companion, able to offer navigational guidance and entertainment during journeys. The full introduction can be found below:

Hello, let me introduce myself to you, I'm NAV and I'm designed to be your assistant, advisor or companion whilst you drive. My job is to issue navigational guidance to help you get to where you're going and provide you with useful information and maybe some entertainment along your journey. As your intelligent assistant throughout the drive you can ask me questions about your journey, the area through which we are driving, or ask me to repeat any navigational guidance which you may not understand. I have been programmed as an interactive navigational assistant so please talk to me as you would as passenger and let me know if there is anything else you would like me to add to assist you. Please say yes to let me know that you can hear and understand me.

Once participants had issued verbal confirmation that they were able to hear and understand NAV. They were then guided though each of the three routes in turn, using landmark based navigational guidance, derived from the collaborative participant transcripts (as detailed in chapter 8). Here, rather than use distance to turn information like traditional navigation devices, participants were issued with landmark information to identify and pinpoint turnings.

Upon completion of the first route NAV would announce the route end. The experimenter would then request that NAV move into 'silent mode'. The experimenter would then direct participants to the start of the next route. Once the participant has reached the start points of routes 2 & 3 the experimenter then asked NAV to move out of 'silent mode', this action then saw NAV immediately begin to introduce upcoming route. Here, NAV gave participants the name of the road names of the route start and end points along with an estimation of the time 'in current traffic' that the route would take to complete.

Throughout all drives, the experimenter sat in the passenger seat of the vehicle, observing participant/system interactions. Throughout the study the experimenter did not assist the driver in the navigation task and only intervened if the driver made a navigational error. Here, the experimenter directed the driver back onto the correct route and subsequently asked NAV to resume issuing navigational information to the driver.

As with each of the road trials within this thesis participants travelled routes twice, one week apart to attempt to replicate weekly travel to a meeting or appointment. After the second, final drive drivers were asked to complete landmark and route recognition exercises which consisted of identifying and ordering a series of images experienced on route (see section 4.5.2 for extended -methodology). Additionally, drivers were asked to draw a sketch map of the routes travelled, incorporating as many environmental features as they could remember, including landmarks, road names, road geometry, junctions and any instances of route overlap which they could recall.

After completing each of the route learning tasks participants were debriefed, here they were informed that the prototype natural language interface which they had interacted with was actually an actor who issued navigational guidance with the assistance of a live video feed. It was explained that this information was withheld from them as having knowledge of the experimental setup may have influenced how they would have naturally interacted with the system.

9.2 RESULTS - NAV VS SATNAV

This section will compare the navigational performance, workload and visual search (on junction approaches) of participants in the NAV and SatNav experimental conditions. Navigational performance will be indicated by the total number of route errors made by participants across drives one and two. Objective and subjective measurements of participants' workload were taken using a tactile detection device and NASA-TLX questionnaires respectively. Finally, participants' visual search strategies on the approach to a navigational junction were analysed and compared across experimental conditions

9.2.3 Navigational performance

The total number of navigational errors made by participants across experimental drives one and two were recorded and compared across navigational conditions. Normality tests revealed navigational error data followed a non-normal distribution, therefore non-parametric tests were performed.

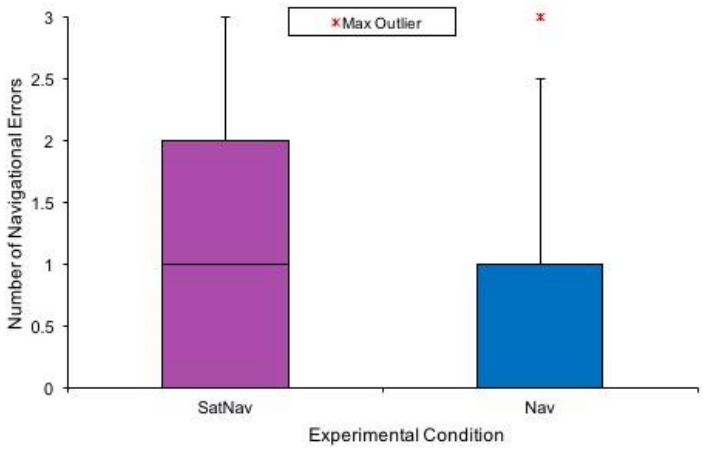


Figure 9-3: Average number of navigational errors (wrongs turnings) made by SatNav and NAV participants on experimental drives one and two.

A Mann-Whitney U test was run to determine if there were differences in the number of navigational errors made on-route by SatNav and NAV participants. Distributions of the engagement scores for males and females were similar, as assessed by visual inspection. Median number of route errors score was not statistically significantly different between SatNav and NAV participants, U = 94.5, z = -.791, p = .429, using an exact sampling distribution for U (Dineen & Blakesley, 1973).

9.2.4 NASA TLX measures

NASA TLX questionnaires were administered after participants had completed their first and second drives, this provided a subjective measure of driver workload (average cumulative scores presented in figure 9-4 below). Normality tests revealed normally distributed data.

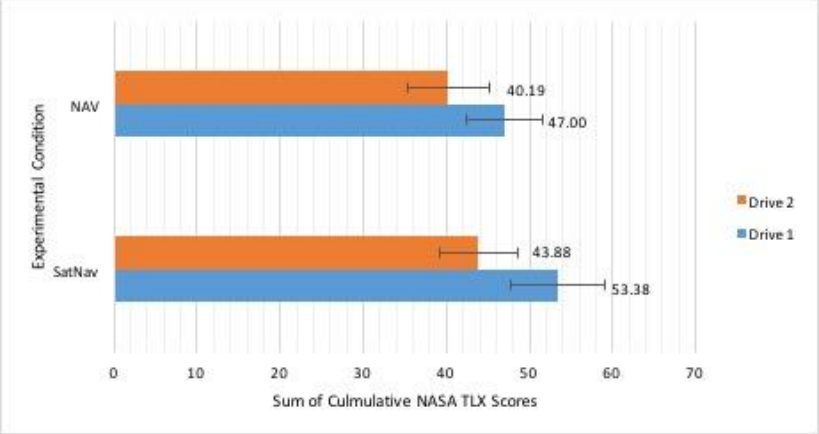


Figure 9-4 Cumulative NASA TLX scores illustrating the perceived workload scores of SatNav and NAV participants after Drive 1 and Drive 2.

- An independent samples t-test confirmed that there were no significant differences in the NASA-TLX ratings of SatNav (M = 56.93, SD = 18.95) and NAV (M = 47.00, SD = 18.67) participants on drive one (p = .152).
- Similarly, an independent samples t-test also confirmed that there were no significant differences in subjective NASA-TLX rating of Satnav (M = 46.80, SD = 16.47) and NAV (M = 40.19, SD = 20.42) participants on drive two (p = .331).
- A paired samples t-test was then run to determine whether there was a statistically significant mean difference between the perceived

workload NASA-TLX rating of Satnav participants, on drive one compared to drive two. The assumption of normality was not violated, as assessed by Shapiro-Wilk's test (.506). Participants in the Satnav condition perceived their workload to be higher on their first experimental drive (M = 56.93, SD = 18.95), compared to their final, second drive (M = 46.80, SD = 16.47). A statistically significant difference of 10.13 in NASA-TLX cumulative ratings, 95% CI [3.38, 16.88), t (14) = 3.22, p<.05, d = 0.83.

- A paired samples t-test was also conducted to determine whether there was a statistically significant mean difference between the perceived workload NASA-TLX rating of NAV participants, on drive one compared to drive two. The assumption of normality was not violated, as assessed by Shapiro-Wilk's test (.883). Participants in the NAV condition perceived their workload to be higher on their first experimental drive (M = 47.00, SD = 18.67), compared to their final, second drive (M = 40.19, SD = 20.42). Though, the mean difference of 6.81 in NASA-TLX cumulative ratings was not found to be statistically significant, 95% CI [-.476, 14.10), t (15) = 1.99 , p = .065, d = 0.49.

9.2.5 TDT measures

Throughout the drives participants were required to respond to the impulses issued by the TDT device. The percentage of missed impulses and reaction time in response to impulses provided an objective measure of driver workload. Normality tests revealed normally distributed data.

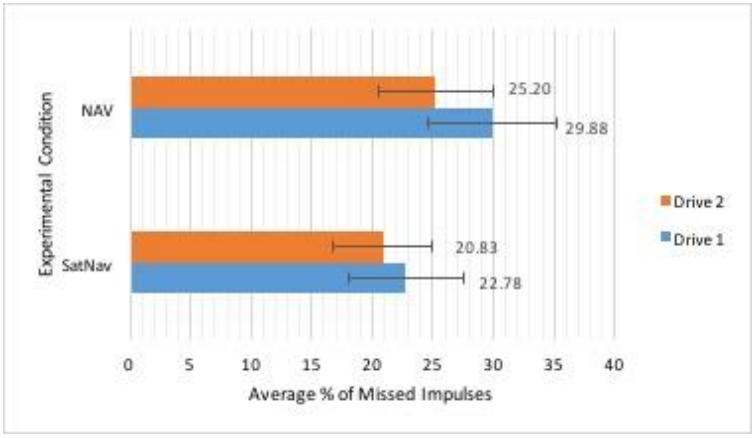


Figure 9-5: Average percentage of TDT impulses missed by SatNav and NAV participants. Illustrating the average number (expressed as a percentage) of TDT impulses which participants failed to respond to on-drive.

- An independent samples t-test confirmed that there were no significant differences in the number of TDT impulses missed by SatNav (M = 22.78, SD = 18.59) and NAV (M = 29.88, SD = 20.16) participants on experimental drive one (p = .920).
- Similarly, an independent samples t-test also confirmed that there were no significant differences in the number of TDT impulses missed by SatNav (M = 20.83, SD = 16.13) and NAV (M = 25.20, SD = 17.79) participants on experimental drive two (p = .616).
- A paired samples t-test confirmed that there were no significant differences in the number of TDT impulses missed by SatNav participants from drive one (M = 22.78, SD = 18.59) to drive two (M = 20.83, SD = 16.13) (p = .463).
- Similarly, a paired samples t-test confirmed that there were no significant differences in the number of impulses missed by NAV participants from drive one (M = 29.88, SD = 20.16) to drive two (M = 25.20, SD = 17.79) (p = .143).

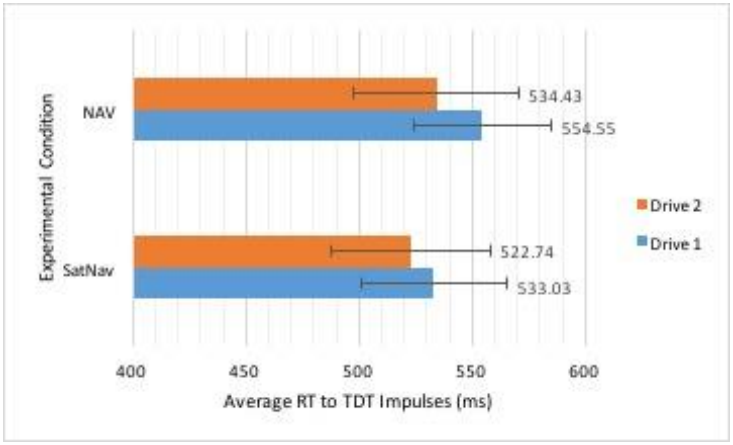


Figure 9-6: Average reaction time data of SatNav and NAV participants. Illustrating the average amount of time (reported in milliseconds) participants took to respond to the onset of a TDT impulse

- An independent samples t-test confirmed that there were no significant differences in the reaction time of SatNav (M = 533.03, SD = SD = 125.20) and NAV (M = 554.56, SD = 114.16) participants toward the onset of TDT impulses on experimental drive one (p = .599).
- Similarly, an independent samples t-test also confirmed that there were no significant differences in the reaction time of SatNav (M = 522.74, SD = 136.44) and NAV (M = 534.44, SD = 137.60) participants

and NAV participants towards the onset of TDT impulses on experimental drive two (p = .996).

- A paired samples t-test confirmed that there were no significant differences in the reaction time of SatNav participants from drive one (M = 533.03, SD = 125.20) to drive two (M = 522.74, SD = 136.44) (p = .651).
- Similarly, a paired samples t-test confirmed that there were no significant differences in the reaction time of NAV participants from drive one (M = 554.56, SD = 114.16) to drive two (M = 534.44, SD = 137.60) (p = .474).

9.2.6 Eye tracking measures

Throughout all drives participants wore a pair of SensoMotoric Instruments (SMI) eye tracking glasses which collected binocular gaze data at 30 frames per second (FPS). This data was then used to assess participants' visual behaviours on approach to navigational junctions. The visual behaviours of participants were examined at the same five junctions which were selected for further analysis in earlier iterations of the road trial these junctions were representative of the routes as whole and included side turns (turning left or right off a straight path road), roundabouts and a T-Junction. All fixations were coded from the geographical point of the first navigational prompt issued by the SatNav, to ensure a fair comparison across conditions. Eye tracking coding was performed in BeGaze 3.6 and involved identifying participants' fixations within each junction's schematic representation (as shown in figure 9-7). Participants' total dwell times and mean fixation times within the specific areas of interest were then compared across experimental conditions.

Areas of interest for the Satnav and NAV conditions were examined in the same way as within the Satnav, Informed Passenger and Collaborative passenger conditions, detailed in section 5.4. Table 5-3 on Page 138 lists the different landmarks which were situated to the left, right and ahead of the participant at each of the examined navigational junctions. Using the approach detailed within section 5.4,

these landmarks were grouped and labelled as left, right or forward landmark AOIs, according to their position on road.

9.2.6.1 Route 1 – Junction 4

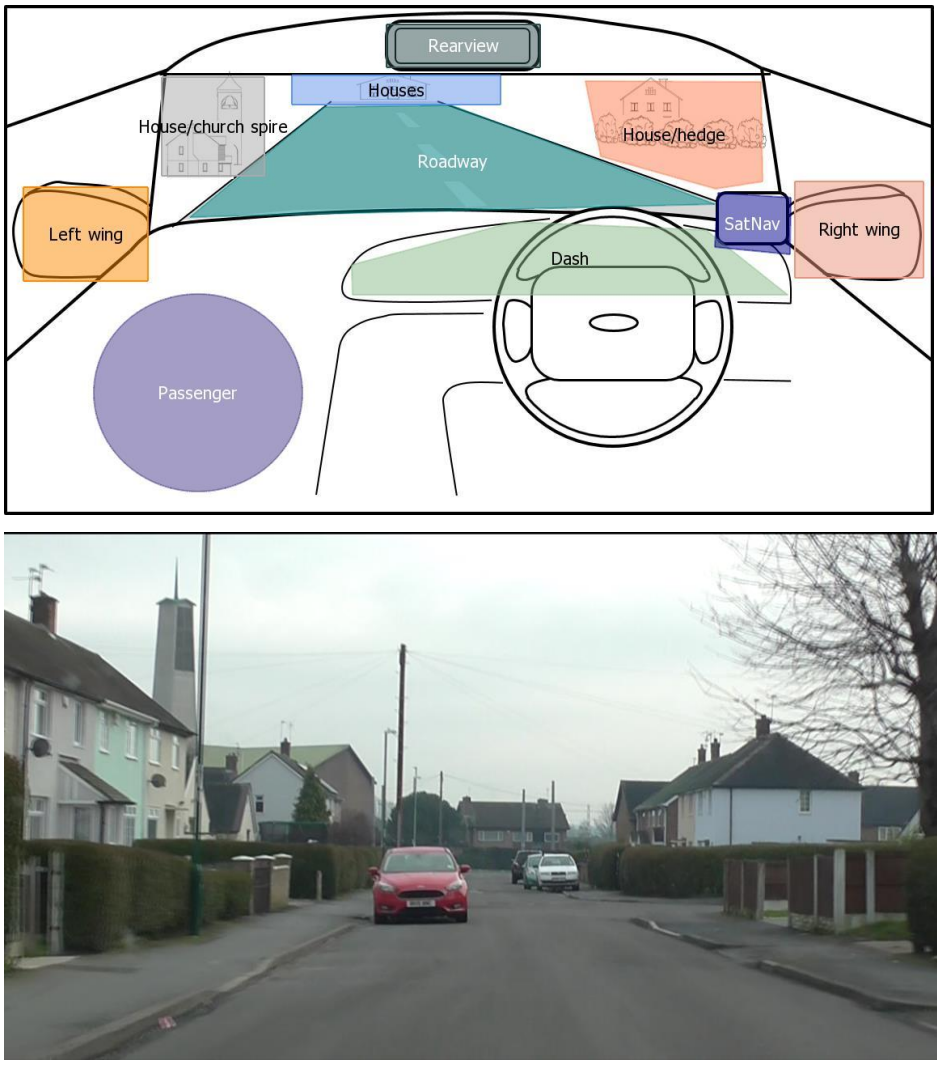


Figure 9-7: Representative image of on-route junction, displaying pre-defined AOIs. On-route image of junction displayed below.

Areas of interest were defined for each navigation junction (displayed in Figure 9-7) prior to commencing eye-tracking analysis. Pre-defined areas of interest (AOI) for route 1, junction 4 consisted of the in-car passenger, left wing mirror, house/church spire (on left), rear-view mirror, houses (directly ahead of the driver), roadway, houses/hedge (on right), right wing mirror, Satnav, in-vehicle dash. Participant dwell and mean fixation times within each of these areas of interest were then compared across experimental conditions.

A series Mann-Whitney U tests were conducted to see if there were any differences between the SatNav and NAV experimental conditions in the dwell and mean fixation times of participants, within the pre-defined AOIs. Distributions of dwell and mean fixation times were not similar for all experimental conditions, as assessed by visual inspection.

Satnav



NAV

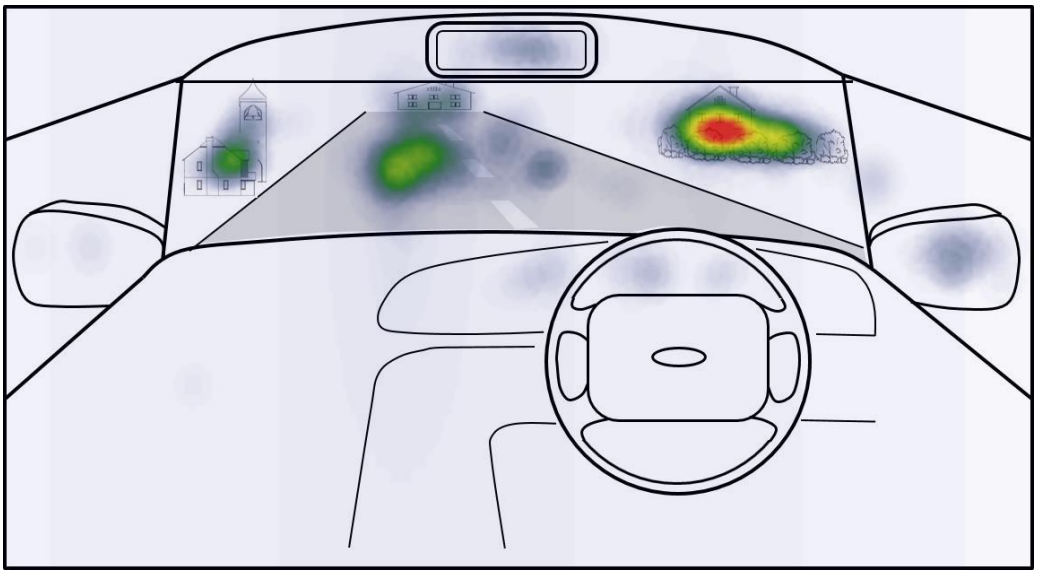


Figure 9-8 Heat map representations of the average fixation times of Satnav and NAV participants at Route 1 Junction 4

Mann-Whitney U tests confirmed that participants dwell times were statistically significantly different, between experimental conditions, within the following areas of interest.

- **Area of interest: Hedge** –NAV (mean rank = 18.50) participants had significantly longer dwell times within the hedge AOI than Satnav participants (mean rank = 6.50), U = 144, z = 4.16, p = <.0005.
- **Area of interest**: **Church spire** - NAV (mean rank = 15.83) participants had significantly longer dwell times within the Church spire AOI than Satnav participants (mean rank = 9.17), U = 112, z = 2.43, p = .020.

Mann-Whitney U tests confirmed that participant mean fixation times were statistically significantly different, between experimental conditions, within the following areas of interest.

- **Area of interest: Hedge** –NAV (mean rank = 17.25) participants had significantly longer mean fixation times within the hedge AOI than Satnav participants (mean rank = 9.08), U = 129, z = 2.78, p = .005.
- **Area of interest**: **Church spire** - NAV (mean rank = 16.46) participants had significantly longer mean fixation times within the Church spire AOI than Satnav participants (mean rank = 9.81), U = 119.5, z = 2.39, p = .022.

9.2.6.2 Route 1 – Junction 6

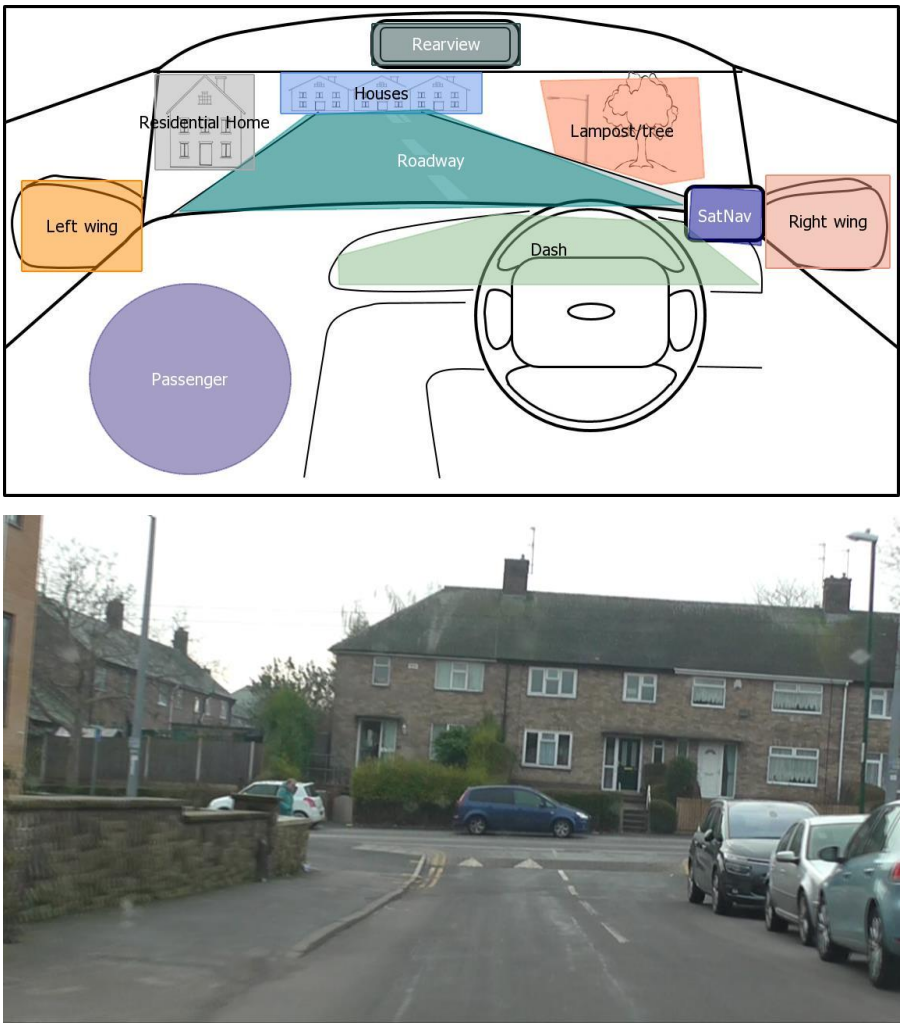


Figure 9-9: Representative image of on-route junction, displaying pre-defined AOIs. On-route image of junction displayed below.

Pre-defined areas of interest (AOI) for route 1, junction 6 consisted of: the in-car passenger, left wing mirror, residential home (on left), rear-view mirror, houses (directly ahead of the driver), roadway, lamppost/tree (on right), right wing mirror, Satnav, in-vehicle dash. Participant dwell and mean fixation times within each of these areas of interest were compared across experimental conditions.

A series Mann-Whitney U tests were conducted to see if there were any differences between the SatNav and NAV experimental conditions in the dwell and mean fixation times of participants, within the pre-defined AOIs. Distributions of dwell and mean fixation times were not

similar for all experimental conditions, as assessed by visual inspection.

Satnav



NAV

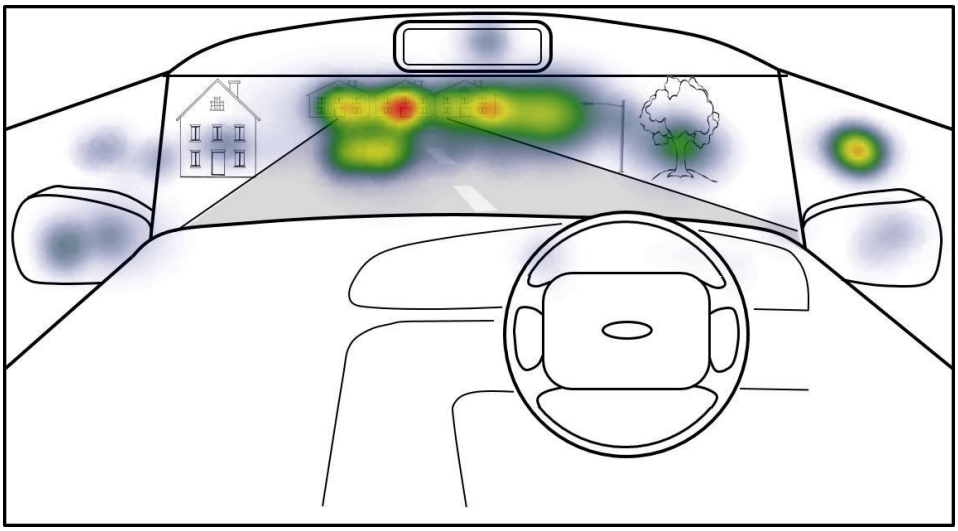


Figure 9-10 Heat map representations of the average fixation times of Satnav and NAV participants at Route 1 Junction 6

Mann-Whitney U tests confirmed that participants dwell times were statistically significantly different, between experimental conditions, within the following areas of interest.

- **Area of interest: Lamppost** –NAV (mean rank = 15.60) participants had significantly longer dwell times within the Lamppost AOI than SatNav participants (mean rank = 9.23), U = 101, z = 2.74, p = .026
- **Area of interest: Houses** - NAV (mean rank = 16.85) participants had significantly longer dwell times within the houses AOI than Satnav participants (mean rank = 8.27), U = 113.5, z = 3.03, p = .002.

  Mann-Whitney U tests confirmed that participant mean fixation times were statistically significantly different, between experimental conditions, within the following area of interest.

  Area of interest: Lamppost –NAV (mean rank = 15.40) participants had significantly longer mean fixation times within the Lamppost AOI than Satnav participants (mean rank = 9.38), U = 99, z = 2.59, p = .036.

9.2.6.3 Route 2 – Junction 2

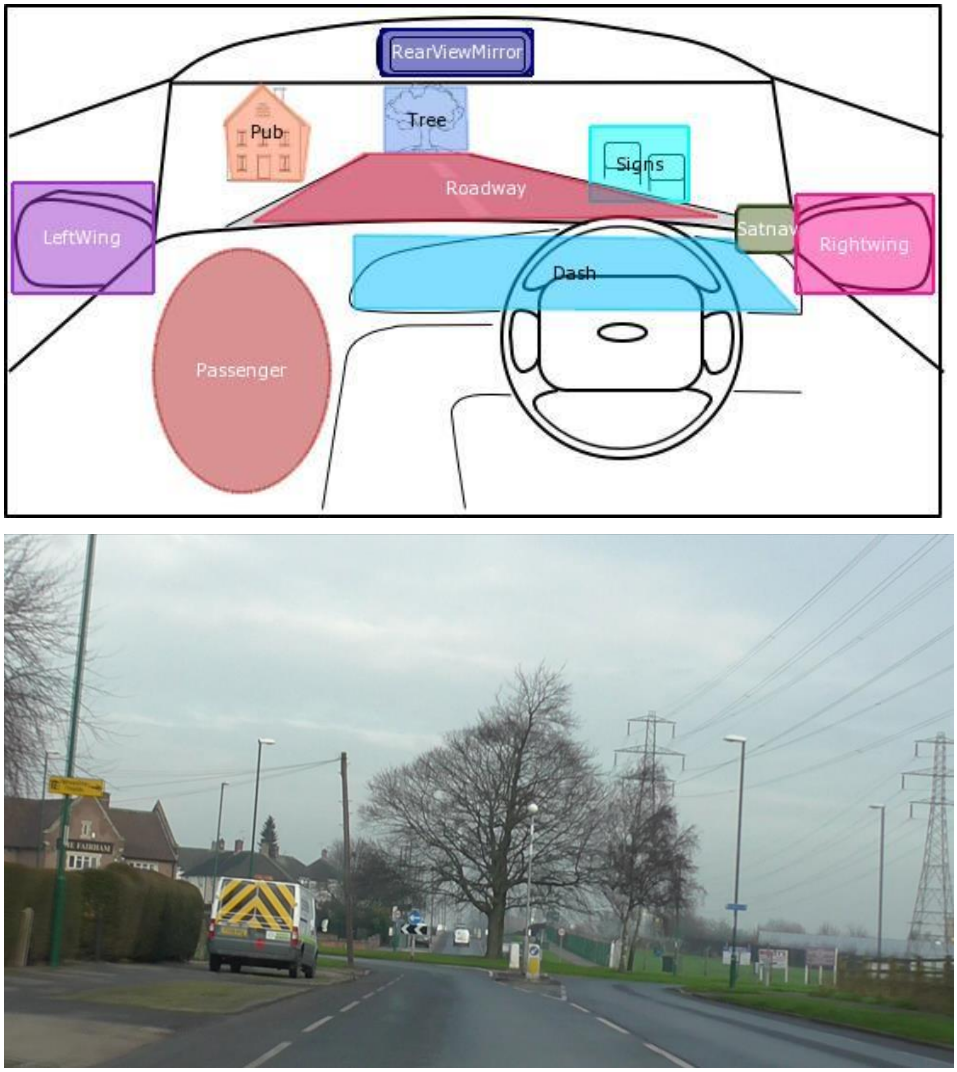


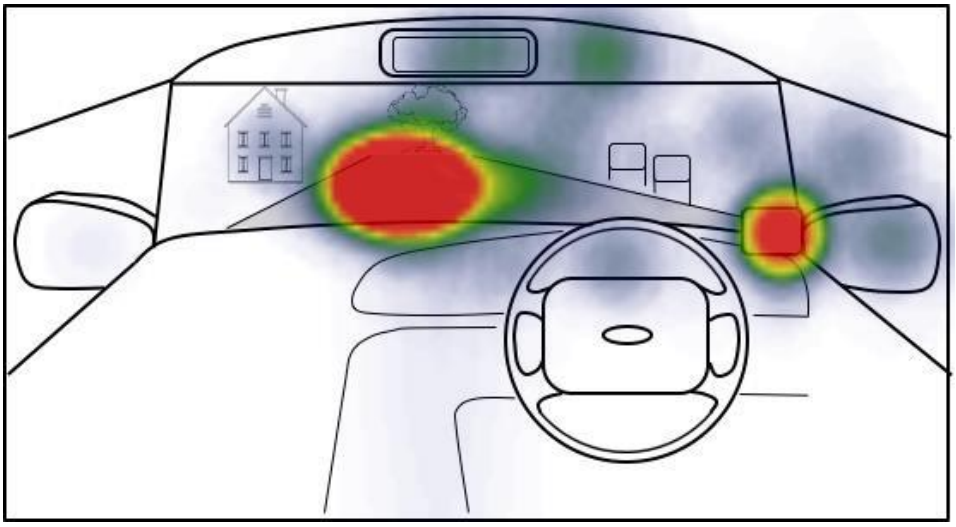
Figure 9-11 Representative image of on-route junction, displaying pre-defined AOIs. On-route image of junction displayed below.

Pre-defined areas of interest (AOI) for route 2, junction 2 consisted of: the in-car passenger, left wing mirror, pub (on left), rear-view mirror, roundabout/tree (directly ahead of the driver), signs (on right), right wing mirror, Satnav, in-vehicle dash. Participant dwell and mean fixation times within each of these areas of interest were compared across experimental conditions

A series Mann-Whitney U tests were conducted to see if there were any differences between the SatNav and NAV experimental conditions in the dwell and mean fixation times of participants, within the pre-defined AOIs. Distributions of dwell and mean fixation times were not

similar for all experimental conditions, as assessed by visual inspection.

Satnav



NAV

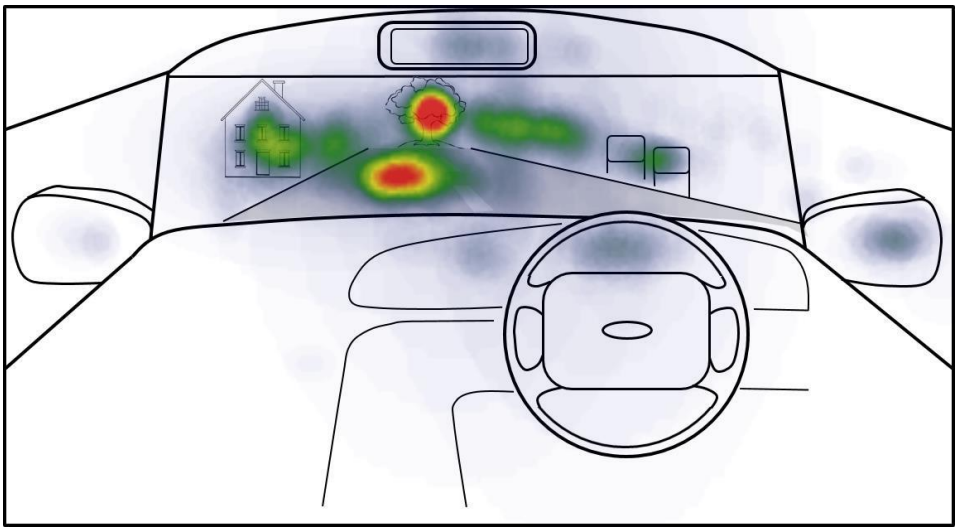


Figure 9-12 Heat map representations of the average fixation times of Satnav and NAV participants at Route 2 Junction 2

Mann-Whitney U tests confirmed that participants dwell times were statistically significantly different, between experimental conditions, within the following areas of interest:

- **Area of interest: Roadway** –Satnav (mean rank = 18.31) participants had significantly longer dwell times within the roadway AOI than NAV participants (mean rank = 7.25), U = 9.00, z = -3.75, p = < .0005.
- **Area of interest**: **Signs** – NAV (mean rank = 17.25) participants had significantly longer dwell times within the signs AOI than Satnav participants (mean rank = 9.08), U = 129, z = 2.87, p = .005.
- **Area of interest**: **Tree** – NAV (mean rank = 18.67) participants had significantly longer dwell times within the tree AOI than Satnav participants (mean rank = 7.77), U = 146, z = 3.71, p= <.0005.
- **Area of interest**: **Pub** - NAV (mean rank = 18.92) participants had significantly longer dwell times within the pub AOI than Satnav participants (mean rank = 7.54), U = 149, z = 3.88, p = <.0005.

Mann-Whitney U tests identified no statistically significant differences in participant mean fixation times, between experimental conditions, within any of the pre-defined areas of interest. This means that Satnav and NAV participants had statistically similar mean fixation times within the identified AOIs.

9.2.6.4 Route 2 – Junction 4

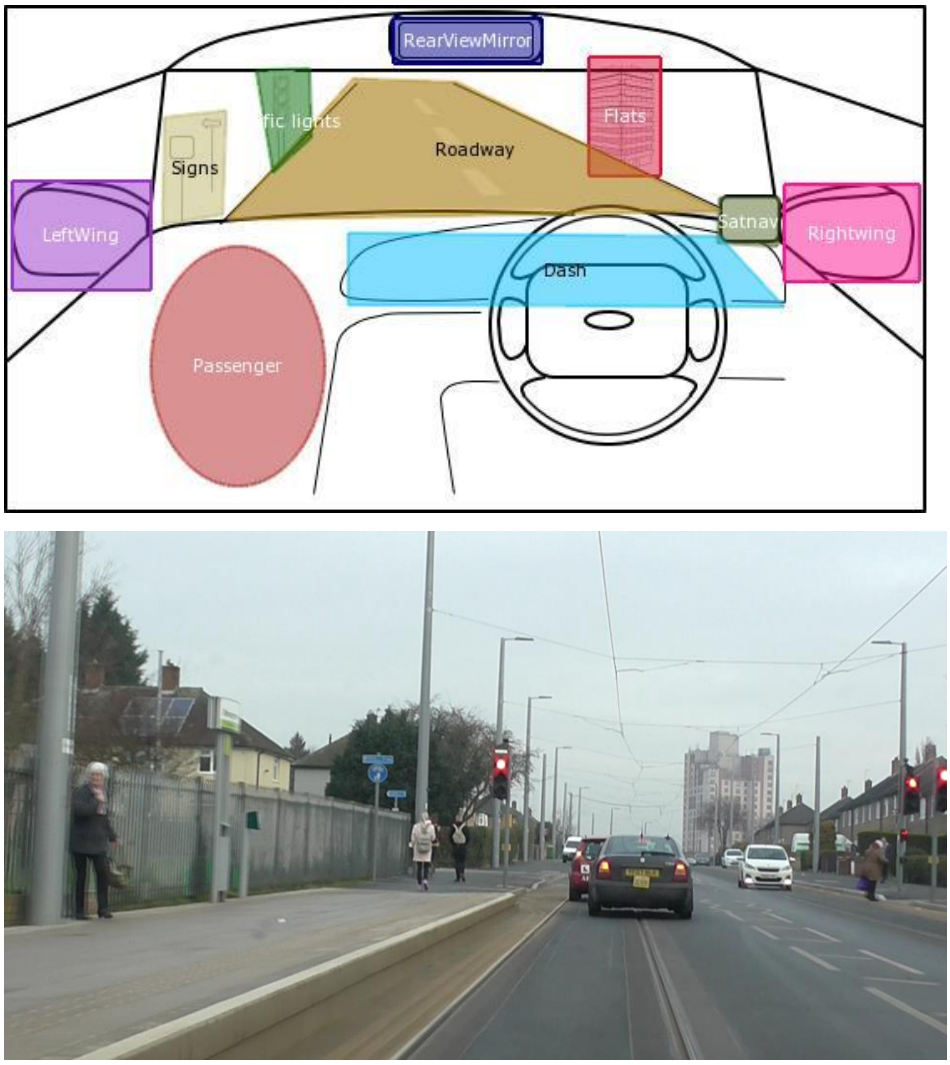


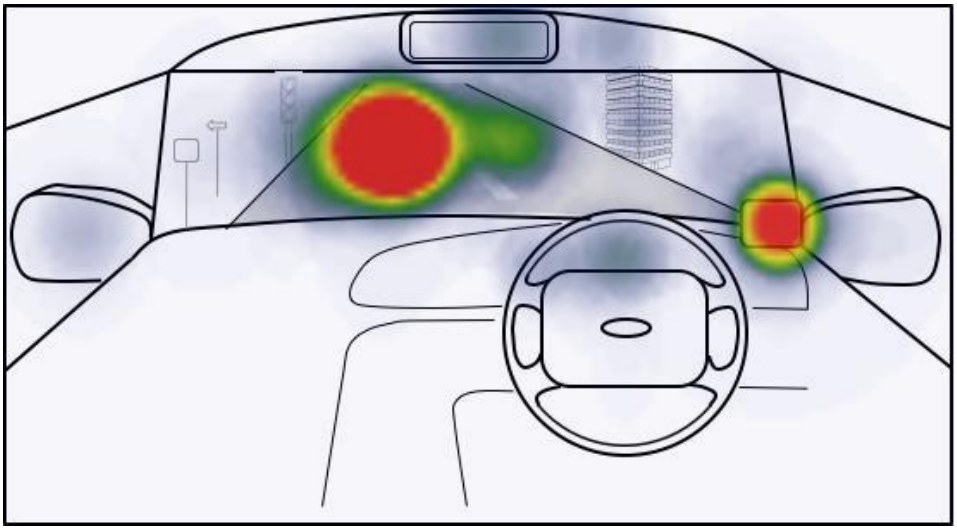
Figure 9-13: Representative image of on-route junction, displaying pre-defined AOIs. On-route image of junction displayed below.

Pre-defined areas of interest (AOI) for route 2, junction 4 consisted of: the in-car passenger, left wing mirror, signs (on left), traffic lights (on left), rear-view mirror, roadway, block of flats (on right), right wing mirror, Satnav, in-vehicle dash. Participant dwell and mean fixation times within each of these areas of interest were compared across experimental conditions.

A series Mann-Whitney U tests were conducted to see if there were any differences between the SatNav and NAV experimental conditions in the dwell and mean fixation times of participants, within the pre-

defined AOIs. Distributions of dwell and mean fixation times were not similar for all experimental conditions, as assessed by visual inspection.

Satnav



NAV

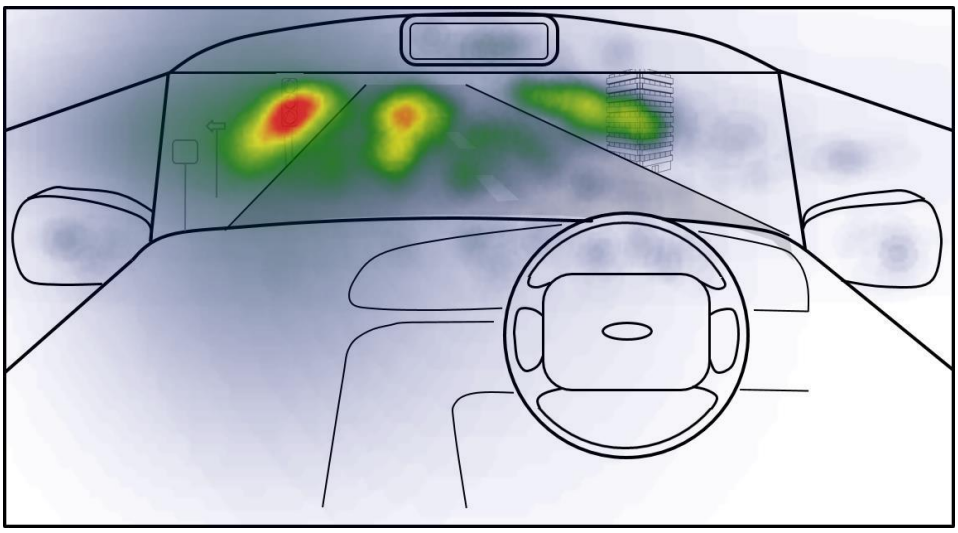


Figure 9-14 Heat map representations of the average fixation times of Satnav and NAV participants at Route 2 Junction 4

Mann-Whitney U tests confirmed that participants dwell times were statistically significantly different, between experimental conditions, within the following areas of interest:

- **Area of interest: Traffic lights** –NAV (mean rank = 18.00) participants had significantly longer dwell times within the traffic lights AOI than Satnav participants (mean rank = 8.38), U = 138, z = -3.30, p = .001.
- **Area of interest**: **Flats** – NAV (mean rank = 17.58) participants had significantly longer dwell times within the flats AOI than Satnav participants (mean rank = 8.77), U = 133, z = 3.13, p = .002.
- **Area of interest**: **Roadway** – Satnav (mean rank = 17.23) participants had significantly longer dwell times within the roadway AOI than NAV participants (mean rank = 8.42), U = 23, z = -2.99, p = .002.

Mann-Whitney U tests confirmed that participant mean fixation times were statistically significantly different, between experimental conditions, within the following area of interest.

- **Area of interest: Traffic lights** –NAV (mean rank = 16.50) participants had significantly longer mean fixation times within the traffic lights AOI than Satnav participants (mean rank = 9.77), U = 120, z = 2.31, p = .022.
- **Area of interest: Flats** – NAV (mean rank = 16.83) participants had significantly longer mean fixation times within the flats AOI than Satnav participants (mean rank = 9.46), U – 124, z = 2.62, p = .011

9.2.6.5 Route 2 – Junction 7

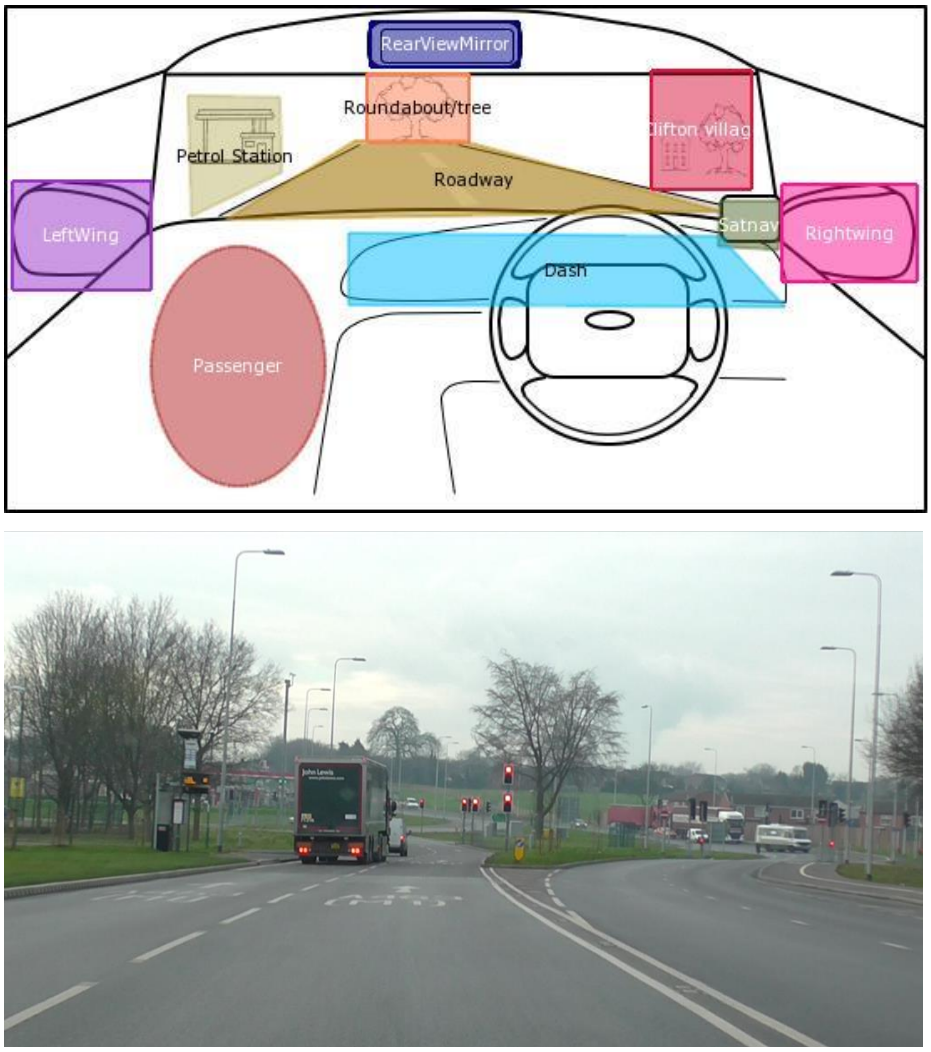


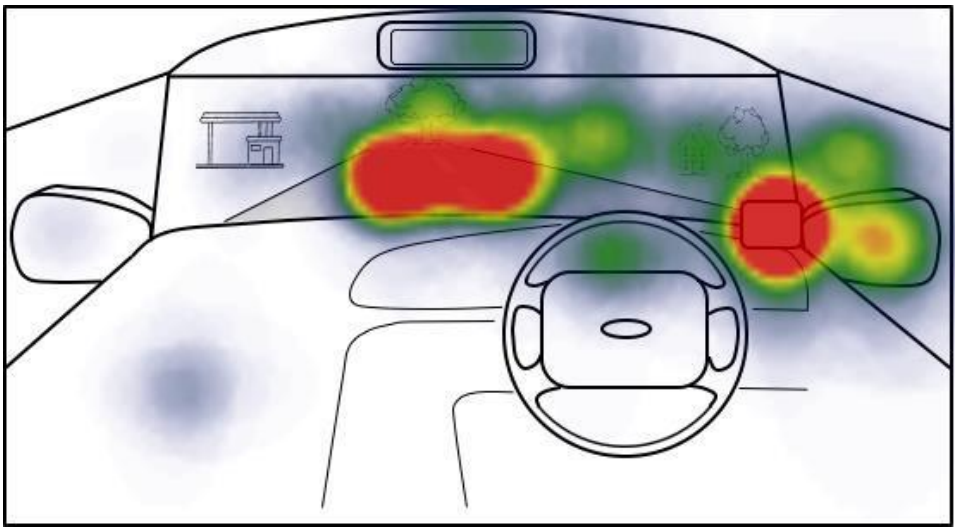
Figure 9-15 Representative image of on-route junction, displaying pre-defined AOIs. On-route image of junction displayed below.

Pre-defined areas of interest (AOI) for route 2, junction 7 consisted of: the in-car passenger, left wing mirror, petrol station (on left), rear-view mirror, roundabout/tree (directly ahead of the driver), rear-view mirror, roadway, Clifton village (on right), right wing mirror, Satnav, in-vehicle dash. Participant dwell and mean fixation times within each of these areas of interest were compared across experimental conditions.

A series Mann-Whitney U tests were conducted to see if there were any differences between the SatNav and NAV experimental conditions

in the dwell and mean fixation times of participants, within the pre-defined AOIs. Distributions of dwell and mean fixation times were not similar for all experimental conditions, as assessed by visual inspection.

Satnav



NAV

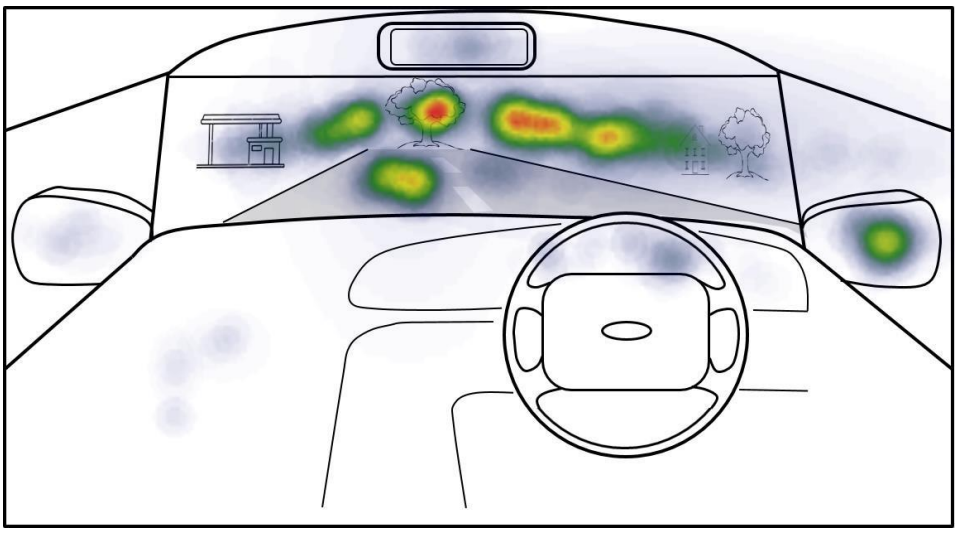


Figure 9-16 Heat map representations of the average fixation times of Satnav and NAV participants at Route 2 Junction 7

Mann-Whitney U tests confirmed that participants dwell times were statistically significantly different, between experimental conditions, within the following areas of interest:

- **Area of interest: Petrol Station** –NAV (mean rank = 16.09) participants had significantly longer dwell times within the petrol station AOI than Satnav participants (mean rank = 9.46), U = 111, z = -2.33, p = .022.
- **Area of interest**: **Roundabout** – NAV (mean rank = 17.18) participants had significantly longer dwell times within the roundabout AOI than Satnav participants (mean rank = 8.54), U = 123, z = 2.99, p = .002.
- **Area of interest**: **Roadway** - Satnav (mean rank = 15.69) participants had significantly longer dwell times within the roadway AOI than NAV participants (mean rank = 8.73), U = 30, z = -2.40, p = .015.

Mann-Whitney U tests identified no statistically significant differences in participant mean fixation times, between experimental conditions, within any of the pre-defined areas of interest. This means that Satnav and NAV participants had statistically similar mean fixation times within the identified AOIs.

9.2.7 Environmental engagement measures

A battery of environmental engagement tests were administered to participants upon completion of the final, second drive. Here, participants completed image sorting and ordering tasks in addition to drawing a sketch of the on-road environment which they had traversed on-route. The results of these tests provided an indication of the participants acquired landmark, route and survey knowledge respectively.

9.2.7.1 Landmark Knowledge

Landmark identification tasks were administered after participants had completed their second, final drive. Here, participants were presented with 12 images and were asked to identify which of the environments represented in these images had appeared on the three routes which they had travelled. To ensure participants scores best reflected their landmark knowledge, the number of inaccurately placed images was deducted from the total number of accurately placed images. This process yielded a percent correct score which is represented as a decimal in figure 41. Normality tests

revealed landmark recognition data followed a non-normal distribution, therefore non parametric tests were performed.

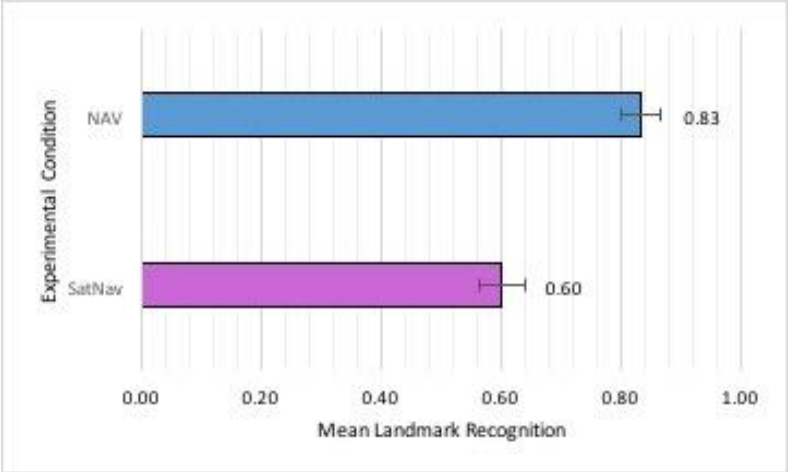


Figure 9-17 Average landmark recognition scores (in decimal format) of participants in the Satnav and NAV experimental conditions

A Mann-Whitney U test was run to determine if there were differences in landmark identification between Satnav and NAV experimental conditions. Distributions of the landmark identification scores were not similar as assessed by visual inspection. Landmark identification scores for NAV participants (mean rank = 21.56) were statistically significantly higher than for Satnav participants (mean rank = 10.07), U = 209, z = 3.66, p = <.0005.

9.2.7.2 Route knowledge

Part of the battery of environmental knowledge tests included a number of route knowledge tasks. As with previous iterations of the road trial, participants were given a set of photographs for each route. Images depicted each junction which participants had encountered on route. Participants were required to place these images in the order which they believed they had encountered them on route. This task was completed separately for routes 1, 2 and 3, in turn. With participants being informed prior to the ordering task which route the images corresponded to. Participant performance was evaluated using an established method (detailed in section 3.3.1.1), which evaluated the veracity of participant route knowledge based on the number of errors they made when ordering route images. Route knowledge is

therefore represented by a route error score – signifying the number of placement errors made by participants. The error score scale moves from 0 to 1, with lower scores representing fewer placement errors and therefore superior route knowledge. Tests of normality indicated normally distributed data.

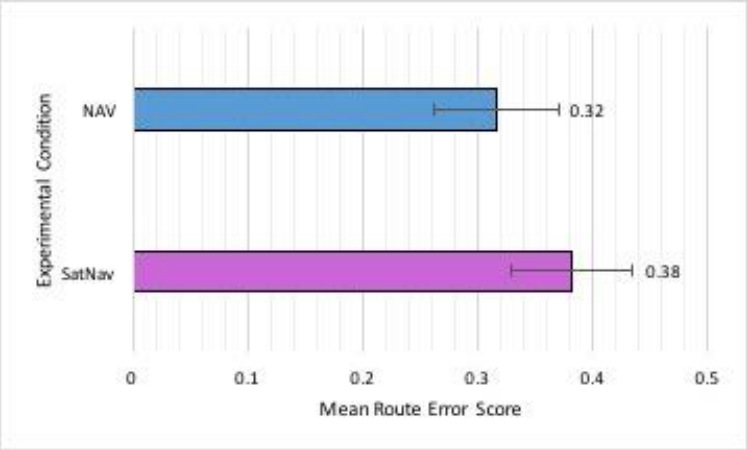


Figure 9-18: displaying the average route error scores from routes 1, 2 & 3 of participants in the Satnav and NAV experimental conditions

An independent samples t-test confirmed that there were no significant differences in the average route error scores of SatNav (M = .381, SD = .211) and NAV (M = .316, SD = .223), (p = .416).

9.2.7.3 Survey knowledge

To evaluate acquired survey knowledge participants were required to draw a sketch map of the routes travelled. Here, they were asked to incorporate as many landmarks as they could remember, placing the landmarks accurately within their sketched environment, they were also asked to include road names, points of route overlap and sections of pathway and junctions. The components detailed within each participant sketch maps for the Satnav and NAV experimental conditions are detailed in table 9-1.

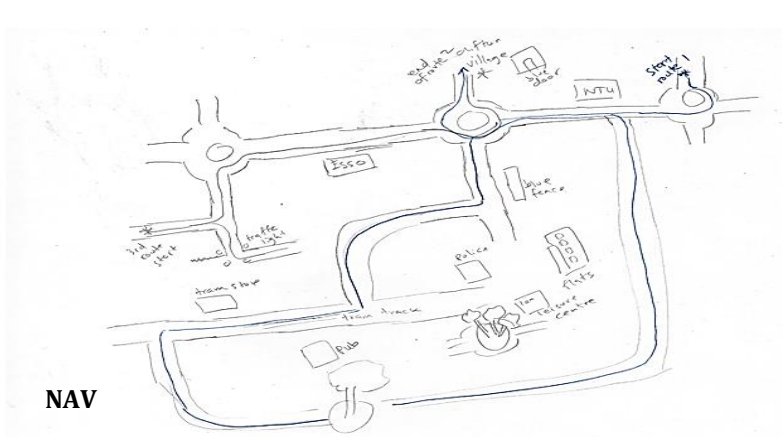
Sketch maps were then assessed on the basis of the various components they contained (e.g. landmarks, accuracy of landmark placement, navigational junctions, pathways). To ensure that this subjective assessment of participant sketch maps was an accurate reflection of the components contained within participants' sketches, a

portion of maps (5 maps from both experimental conditions [10 in total]) were assessed by another human factors specialist who acted as second reviewer. Cohens Kappa was then run to determine if there was agreement between both reviewers on the selection of maps assessed. The subsequent results indicated there was very good agreement between the two rater's judgements, k = .810 (95% CI, .690 to .930), p<.0005.

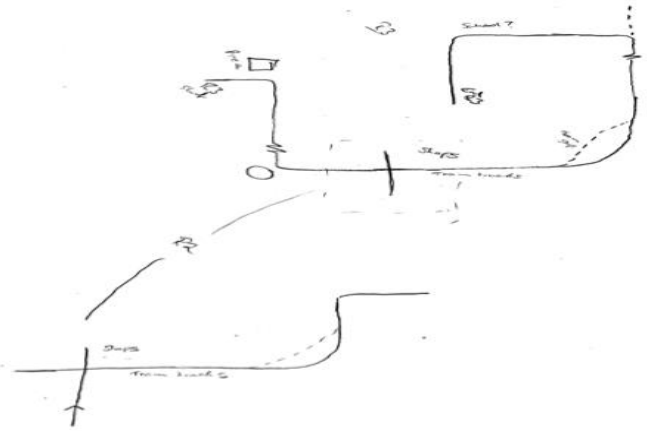
This section therefore used the experimenter's assessments of participants sketch maps to quantitatively determine whether the individual components contained within participants sketches differed significantly across conditions. Sketch maps were then assessed on the basis of their overall structure and detail using an established method developed by Appleyard (1970). Representative examples of participant sketch maps for the Satnav and NAV experimental conditions are provided in figure 9-19

Participant No	No Landmarks		Landmark Orientation		No Pathways		Points of Intersect		No Road Names		Map Type		Sequentially/Spatially Dominant	
	SN	NAV	SN	NAV	SN	NAV	SN	NAV	SN	NAV	SN	NAV	SN	NAV
1	7	16	0.43	0.50	3	6	**0**	**1**	3	0	Fragmented	Branch and Loop	Sequential	Sequential
2	5	10	0.20	0.30	3	3	**1**	**0**	0	0	Chain	Fragmented	Sequential	Sequential
3	5	10	0.60	0.00	2	2	**1**	**0**	0	0	Chain	Scatter and Cluster	Sequential	Spatial
4	5	11	0.00	0.73	2	6	**1**	**0**	0	0	Chain	Chain	Sequential	Sequential
5	5	16	0.40	0.44	2	3	**0**	**0**	0	0	Fragmented	Chain	Sequential	Sequential
6	3	13	0.00	0.30	2	2	**0**	**0**	0	0	Fragmented	Fragmented	Sequential	Sequential
7	2	18	0.00	0.22	3	3	**0**	**0**	2	0	Chain	Mosaic	Sequential	Spatial
8	8	10	0.75	0.00	3	1	**0**	**0**	0	0	Chain	Scatter and Cluster	Sequential	Spatial
9	0	17	0.00	0.35	2	2	**0**	**0**	0	1	Chain	Fragmented	Sequential	Sequential
10	0	9	0.00	0.00	2	3	**0**	**1**	0	0	Chain	Chain	Sequential	Sequential
11	8	9	0.00	0.00	3	3	**0**	**1**	0	0	Fragmented	Chain	Sequential	Sequential
12	3	10	0.00	0.50	2	6	**0**	**2**	0	0	Fragmented	Branch and Loop	Sequential	Sequential
13	3	9	0.00	0.33	3	4	**0**	**1**	2	0	Chain	Chain	Sequential	Sequential
14	3	12	0.67	0.40	5	6	**2**	**0**	0	1	Branch and Loop	Branch and Loop	Sequential	Sequential
15	6	7	0.00	0.00	4	2	**0**	**0**	5	1	Chain	Fragmented	Sequential	Sequential
16	-	12	-	0.75	-	5	-	**2**	-	0	-	Branch and Loop	-	Sequential

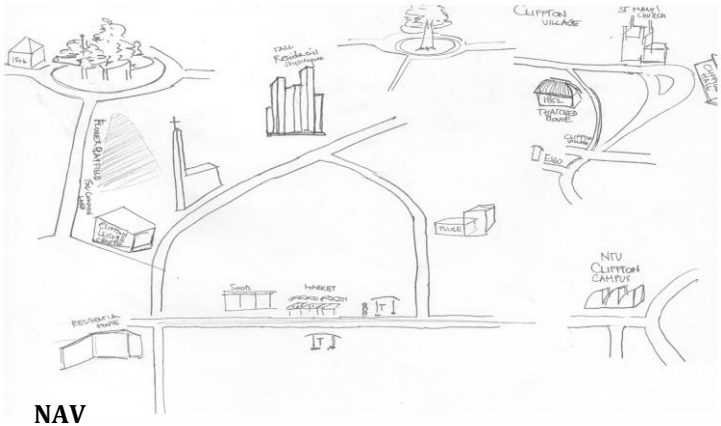
Table 9-1 Sketch map components and classification of Satnav and NAV participant sketch maps



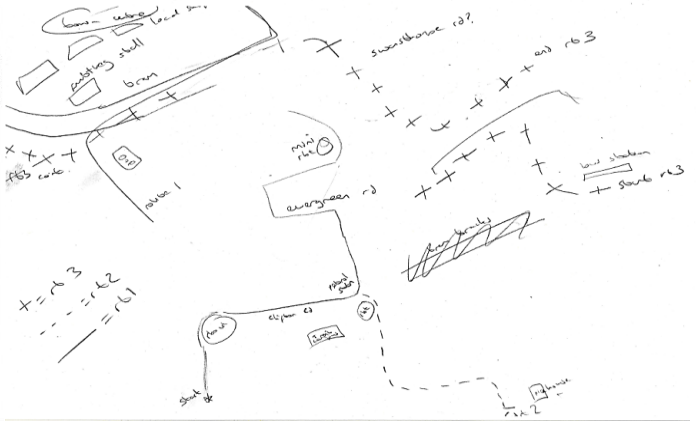
NAV



Satnav



NAV



Satnav

Figure 9-19 Representative examples of Satnav (on right) and NAV participant sketch maps (on left)

9.2.7.3.1 Quantitative assessment of sketch map components

The section below examines the total number of landmarks contained within participant sketch maps, assessing the variations across the Satnav and NAV experimental conditions. Normality tests revealed landmark data followed a non-normal distribution, therefore non parametric tests were performed.

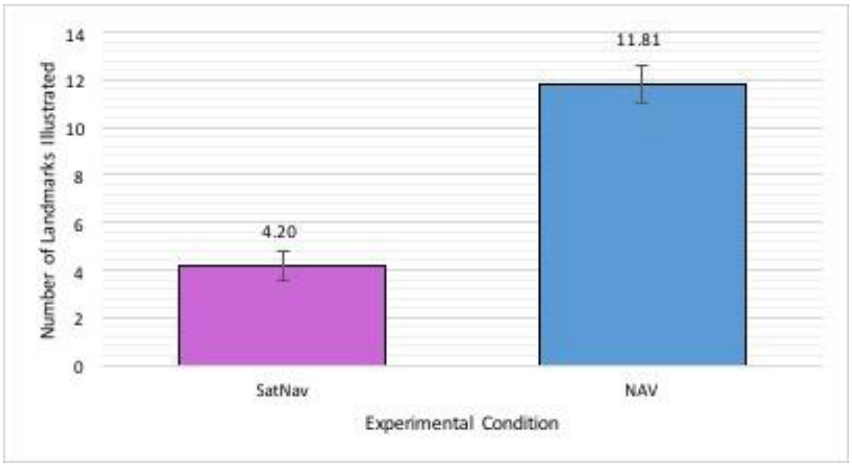


Figure 9-20: mean number of landmarks illustrated in participant sketch maps in the SatNav and NAV experimental conditions.

A Mann-Whitney U test was run to determine if there were differences in between Satnav and NAV experimental conditions in the number of landmarks depicted in participant sketch maps. Distributions of the landmark identification scores were not similar as assessed by visual inspection. Landmark identification scores for NAV participants (mean rank = 23.34) were statistically significantly higher than for Satnav participants (mean rank = 8.17), U = 237.5, z = 4.66, p = <.0005.

Figure 9-16 illustrates landmark orientation scores of Satnav and NAV participants, scores were derived by determining the placement accuracy of landmarks within the sketch map environment drawn by the participants. The resulting output was a decimal number, in which total placement accuracy is illustrated by a score of 1 (see section 3.3.1.1 for more detail).

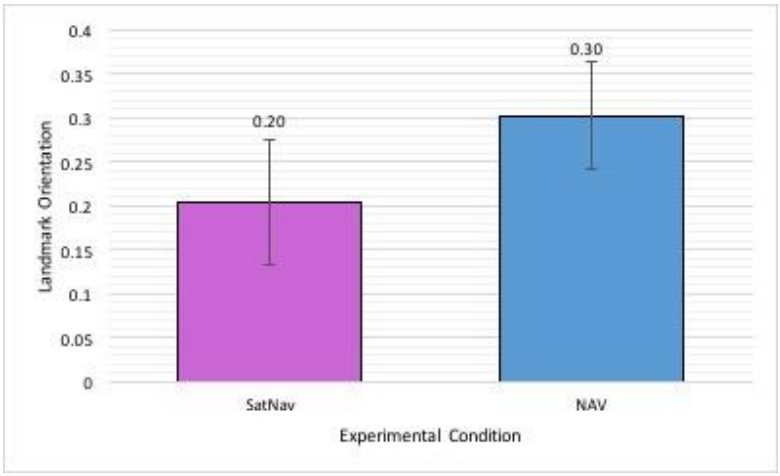


Figure 9-21: Mean landmark orientation score of Satnav and NAV participants indicating the accuracy of landmark placement within participant sketch maps.

A Mann-Whitney U test was run to determine if there were differences in the landmark orientation scores of Satnav and NAV participants. Distributions of the engagement scores were not similar as assessed by visual inspection. Landmark orientation scores for Satnav (mean rank = 14.17) and NAV participants (mean rank = 17.72) were not statistically significantly different, U = 147.5, z = 1.14, p = .281.

In addition to analysing the landmark information contained with participant sketch maps. The number of path segments (pre-defined groupings of roads and junctions within the on-road test area) which were depicted within participants' sketches were also analysed and compared across conditions.

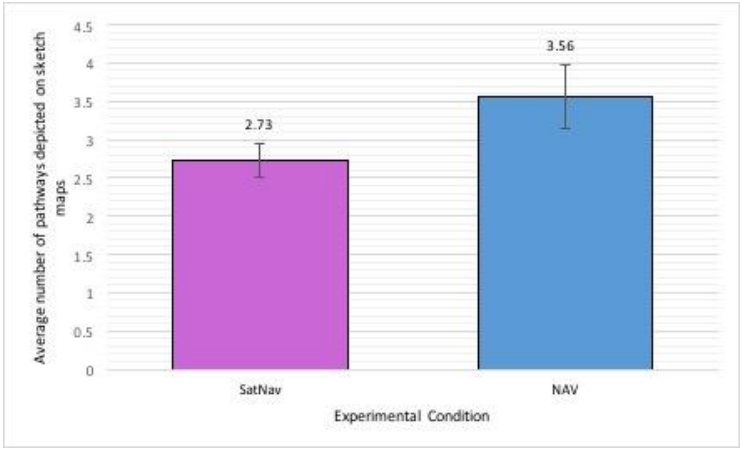


Figure 9-22: mean number of pathways illustrated by Satnav and NAV participants within sketch map illustrations.

A Mann-Whitney U test was run to determine if there were differences in the number of pathways depicted by Satnav and NAV participants within their sketch maps. Distributions of the engagement scores were not similar as assessed by visual inspection. The number of pathways depicted by Satnav (mean rank = 13.87) and NAV participants (mean rank = 18.00) were not statistically significantly different, U = 152, z = 1.33, p = .216.

The three experimental routes which participants traversed, intersected at three, separate points (see figure 4-7 for highlighted points of route intersect). Participants were asked to incorporate any route intersections they remembered within their sketch maps. Sketch maps which contained accurate references to these route intersections were analysed and compared across conditions.

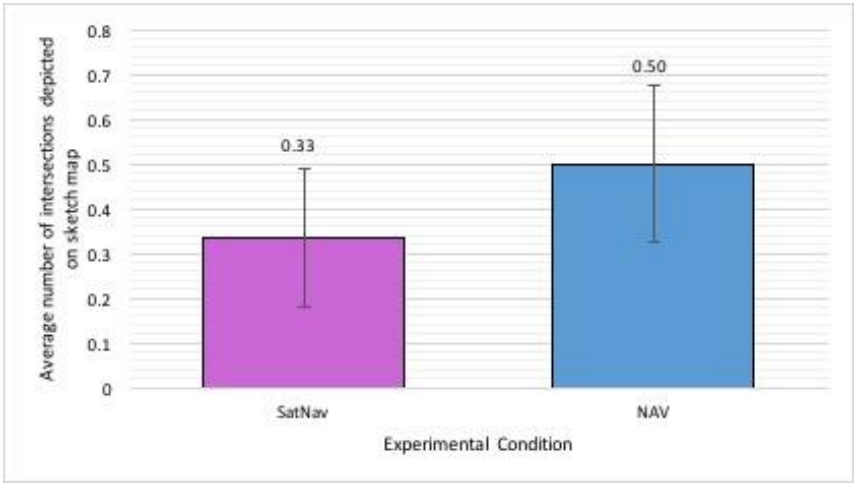


Figure 9-23: Mean number of intersections depicted in the sketch maps of Satnav and NAV participants.

A Mann-Whitney U test was run to determine if there were differences in the number of route intersections depicted by Satnav and NAV participants within their sketch maps. Distributions of the engagement scores were not similar as assessed by visual inspection. The number of route intersections depicted by for Satnav (mean rank = 15.07) and NAV participants (mean rank = 16.88) were not statistically significantly different, U = 134, z = .672, p = .599.

Finally, participants were asked to incorporate any road names they remembered from the three experimental routes into their sketch maps.

Accurate references to road names were then analysed and compared across conditions.

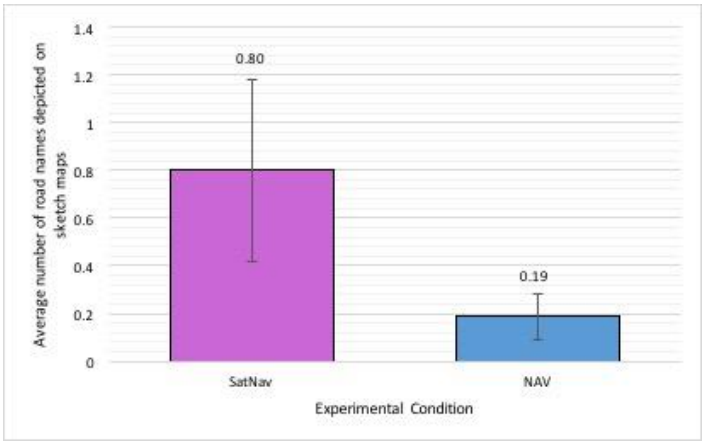


Figure 9-24: mean number of road names illustrated in the Sketch maps of SatNav and NAV participants

A Mann-Whitney U test was run to determine if there were differences in the number of road names depicted by Satnav and NAV participants within their sketch maps. Distributions of the engagement scores were not similar as assessed by visual inspection. The number of road names incorporated into sketch maps by Satnav (mean rank = 17.03) and NAV participants (mean rank = 15.03) were not statistically significantly different, U = 104.5, z = -.837, p = .545.

9.2.7.3.2 Subjective assessment of Sketch maps structure

Increasing complexity

Map Type	Experimental Condition	
Spatial (landmark based)	**Satnav**	**NAV**
Scatter & Cluster	-	2
Mosaic	-	1
Link	-	-
Pattern	-	-

Increasing complexity

Map Type	Experimental Condition	
Sequential (road based)	**Satnav**	**NAV**
Fragmented	5	4
Chain	9	5
Branch & Loop	1	4
Netted	-	-

Table 9-2 Number of participants who drew particular categories of map

In addition to the quantative assessment of sketch map components the complexity of participant sketch maps were classified under the

categorisation scheme first proposed by Appleyard (1970) and used in the later research of Burnett and Lee (2005). In this approach, maps are considered to be either 'sequentially dominant' (primarily roads) or 'spatially dominant' (primarily landmarks). These broad categories are then further broken down into sub-categories in which the increasing complexity of maps is identified (see Figure 9-20). Maps which range from simplistic sketches with no integration of elements (e.g. spatial scattered) are placed at the lowest end of the complexity scale, sitting at the opposite end of this scale are holistic, integrated maps which marry landmarks and road sequences into a whole view (e.g. sequential netted).

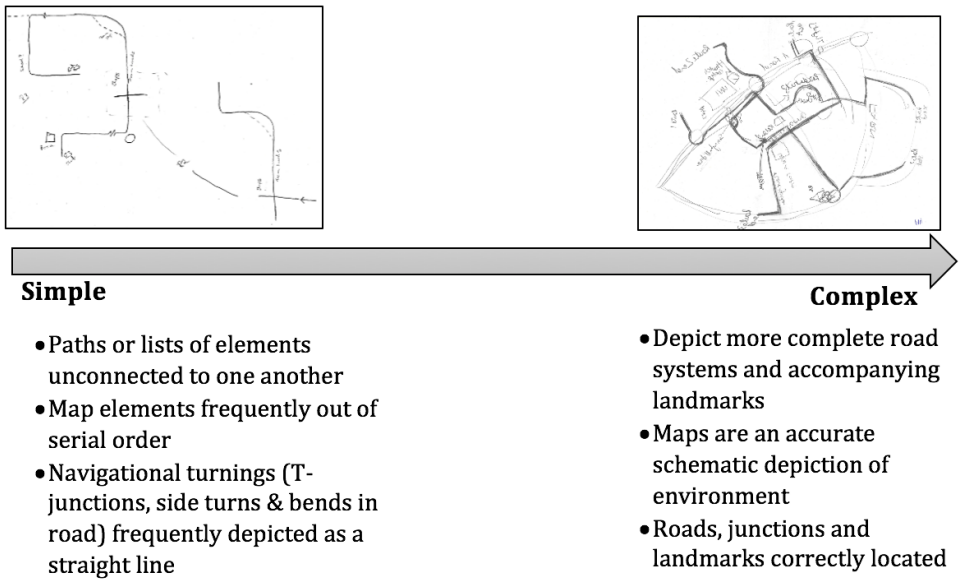


Figure 9-25 Complexity of participant sketch maps and associated elements

Table 9-2 on the previous page, shows the categories of maps drawn by participants in the Satnav and NAV navigation conditions, and reveals that in the Satnav condition one third of participants (five out of fifteen) drew the simplest category maps (i.e. sequential fragmented) with the predominant number of maps within this condition (nine out of fifteen) being *chain* maps. Whilst chain map structures are more schematic in their appearance than *fragmented* maps they are equally simplistic representations, with navigational turns and intersections frequently represented as a straight line.

Indeed, some of these maps were no more than lists of places or components remembered off route.

However, analysis of NAV participant sketch maps revealed that a wider range of map types were drawn. Here, a number of participants chose to draw their maps based around the landmark configurations which they remembered from experimental routes (e.g. the extreme lower, left-hand image in figure 9-14). Whilst NAV participants drew a greater variety of map types the schematic structure of a number of these maps was frequently simplistic (9 out of the 16 sketch maps were classified as either fragmented or chain maps). However, whilst the road layout within these maps was underdeveloped and simplistic, NAV participant maps were frequently populated with signifcantly more landmarks (as detailed in figure 9-15) and as a result offfered a more accurate depiction of the experimental route environemt.

9.2.8 NAV Transcript Analysis

Finally, participant transcripts were examined to identify any common features amongst driver interactions with NAV. A selection of participant transcripts were chosen based on their performance on the corpus of environmental knowledge tests, administered after the second, final drive. Table 9-4 displays the ranked scores of participants' performance on the landmark, route knowledge and sketch map tasks (with sketch map completeness assessed across the components listed in section 9.2.7.3).

NAV: Environmental engagement measures								
Participant	Landmark knowledge	Route Error Score	No Landmarks	Landmark Orientation	No Pathways	Points intersect	No Road names	Map Type
P14	0.83	0.1	12	0.40	6	0	1	Branch and Loop
P12	1	0.09	10	0.50	6	2	0	Branch and Loop
P1	0.83	0.05	16	0.50	6	1	0	Branch and Loop
P5	1	0.22	16	0.44	3	0	0	Chain
P16	1	0.13	12	0.75	5	2	0	Branch and Loop
P6	1	0.3	13	0.30	2	0	0	Fragmented
P7	0.83	0.71	18	0.22	3	0	0	Mosaic
P11	0.83	0.14	9	0.00	3	1	0	Chain
P10	0.83	0.71	9	0.00	3	1	0	Chain
P8	0.83	0.23	10	0.00	1	0	0	Scatter and Cluster
P3	0.83	0.34	10	0.00	2	0	0	Scatter and Cluster
P9	0.67	0.15	17	0.35	2	0	1	Fragmented
P4	0.5	0.59	11	0.73	6	0	0	Chain
P13	0.67	0.57	9	0.33	4	1	0	Chain
P2	0.83	0.45	10	0.30	3	0	0	Fragmented
P15	0.83	0.28	7	0.00	2	0	1	Fragmented

Table 9-3 Ranked scores of environmental engagement scores for NAV participants. Highlighted sections indicate transcripts which were analysed

Participants' rankings of acquired environmental knowledge were determined by the experimenter who considered the components of an individual's spatial knowledge holistically (landmark, route and survey knowledge). Making a considered subjective assessment of the participants' acquired knowledge based their performance in landmark and route knowledge tests, and the various components depicted within participant sketch maps.

The purpose of analysing this section of participant transcripts was to examine any similarities and differences within the interactions of those participants that rated highly on post-trial environmental knowledge tests, and those that performed poorly in comparison. Transcript analysis was performed in NVivo, where a number of themes emerged.

In the section ahead where references are made to 'both' groups of participants, this is referring to participants with high and low environmental ratings within the NAV condition (as indicated by the shaded sections in table 9-4).

Confirmation of understanding

Both groups of participants frequently indicated their understanding or 'receipt' of navigational information through the use of short verbal acknowledgements. This frequent behaviour may be attributed to the driver's awareness that the NAV system lacked a visual connection to them as the driver, therefore rather than use non-verbal cues to confirm that they had heard and understood information (as observed in the Informed and Collaborative passenger condition), they vocalised this understanding to ensure that navigational guidance continued, unencumbered.

Alternatively, participants may have communicated with the NAV system in this way out of politeness, as in traditional human interactions it is customary for the listener to acknowledge what the speaker is saying, which serves to 'ground' the conversation. Grounding criterion is the mutual belief between conversational

partners that everyone involved has a clear enough understanding of the concept to move forward, but this process of grounding may be performed differently depending on what medium the conversation is being conducted through (Clark & Brennan, 1991). For example, in face to face conversations the acknowledgement of what the speaker is saying can be performed non-verbally through gestures and body language. However, in conversations, conducted over the phone, the listeners' acknowledgement of the speaker must be performed verbally, therefore communicating that both conversational partners have a clear understanding of what is being communicated, allowing the conversation to progress (Clark & Brennan, 1991).

NAV: Continue along this road until you reach roundabout with large tree at the centre**.**

Participant 1: Okay Doke (laughs)

NAV: Approximately 0.15 km

Participant 1: Thank you, that is great. Oh, here it is.

NAV: Turn right onto Whitegate vale

Participant 14: Yeah got it.

NAV: Approaching tram stop

Participant 13: Yeah, I see the tram stop

NAV: On your right, you will pass large unusual looking Methodist church.

Participant 2: Yep I can see it.

System questioning

Both groups of participants frequently put questions to NAV throughout the two experimental drives. However, the focus of these questions varied between participants who had high and low environmental knowledge ratings.

Participants with Low ratings of environmental knowledge

Within this group the most common topics of questioning by drivers were:

1. **Turn location** – here, participants requested clarification from NAV that the turn location which they had identified was correct. Burnett (1998) defined this point within the navigation task as the 'confirm' stage. Here, drivers require information to establish whether they have identified the correct manoeuvre or whether a navigational error has been made. Whilst NAV provided landmark references to assist drivers with the identification of the correct turning, participants may not have felt confident in their interpretation of this information, subsequently requesting additional information to confirm they are on the correct path.

NAV: Yes, Widecombe lane. On the right can you see the new black fence?

Participant 2: So, is it this one?

NAV: At roundabout, first left onto Green lane

Indicates

Participant 13: Here?

Additionally, the absence of a secondary representation of route information within the NAV condition may have meant that drivers required additional

reassurance of the turn location before committing to the manoeuvre. The Satnav visual interface commonly provides this information to drivers, providing reassurance that they are on the correct path.

2. **Direction of Travel** - here, participants requested additional information from NAV so that they could identify the designated turn location within their driving environment. Burnett (1998) defined this point within of the navigation task as the 'identify' stage. Here drivers require information to pinpoint turnings within the road environment so that they can make appropriate determinations about numerous driving elements including; the direction of travel, their speed control on a junction approach and the correct on-road positioning for the final junction approach. Similar to the previous *turn location* theme, despite drivers receiving navigation information enriched with landmark references, they may have been unsure of their turn direction or lane positioning without a secondary visual representation of this information.

NAV: OK. Beware of the Tram only turn

Participant 2: Straight? Which lane?

NAV: At roundabout, go round to the right. Half way, move to far-left lane as you travel. Is this clear?

Participant 13: Yeah. This way right? [00:07:19.23]

* Indicates*

3. **Speed Limit** – Drivers requested additional speed limit information throughout their journeys. Ensuring that they were adhering to legal speed limits whilst driving. Moreover, these requests, which were in addition to the speed limit information contained within standard NAV guidance, may have been an attempt to test the NAV system.

Participant 13: What's the speed limit here?

NAV: Speed limit, 20mph Clifton

Participant 4: What's the speed limit on this road?

NAV: Speed limit, 30 mph

Participant 4: That's helpful.

As the NAV system was framed to participants as a prototype natural language navigation system they may have been unsure of its technical limitations and the information it was able to access throughout the journey. Speed limit requests may have been one way in which drivers tested system function and content.

Participants with High ratings of environmental knowledge

Within this group the most common topics of questioning by drivers were:

1. **Environmental questioning** – here, drivers requested additional environmental information from NAV. Whilst a number of these requests were related to the driver's immediate environment and environmental features which were encountered on route, other requests were more abstract.

NAV: Would you like more information about the Fairham pub.

Participant 1: Have you got any information on the tram network?

NAV: Description, Fairham pub. Pub and family style restaurant. 3.8 stars out of 5 stars on Google. based on 9 reviews. Brian Jenkins said "it could do with a clean, 2 stars", Gary S said "good and cheap, but lager not good, 5 stars", John Wheldon said "somewhere to drink"

Participant 14: (laughs)

NAV: but food not good, 5 stars

Participant 14: Sounds like a classy establishment. Where can I hire an aeroplane? (laughs)

NAV: Great, continue along Summerwood lane until you reach T junction. Caution, speedbumps. At the T junction turn right onto Farnborough road.

Participant 5: What is this building my right?

Drivers may have used such requests, centred around their orientation to gain an awareness of their current location, in relation to their general surroundings (Burnett, 1998). Another explanation is that drivers were attempting to test system competences and functions, to establish what information NAV was capable of delivering.

2. **Non-driving function** – here, drivers put questions to either NAV or the experimenter to gain an awareness of how NAV worked. Such questions centred around how NAV accessed the information which was issued and at whether specific points along the journey triggered the issuance of such information.

NAV: John Weldon said "somewhere to drink but needs pool table covered, 2 stars". Continue to traffic lights head

Participant 1: Ok turn right, that was an incredibly awesome set of reviews to read. Do they change or not?

Participant 14: (to NAV) how do you choose where to give information NAV?

NAV: Source of information, google. Google maps, yahoo, YELP, CNN, Sky news

Participant 14: Do you just have waypoints to give interesting stuff or not?

NAV: Information available on demand. Approaching traffic lights, at traffic lights turn right onto Southchurch drive

Drivers questioning of both system and experimenter highlight the novelty of the NAV system and the curiosity roused by system interactions.

3. **Route information** – Additional route information was also requested by drivers on route. Such appeals were centred around the drivers desire to know the period of time they would be spending on the current stretch of road. Burnett (1998) defined this point within of the navigation task as the 'confidence' stage. Here drivers require information to gain reassurance that they are on the correct route or to ensure that the system is functioning properly. As previously highlighted, the absence of visual secondary representation of this information where the distance-to-next-turn is commonly displayed may have prompted drivers to request such additional information so that they are informed of the immediacy of the next manoeuvre.

NAV: Farnborough road, continue.

Participant 1: How long do we stay on this road for?

NAV: Clifton road, continue to traffic lights ahead then turn left onto Farnborough road

Indicates

Participant 14: Wasn't that the end (of the route), Farnborough road?

Politeness and praise

There were also examples of both groups of participants using politeness strategies in their interactions with NAV. Previous work has suggested that strategies employed within a conversation, such as complementing, joking and

showing solidarity can be indicative of an interlocutors' desires and wants (Brown & Levinson, 1987).

NAV: On your right is Nottingham Trent university, Clifton campus. Would you like some information about Clifton campus?

Participant 5: Yes please.

NAV: On your left, you will see large residential home with police station on your right. Follow the road around to the left, beware of tram only turn.

Participant 1: Nice, cheers. Definitely haven't been down one of those (sarcastically). Cost me £60 in fines.

NAV: OK, continue, follow road round to the left caution beware of tram only turn

Participant 13: Hmm yeah. Nice catch!

NAV: Speed limit, 30 mph

Participant 4: That's helpful.

Whilst the choice of language used by participants within the above interactions may not be attempts to praise NAV, these examples highlight how the linguistic choices made by participants within such interactions overlap with human social communication and conversational norms. Previous research (Large, Clark, Quandt, Burnett, & Skrypchuk, 2017) has suggested that such utterances may represent challenges for designers of voice user interfaces systems, who must define and formulate appropriate system responses where the pragmatic function of communications is unclear or inconsistent across interactions.

Anthropomorphising system

Drivers with *high* ratings of environmental knowledge frequently anthropomorphised NAV throughout both journeys. Drivers used terms of

endearment when communicating the system, assumed NAV was behaving in a 'grumpy' manner when the system didn't respond immediately and took responsibility for errors when they didn't heed system 'warnings'.

NAV: Tram network Nottingham, searching database**.**

Participant 1: (delay in NAV response) I've killed him, I'm sorry. Tell me about the pub then. Don't be grumpy.

NAV: Information available on demand. Approaching traffic lights, at traffic lights turn right onto Southchurch drive

Participant 14: I don't think he quite understood me

Previous work has demonstrated that this process of anthropomorphism-by-interpretation (anthropomorphic attributions and behaviours made during routine use of everyday technologies) can influence drivers' attitudes and feelings towards in-vehicle navigation systems during routine interactions. This, in turn, may influence how drivers engage with the navigational device and their wider driving environment (Large D. R., 2013). Therefore, the anthropomorphising of the NAV device by drivers with high ranking scores of environmental engagement, may have influenced subsequent engagement with the driver's wider environment.

Rudeness/ Contradicting system

Whilst both groups of participants employed politeness strategies in NAV interactions, participants with *low* ratings of environmental engagement also demonstrated traits for rudeness, utilising command style interactions and contradicting system information.

NAV: Speed limit 20mph

Participant 13: That's a lie.

NAV: Database shows speed limit 20 mph

Participant 13: (laughs) arguing with me

NAV: Far left-hand lane, the turning to Clifton village is fairly concealed

Participant 4: Yeah, you should've told me that before**.**

The authors of a recent article (Gordon, 2018) refer to today's interactions with voice-based systems such as Alexa, Siri, Cortana etc as the 'age of casual rudeness'. Speakers, no longer bound by the politeness norms of traditional human conversation, use commands in system interactions, in place of requests, with 'please' or 'thank you' in such interactions rendered superfluous. Whilst such commands in system interactions allow the speaker to quickly make, concise requests. The article raises concerns for those generations growing up with such command-based technologies, musing as to whether communicating in this way could result in individuals having an 'empathic blind spot'. Where individuals could utilise this same command structure in human conversations.

9.3 SUMMARY OF DATA

9.3.1 Navigational errors

Whilst there was a trend for fewer navigational errors in the NAV condition, no statistically significant differences were found in the total number of navigational errors made by Satnav and NAV participants, across both experimental drives.

9.3.2 Nasa TLX measures

Statistical analyses reveled no significant differences in the perceived workload of Satnav and NAV participants across both experimental drives ones and two.

However, within subject's statistical analyses revealed a significant drop in the perceived workload of Satnav participants from drive one to drive two. Analyses also revealed that participants in the NAV condition perceived their workload to be lower on their second experimental drive. However, this reduction in workload was not

found to be statistically significant. This means that whilst participants in both experimental conditions perceived their workload as being reduced on their second, final drive only Satnav participants' experienced a statistically significant reduction in workload.

9.3.3 TDT measures

Statistical analyses revealed no significant differences in percentage of missed TDT impulses between experimental conditions. Therefore, Satnav and NAV participants missed a statistically similar number of TDT impulses across both experimental drives.

Similarly, statistical analyses revealed no significant differences in the reaction time of participants towards the onset of a TDT impulse. Therefore, participant reaction time, towards the onset of TDT impulses was statistically similar across the Satnav and NAV experimental conditions.

9.3.4 Eye tracking measures

Table 9-6 presents a summary of eye tracking results. Each of the examined junctions are listed in the far-right column. Followed by a column to indicate experimental condition and each of the examined areas of interest for each junction. Where significant results were found these are presented along the row of the experimental condition which had the longer dwell or mean fixation time, indicating the direction of significant result. For example, in table 9-5 presented below, NAV participants are shown to have significantly longer dwell times than Satnav participants, in the right landmark area of interest.

		Right Landmark
Example Junction	Satnav	
	NAV	*SN

Table 9-4 Example table of significant results within eye tracking data

Junction/Experi-mental condition		Area of interest																	
		Passenger		Left wing		Left landmark		Rear-view mirror		Forward landmark		Roadway		Right landmark		Right wing		Dash	
		Dwell	MF	Dwell	MF	Dwell	MF	Dwell	MF	Dwell	MF	Dwell	MF	Dwell	MF	Dwell	MF	Dwell	MF
Route 1 Junction 4	Satnav	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NAV	-	-	-	-	*SN	*SN	-	-	-	-	-	-	*SN	*SN	-	-	-	-
Route 1 Junction 6	Satnav	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	NAV	-	-	-	-	-	-	-	-	*SN	-	-	-	*SN	*SN	-	-	-	-
Route 2 Junction 2	Satnav	-	-	-	-	-	-	-	-	-	-	*NAV	-	-	-	-	-	-	-
	NAV	-	-	-	-	*SN	-	-	-	*SN	-	-	-	*SN	-	-	-	-	-
Route 2 Junction 4	Satnav	-	-	-	-	-	-	-	-	-	-	*NAV	-	-	-	-	-	-	-
	NAV	-	-	-	-	*SN	*SN	-	-	-	-	-	-	*SN	*SN	-	-	-	-
Route 2 Junction 7	Satnav	-	-	-	-	-	-	-	-	-	-	*NAV	-	-	-	-	-	-	-
	NAV	-	-	-	-	*SN	-	-	-	*SN	-	-	-	-	-	-	-	-	-

Table 9-5 Eye tracking results by navigational junction. Significant result indicted by an * , with the direction of result provided along the row with the significantly longer Dwell or mean fixation time

9.3.5 Landmark Knowledge

Participants in the NAV condition demonstrated superior landmark knowledge over Satnav participants. Here, participants navigating with the assistance of NAV accurately identified significantly more landmarks which had appeared along experimental routes than participants in the Satnav condition.

9.3.6 Route knowledge

Statistical analyses revealed no significant differences between the route error scores of Satnav and NAV participants. Here, participants in the Satnav and NAV experimental conditions ordered images of routes scenes with statistically equivalent levels of accuracy.

9.3.7 Survey knowledge

- Nav participants incorporated significantly more landmarks than Satnav participants within their sketch maps. This means that participants in the NAV experimental condition were able to remember significantly more landmarks from the traversed routes than their Satnav counterparts.
- No significant differences were found in the landmark orientation of Satnav and NAV participants in sketch map illustrations. Demonstrating that the accuracy with which participants placed landmarks within their sketch maps was statistically equivalent across navigational conditions.
- No significant differences were found between the Satnav and NAV experimental conditions in the number of pathways which were accurately incorporated into participant sketch maps. Indicating that participants receiving navigation guidance from a Satnav and NAV remembered a statistically equivalent number of road sections across the routes travelled.
- No significant differences were found in the number of route intersections highlighted by Satnav and NAV participants. Indicating that participants receiving navigational guidance from a Satnav and NAV remembered a statistically equivalent number of route intersections which were subsequently incorporated within their sketch maps.

- No significantly differences were observed between the Satnav and NAV experimental conditions in the number of road names remembered and subsequently incorporated into participant sketch maps.
- Participants in the Satnav condition predominantly draw simplistic sketch maps (fragmented & chain) compared to participants NAV condition who drew a wider variety of maps (both spatially and sequentially dominant) and frequently drew upon a vast array of landmarks to organise sketch map structure and layout.

9.3.8 Transcript analysis

- Transcript analysis revealed a number of similarities and differences in how participants in the NAV condition interacted with the NAV NLI. Whilst both groups (high and low scoring participants) used a number of politeness strategies when communicating with NAV and requested navigational confirmations to ensure they had made the correct path selections. Participants who had scored low on environmental engagement measures frequently used NAV as an interactive Satnav device, requesting verbal confirmations for the same information which they would expect to receive in a visual format within current systems (e.g. turn location, direction of travel). Furthermore, there was an evident hierarchy within low scoring interactions. Here, participants frequently utilised command-based language in NAV interactions, as oppose to making system requests. Conversely, high scoring participants frequently anthropomorphised NAV, attributing human emotions to the system if NAV acted contrarily. Here, high scoring participants communicated with the system as a peer, framing questions as requests and attempting to engage in a voluble dialogue, which was frequently unrelated to the navigational task.

10

CHAPTER 10: DISCUSSION, FINAL RECOMMENDATIONS AND CONCLUSIONS

This chapter aims to synthesise the research findings presented bin this thesis and the background literature, addressing all of the specific research aims, presented in chapter 1. For clarity, research aims are presented again, on the following page (Figure 10-1), along with the corresponding section of this chapter which addresses the specific aim.

This chapter begins by exploring how the results of the NAV on-road trial, which saw participants navigate by following the wayfinding guidance of an NLI interface, compared to the results of those participants who navigated using current market navigation technologies (i.e. Satnav). A resulting argument will be presented for NLIs which utilise this same interactive, landmark based route information to guide drivers through routes. Guidelines for such future intelligent HMIs are then generated based on previous literature and the results obtained within this thesis.

Finally, the limitations of the research conducted as part of this thesis will be explored with comments being made on study design and participant demographics. These limitations will be reflected upon in the context of potential future work which will focus on the limitations of the utilised technology in mimicking the driver/passenger as a whole.

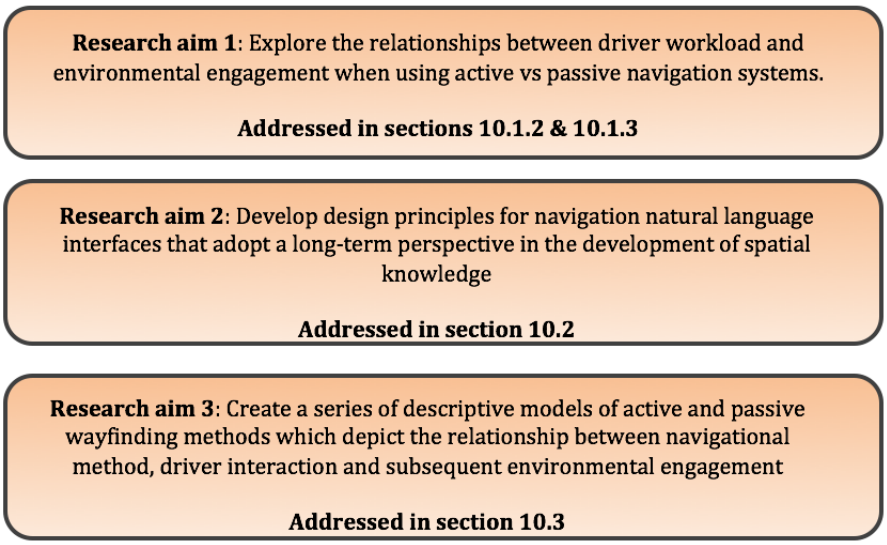


Figure 10-1 Initial research aims and corresponding chapter sections where each aim is addressed/discussed.

10.1 DISCUSSION OF NAV RESULTS IN THE CONTEXT OF CURRENT SATNAV TECHNOLOGIES

10.1.1 Navigational errors

Results from the on-road trial, detailed in chapter nine revealed a trend for fewer navigational errors within the NAV experimental condition, compared to those participants who followed the navigational guidance of a Satnav device (see section 9.2.3, page 220). Whilst these differences failed to reach levels of significance, the observed differences can provide an indication as to how navigational method and the information used to guide drivers can impact upon wayfinding performance. It is likely that drivers within the NAV experimental condition, made fewer navigational errors, on average, compared to Satnav participants as they were able to check their understanding of issued route instructions on the junction approach, prior to committing to the manoeuvre. This allowed drivers to pinpoint the location of the junction by requesting additional environmental information. Alternatively, drivers could confer with the NAV system to confirm whether the junction they had intended to take was the correct turning. In comparison, Satnav drivers were

presented with a visual interface which they used to independently discern the location of the designated manoeuvre (indicated by prior verbal system commands).

However, as the number of navigational errors made by participants in the Satnav and NAV conditions were not statistically significantly different, the NAV condition may have been unable to replicate the entire driver/passenger interaction experience. The Informed Passenger and Collaborative navigation conditions demonstrated the range of interactions that take place between driver and passenger on approach to a navigational junction. Here, gestures were seen to play a large role in assisting drivers in quickly pinpointing manoeuvres within their environment. The absence of a comparable visual stimulus, within the NAV condition may have meant that drivers didn't receive verbal confirmation of their selected navigation junction quickly enough to either change course or proceed with their junction selection.

Providing drivers with a visual indication of the correct junction within their road environment could mimic the function of passenger hand gestures and head nods, serving as a confirmation of the correct path to drivers. The proposed visual stimuli could be provided by a head up display (HUD), or an augmented road view which could highlight the intended path for the drivers. Or indeed with the employment of a digital avatar (Okamoto & Sano, 2017, September) which could provide appropriate multi-sensory inputs to communicate critical information quickly. Such modifications have been previously discussed within the literature and are discussed in greater detail within the future work section of this chapter (section 10.4).

10.1.2 Driver workload

One of the aims of this thesis (research aim 1) was to explore the relationships between driver workload and environmental engagement associated with 'active' and 'passive' forms of navigation. Three existing, recognised navigational models – a satnav ('passive'), an informed passenger and a collaborative passenger ('active'), were

selected as these differed according to the content of information they relayed to the driver, and the level of interactivity they permitted. Results from excursions using each of these methods were subsequently used to inform the design of a natural language system (NAV-NLI) that adopted a long-term perspective in the development of spatial knowledge, and this was subsequently evaluated in the same environment.

It was evident that subjective workload was equivalent across all conditions, with generally no significant differences revealed between experimental conditions, and across both drives, although drivers provided with the satnav tended to indicate higher levels of workload overall (see section 5.2, page 133 & section 5.3, page 134). This is in contrast to the earlier findings of Burnett and Lee (2005), who predict higher initial levels of workload associated with more active forms of navigation, due to the depth of processing required in order for drivers to maintain orientation and make specific navigational decisions, particularly when presented with a number of viable options.

However, whilst the informed and collaborative passenger (and ultimately, the NAV-NLI) represent increasingly 'active' methods of navigation – providing drivers with more extensive navigational prompts peppered with environmental information – drivers did not report an associated increase in workload (see section 9.2.4, page 221 onwards for NAV workload results). This is likely to be because drivers were provided with a more 'natural', interactive support across the entire journey, rather than specific, functional commands delivered at isolated navigational decision points. Moreover, drivers were able to question their 'navigator' to improve their understanding of route instructions and ensure they had correctly identified the upcoming and subsequent manoeuvres. In essence, the informed and collaborative passenger (and indeed, the NAV-NLI) were able to provide drivers with an interactive, personalised experience, and provide appropriate reassurance, thereby improving confidence while not necessarily impacting on workload. Moreover, the use of natural language (delivered either by the passenger or NAV), also ensured that

information was easy to receive and process – factors that are also likely to minimise the disruption to workload.

It is also noteworthy that, although drivers did not perceive differences in workload between conditions, there were notable reductions in either objective or subjective workload, from drive one to drive two in all of the four experimental conditions. This is likely to reflect increased route familiarity making the navigational process less challenging during the second drive, although it is worth positing that it may also indicate increased familiarity with the experimental procedure and test vehicle, thereby influencing drivers' expectations and perceived competence/workload.

10.1.3 Environmental engagement & Spatial knowledge acquisition

In addition to drivers within the NAV condition visually examining their wider physical environment on junction approaches significantly more than their Satnav counterparts, they were also able to remember significantly more of this environmental information, as indicated by their superior performance on a battery of post-trial environmental knowledge tests. Participants within the NAV condition generally displayed superior landmark and high-level survey knowledge than those participants who used a Satnav device to navigate experimental routes (see section 9.2.7, page 240).

Drivers who navigated experimental routes using the NAV system, were able to develop significantly improved landmark knowledge as a result of the systems landmark based, interactive navigational support. Participants followed guidance which utilised landmarks within the driving environment to assist with the accurate identification of upcoming manoeuvres, providing reassurance to drivers that they were travelling along the right path. These findings of superior landmark knowledge amongst NAV participants, may be attributed to landmarks being frequently referenced within system prompts. Moreover, this demonstration of superior landmark knowledge may be attributed to greater interactivity within the

systems' design. Permitting drivers to question route guidance, and encouraging system interactions, led to more occasions were landmarks and routes were mentioned and discussed between system and driver, resulting in participants remembering and recalling with significantly higher accuracy.

This enhanced interactivity within a navigation system also saw NAV participants benefitting from superior survey knowledge, allowing participants to identify and place parts of the experimental routes accurately in relation to one another. NAV participants who demonstrated this "map-like" understanding of the large-scale experimental space, were able to draw sketch maps containing significantly more detail than their Satnav counterparts. Additionally, the landmarks which NAV participants depicted within their sketch maps also reveal that the environmental information which participants remembered was largely shaped by the driver's personal interactions with the system. For example, those drivers who spontaneously engaged with NAV whilst driving, asking the system for additional environmental information (e.g. where they could rent an aeroplane nearby or average houses prices of an area), were not only likely to remember the systems' response, they were able to remember the location on route at which the system issued the information, subsequently incorporating the systems' response as a point-of-interest within their sketch maps.

10.2 DESCRIPTIVE MODELS OF PASSIVE/ACTIVE NAVIGATION

This section addresses research aim 2 and presents a series of descriptive models (Figure 10- 2) which detail each of the navigational methods examined as a part of this work. The models are displayed on an 'engagement' continuum, which displays passive navigation technologies at one end and the active at the other. Each of the utilised experimental methods are placed along this continuum according to the content of information they relay to the driver, the level of interactivity they permit, the driver's willingness or ability to engage with the navigational method and the subsequent impact upon the driver's cognitive map formation.

The top, central model depicts the Satnavs' interaction with the driver. Here, the Satnav device (represented by the central grey rectangle) issues information to the driver, allowing them to navigate their environment. These navigational instructions commonly take the form of auditory turn-by-turn prompts utilising distance-to-turn information, alongside directional (left, right, straight on) instructions. However, this information is issued in a one-way flow (from to system to driver), preventing driver interaction and route collaboration. Additionally, the content of such guidance, with its emphasis on distance descriptors, diverges from how humans naturally convey spatial information to one another. In this natural use, spatial language is not prepared to convey fine metric information. Therefore, because of the additional interpretations which the driver is required to perform to accurately relate issued route instructions to their corresponding environment, the interface is depicted as distant and an unnatural fit for the driver. The systems' content, presentation and interaction with the driver subsequently impacts upon the completeness of the driver's internal cognitive map, which remains fragmented despite the driver's ability to draw information from the environment, independently from the system.

The wayfinding information utilised by electronic navigation systems differs dramatically in its content and presentation compared to the

driver navigating with an in-car passenger. Navigational guidance issued by the informed and collaborative passenger frequently contained landmarks in place of distance-to-turn information, with familiar driver-passenger couplings commonly drawing upon previous experiences to situate route guidance. In addition to these differences in verbal route guidance content, the Satnav and in-car passenger both provide drivers with alternative, confirmatory visual stimuli, which acts as a secondary representation of route guidance, enabling drivers to locate or pinpoint the correct manoeuvre.

Drivers using a Satnav to navigate are provided with a visual display which presents a map view of the driver's immediate environment, frequently displaying corresponding map information for up to two manoeuvres ahead. Alternatively, those drivers receiving navigational guidance from an informed passenger were presented with accompanying hand gestures alongside verbal information for each navigational manoeuvre. Similarly, collaborative navigators frequently utilised these same non-verbal cues to pinpoint and identify navigational turnings, drawing the driver's attention outside of the vehicle, to the referenced point within the driver's immediate environment.

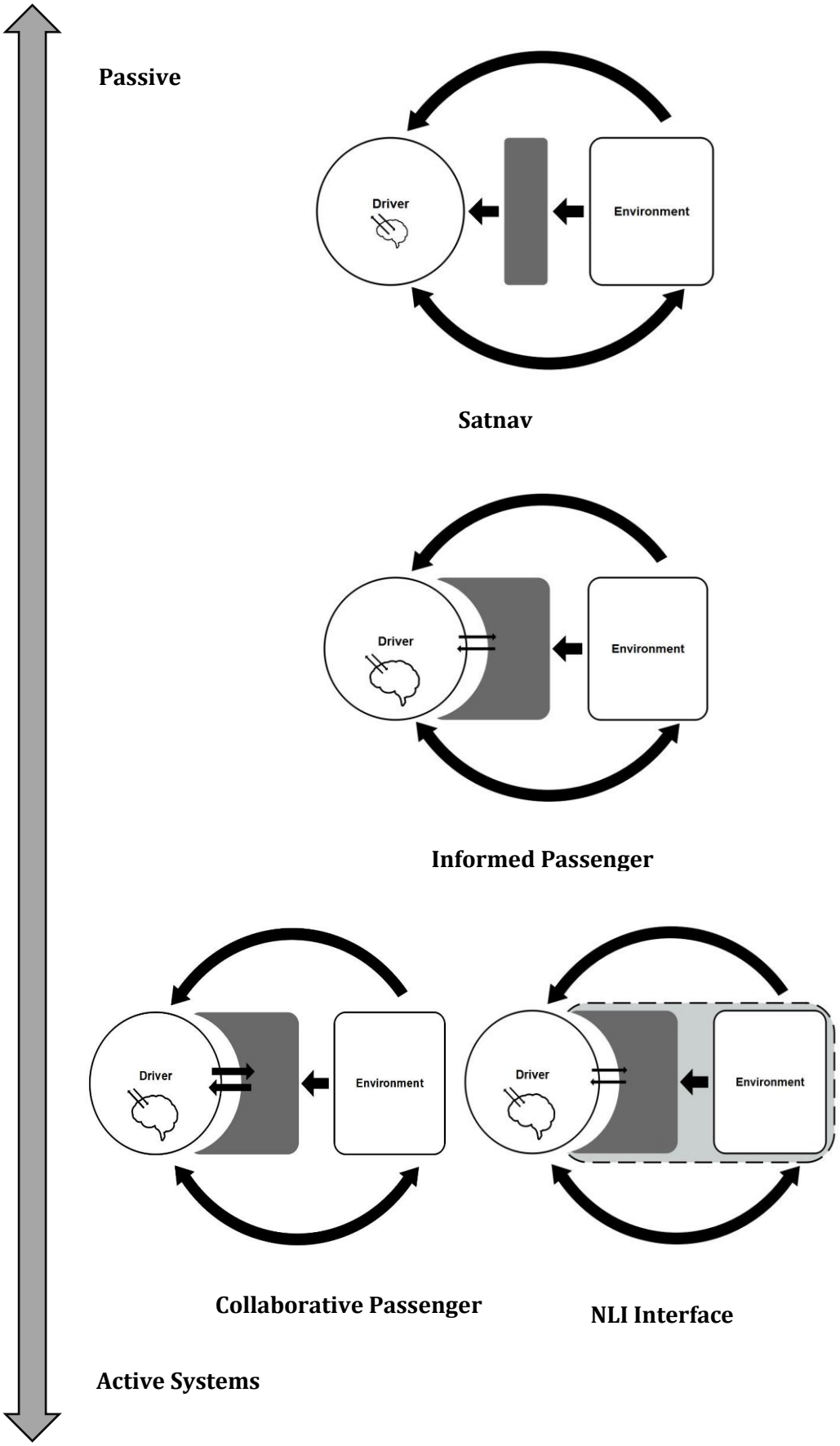


Figure 10-2: A series of descriptive models detailing each of the examined navigational methods - models are placed on a 'passive to active' continuum, highlighting the level of available navigational support

In addition to presenting differing visual cues (interface or passenger hand gestures) which served as a confirmatory function during navigation, the information contained within verbal route instructions differed dramatically as navigational methods moved from current passive systems to increasingly active driver-passenger pairings. Both informed passenger and collaborative guidance utilised a wealth of environmental information allowing the driver to make appropriate navigation decisions. However, whilst both navigational methods utilised environmental information and corresponding non-verbal cues within wayfinding exchanges, driver and passenger verbal exchanges within the collaborative condition were more interactive, which may be partly responsible for the enhanced environmental engagement (indicated through performance on environmental knowledge tests) observed within this condition.

Informed passenger drivers infrequently questioned route guidance information, rarely discussing the same environmental features as collaborative pairings. These differences in the level of interactivity between driver and passenger may be ascribed to the level of confidence placed in the navigator by the driver. For example, the informed passenger was presented to drivers as an 'expert navigator' who had prior experience with the experimental routes. By presenting the informed passenger as proficient navigator, adept at navigating within the experimental environment, drivers may have placed more trust in the guidance issued to them, rendering any additional navigational checks superfluous.

Alternatively, the pre-existing relationship between driver and passenger in the collaborative condition may have introduced a more social dynamic into the in-car environment which may have influenced the driver's willingness to engage. This increased sociability saw collaborative drivers comment on and question the route guidance issued to them. This increased cooperation saw the rigid task roles of 'driver' and 'navigator' become less formal, creating a navigation collaboration which operated as a shared experience for both driver

and passenger. These differences in the depth and interactivity of informed, and collaborative passenger navigational dialogue are represented within figure 10-2 by the larger two-way interaction arrows in the collaborative descriptive model, compared to the weaker interaction arrows in the informed passenger model. The greater interactivity observed within navigational exchanges of collaborative partnerships mean that the collaborative model is placed further along the engagement continuum, as a more 'active' navigational method.

However, as both navigational methods utilised the same (in-car passenger) interaction strategy and only the degree of familiarity between driver and passenger fluctuated between the two navigational conditions, both descriptive models will be discussed together here, as an in-car passenger navigational model. In both the informed passenger and collaborative models, the in-car passenger (represented by the central grey aspect on the middle and bottom left models), is depicted issuing information to the driver, allowing them to navigate their environment. These navigational instructions frequently reference landmarks at navigational choice points, using environmental features to reorient the driver or to affirm that they are on the correct route. This information is issued to the driver in a two-way exchange, allowing the driver the opportunity to check their understanding or question issued guidance. Additionally, within both sets of route guidance, emphasis is placed on landmark information, which previous literature has shown to be important to an individual's cognitive differentiation of an environment (Denis, 2017). Use of such information within route instructions provides the driver with distinctive cues which are easy to memorise and relate to the environment which they are travelling through. As landmark information is how humans would naturally describe route instructions and environmental space to one another, the navigational interface, which in this case is the in-car passenger (both informed and collaborative), is depicted as a close, natural fit for the driver. The navigational content of the passenger's route instructions, and the two-way interaction (both verbal and non-verbal), with the driver subsequently influences the completeness of the driver's internal

cognitive map, which has the opportunity to be further enhanced through the use of passenger hand-gestures, drawing the driver's attention outside of the vehicle towards the environmental scene.

These differences between the passive Satnav condition and the increasingly active informed passenger and collaborative conditions were also reflected in the completeness and accuracy of participant sketch maps, indicative of acquired higher-level survey knowledge. Participants in the collaborative navigation condition drew significantly more complex maps, populated with significantly more landmarks and identified significantly more points of route intersection than those participants who navigated with the assistance of a Satnav device. Similarly, informed passenger participants were able to remember and identify significantly more landmarks and pathways within their sketch maps compared to Satnav participants. These results could be explained by the differing verbal content of navigational instructions issued to participants and the use of frequent hand gestures within the collaborative condition (used occasionally within the informed passenger condition) which helped navigators to pinpoint turnings and highlight landmarks, accurately drawing the drivers visual attentions to a designated point in the road scene. The verbal navigational instructions, received by collaborative and informed passenger drivers, commonly referenced the world around them, e.g. "take a right turn after the leisure centre". In contrast, Satnav participants received traditional turn-by-turn guidance with the location of manoeuvres described using distance and direction descriptors. However, it is notable from participant sketch maps that some drivers in the collaborative and informed passenger condition highlighted landmarks which were not referred to in navigational instructions. This points to drivers in these conditions focusing more attention outside of the vehicle towards the environment, than those drivers following the guidance of a Satnav device.

However, as it is not always possible, or practical to expect that drivers would always be accompanied by an in-car passenger, who could assist with route navigation. The two-way information exchange

within the driver-passenger model was simulated (in another experimental condition) within an NLI, to explore how drivers may engage with future navigation technologies which are able to respond to additional information requests and the prevailing road context, by issuing contextually aware information to drivers.

Here, the NAV NLI system, is placed in figure 10-2 along the engagement continuum as an active navigation technology, which issues context dependent, landmark based wayfinding guidance through a two-way information exchange with the driver. The NAV interface is represented in the bottom-right descriptive model, by the central dark grey aspect. The system communicates information drawn from the driver's environment, allowing them to navigate through routes. Navigational instructions reference roadside landmarks at navigational choice points, using these environmental features to reorient the driver or to confirm path selection. This information is issued to the driver in a two-way exchange, allowing the driver the opportunity to clarify their understanding, or question issued guidance. Additionally, as the content of this navigational guidance was informed by a number of previous collaborative driver-passenger pairings, emphasis is placed on landmark information, over the traditional distance-to-turn guidance utilised by current navigational systems. The use of landmark information within navigational prompts, exploits how humans would naturally differentiate an environment. Such references provide us with distinctive cues to follow, signalling the parts of the route that require special attention and also drawing the attention to the driver's environment outside of the vehicle.

As landmark descriptors are frequently utilised in human descriptions of space, the NAV interface, like the informed and collaborative passenger conditions, is depicted as being a close, natural fit for the driver, communicating route information in natural navigation language. In turn, the navigational content and interaction style of the NAV system subsequently influences the completeness of the driver's cognitive map, which is depicted as larger and therefore more

developed than drivers utilising a Satnav device to navigate through routes. Whilst the NAV system provided the driver with enhanced landmark and environmental information in system communications, NAV was unable to replicate the hand gestures which were utilised frequently within the Collaborative passenger condition (and occasionally with the informed passenger condition). This meant that NAV interactions lacked the same dynamic, visual component as the collaborative condition, which helped to pinpoint turnings and accurately highlight environmental features. The subsequent addition of this gestural component within collaborative interactions resulted in richer interactions which may have contributed to participants drawings more detailed sketch maps (see section 6.4).

Finally, figure 10-2 depicts how the NLI system may be enhanced, with the addition of information from connected vehicle technologies, which could communicate real time route information to the driver such as current or estimated traffic information, obstructions in the road, or accidents ahead. This information, represented as a grey permeable structure, encapsulating the environment and NAV system, draws both components together to provide the driver with both stable and context-dependent environmental information, communicating this to the driver in a two-way information exchange.

The design of the NAV system, which references the driver's wider environment, encouraging a two-way interaction between system and user, is in contrast with the design of current passive navigation technologies, which issue distance-to-turn descriptors in a one-way information flow. However, the results of this work demonstrate that if future navigation technologies issue route guidance in a two-way information exchange, utilising landmark-based information (over distance descriptors) at navigational choice points, drivers could benefit from enhanced environmental engagement and more complete cognitive map formation. Through the regular use of such systems, it is anticipated that drivers may become less reliant on the system itself, particularly on repeated or regular journeys and begin to re-establish associations between viewing an environmental feature and the

related navigational manoeuvre (e.g. take the left exit at the roundabout, where the Fairham pub is).

10.3 PRINCIPLES FOR DESIGN OF FUTURE NLIS

To address research aim 3 the results from this thesis have been used to create a set of five design principles which should be considered within the design of future NLIs. Each of the principles presented below are supported by existing literature and include findings from the on road trials conducted as part of this thesis:

1. Navigation interfaces should encourage driver-system interaction

The work conducted as part of this thesis revealed the importance of interactions (both verbal and nonverbal) between the driver and the route direction producer (whether a passenger or system). Permitting interactivity within navigational exchanges allows drivers to check their understanding of route information, request additional guidance or request information in a format which they are better able to understand (e.g. the omittance of left and right direction descriptors in favour of hand gestures). The presence of interactivity within navigational exchanges can provide drivers with greater confidence that the path selections which they make on route are correct.

In the work conducted as part of this thesis drivers were able to interact with their navigational partner (or system) in three of the four experimental conditions (informed passenger, collaborative passenger and NAV). In these experimental conditions, prior to commencing each road trial participants were briefed to ask their navigational partner (or system) for more information if they didn't fully understand the navigation information which had been issued to them, or if they were unsure of the location of the next manoeuvre. As most drivers have had some experience navigating on-road with a passenger, this interactivity appeared to flow naturally during informed and collaborative navigational conditions. To ensure that drivers felt comfortable prompting the NAV system for additional information, NAV introduced itself prior to commencing the first experimental

drive (see section 9.1.4). Here, NAV explained its capabilities and emphasised that drivers should engage with the system in the same way as another passenger within the vehicle.

The importance of interactivity in navigational dialogue, is also emphasised in the early linguistic work of Wunderlich & Reinelt (1982) and (Couclelis, 1996). Here, the authors proposed navigational models largely centred around the communications which take place between the speaker, providing route instructions, and the addressee, who requested them.

2. Encourage visual interaction between the driver and appropriate features of the outside environment

Previous work has highlighted the importance of landmarks within human navigation and suggested that the employment of landmarks works best when accompanied by a 'prescribing action' (e.g. turn left at the Fairham pub) (Allen, 1997; Denis, 1997; Lovelace, Hegarty, & Montello, 1999). The use of landmarks in this way serves to reduce navigational uncertainty at points on route where directional choices are required.

Moreover, previous literature has also stated their importance when used to quantify progress (Lovelace, Hegarty, & Montello, 1999). Here landmarks act as confirmations that the driver is on the right path. The use of landmarks as route confirmations becomes increasingly important in the absence of a visual interface, along stretches of road where no action is required. Here, referencing a feature within the driver's immediate environment provides the driver with reassurance that they remain on the right path.

However, the selection of appropriate landmarks for use within route instructions can ultimately determine their perceived usefulness. Burnett, Smith and May (2001) identified a number of characteristics of 'good' landmarks, which systems should adhere to for best results, where the driving environment permits:

- Permeance – the likelihood that the landmark will be present in either form (shape/size) and label (name)
- Visibility – The landmark should be prominent regardless of conditions (e.g. season, weather)
- Usefulness of location – Landmark should be located close to a decision point or within close proximity of the driver if being used to quantify progress
- Uniqueness – a landmarks' individual appearance or singularity should ensure that it is not be likely to be mistaken for another object within the environment
- Brevity – The conciseness associated with the landmark's description – good landmarks require minimal information to be useable

In this research landmarks commonly featured in the navigational dialogue of the informed passenger, collaborative passenger and NAV system. In the informed passenger condition the decision was taken to use landmarks over distance-to-turn information to highlight navigational turnings as previous work has highlighted that humans have an inherent difficulty in judging distances, with distance estimation being particularly difficult when individuals are unfamiliar with an environment (May, Ross and Bayer, 2003). Whilst route training materials (see section 4.1.3) for the collaborative condition featured landmark references in the audio commentary it wasn't specifed that collaborative navigators should use landmarks to guide their partner. However, Collaborative navigators overwhelmingly chose to incorporate landmark references into their route guidance, using landmarks to highlight the location of upcoming manouveres and referencing environemtal features to reassure drivers of their correct progress along a route. As NAV guidance was constructed using the information contained within a selection of collaborative transcripts (see section 8.2), NAV also utilsied landmarks to pinpoint the location of navigation manouveres and to quantify the drivers progress along a route.

Furthermore, the flexibility of an NLI interaction meant that a greater number of landmarks could be utilised within verbal navigation

dialogue, compared to existing systems. Currently, for landmarks to be contained within verbal navigation prompts, the landmarks' form or function would require a succinct description, to avoid ambiguity or confusion (e.g. the church ahead). However, utilising natural language to communicate route information means that more descriptive cues can be used to highlight landmarks, allowing a larger number of environmental features to be utilised. For example, landmarks which may be partially obscured by another environmental feature can be readily described using natural language (e.g. the church behind the tree on your right). The ability of an NLI system to describe a broader range of landmarks opens up the number and types of landmarks which can be used to guide the driver during wayfinding.

3. System dialogue should adhere to conversational maxims (Grice, 1975) to promote 'natural' conversation

Natural language systems should adhere to the conversational maxims proposed by Grice (1975) to ensure that systems observe the same regularities as humans observe during system/user interactions. The NAV system incorporated these maxims into communications with drivers who subsequently demonstrated superior landmark knowledge (see pages 240-241) over their Satnav counterparts, drawing a greater variety of maps, which incorporated significantly more environmental features (see pages 246-249). The conversational maxims which the NAV systems utilised and how these might relate to other natural language navigation interfaces are presented below:

- **Quantity** – System contributions should be as informative as is required, only issuing information which is relevant to the current route or environment (unless the driver initiates an alternative information request). System contributions should therefore not contain any superfluous information
- **Relation** – Information issued by the system should be relevant to the current navigation task (either upcoming manoeuvre or wider environment) or be relevant to a prior driver-initiated request.
- **Quality** – Systems should only provide the driver with information which can be substantiated by adequate evidence

- **Manner** - System outputs should avoid any ambiguity in their expressions, offering the driver clear and concise navigational guidance which relates directly to their driving environment. Moreover, navigational instructions should be brief and avoid any unnecessary prolixity.

  In this research the NAV interface was able to adopt a number of strategies to ensure that these maxims were observed throughout experimental drives. For example, to avoid any confusion and ambiguity the interface only provided navigation information which was pertinent to the upcoming manoeuvre (relation). Similarly, only information which was relevant to the driver's current physical environment was issued to the driver, unless specially requested by the participant (manner). Where this additional landmark information was provided by the system, prior fact checks were carried out to ensure that only accurate information was issued to drivers regarding landmark origin, form and function (quality).

  In the case of the quantity maxim (which states that a conversant should provide no more or no less information than the conversation demands) it can be difficult for voice-based systems to gauge how much information is appropriate, frequently resulting in over-speak, providing the user with superfluous information. To remedy this, the NAV system allowed users to barge-in when the interface was speaking. In this situation, any utterances made by the driver stopped NAV from talking and prompted it to listen and interpret. This allowed the conversation to progress at an appropriate pace and gave the impression that NAV was listening to, and cooperating with, the driver.

4. System must actively support the different stages of the navigation task

The navigational information NLIs issue to drivers should offer active support throughout each of the stages of the navigation task. Throughout each of these stages systems should permit driver

interaction to reduce navigational uncertainty and enhance performance.

- **Preview** information to gain preparatory knowledge (e.g. at the roundabout ahead you'll be taking the first left onto Green lane)
- **Identify** information to pinpoint the location of the next manoeuvre (e.g. The turn is located after the traffic lights, before the petrol station)
- **Confirm** to establish whether the correct manoeuvre has been identified (e.g. Great! Green lane)
- **Confidence** prompts give reassurance that the correct route is being followed (e.g. On your right-hand side is Nottingham Trent university)
- **Orientation** information gives awareness of current location and wider environment (e.g. Clifton village is situated to the south of Nottingham City centre)

Throughout this work the NAV NLI consistently supported drivers throughout the preview, identify, confirm and confidence stages of navigation. As the navigational manoeuvres on experimental routes closely followed one another, detailed orientation information was not issued to drivers on route to ensure that navigational dialogue did not contain an excess of information which may have distracted drivers from the upcoming manoeuvre. Instead, information which was pertinent to the upcoming manoeuvre was prioritised whilst ensuring there was adequate time between verbal prompts where drivers could question issued route guidance and clarify instructions. However, away from an experimental paradigm, future NLIs could provide drivers with orientation information on stretches of road where no navigational action is required, providing enhanced environmental information to drivers without impacting navigational performance.

The subtleties of natural language mean that future NLIs have the potential to actively support drivers throughout each of these navigational stages without impacting their experience of workload. Where using a visual map or text would require drivers to perform

additional interpretations to process information, the intonations contained in natural language and placed emphasis on spoken words allows spoken information to be interpreted intuitively.

5. Encourage appropriate anthropomorphism

Anthropomorphism concerns the attribution of human characteristics to non-human objects, it is frequently used contemporaneously as a design metaphor to persuade and motivate users and to create novel and engaging products and methods of interaction (Large, 2013, pg. ii). This is typically achieved, as was the case with the NAV NLI, by endowing a product or interface with recognisable human features such as voice.

NAV can be characterised as an anthropomorphised interface as the system delivered navigational information to drivers in a similar manner as a human, referencing environmental features and responding appropriately to driver interactions. Previous work has shown that the mere presence of a voice within a system results in users anthropomorphising the technology (Large & Burnett, 2018, August) and, despite not specifically examining anthropomorphism during the NAV study, it was evident in a number of participant-system interactions described within this thesis (see pages 260-261). Therefore, this is something that should be considered in future natural language systems and hence represents an important design principle to be considered in the development of future NLI systems.

Future NLI interactions should aim to mimic a number of the behaviours observed within the collaborative condition to foster the most positive performance, and environmental engagement outcomes.

Where possible, systems should situate route guidance within the driver's prior experience. Either adapting language to subtly highlight when areas are travelled multiple times within a designated time period (e.g. Turn right and you're *back* on Clifton market square). Alternatively, systems could refer to the previous time the driver took

this route (e.g. take the A634 as if you're travelling to your mother-in-law's house).

Additionally, systems should be able to intelligently infer, via the use of conversational fillers (e.g. umm, hmm), whether a driver has understood route guidance or is having issues identifying the correct roadway on route. Humans are able to interpret what these sounds mean intuitively, quickly inferring whether the driver requires additional information or is content with the information they have received.

10.4 CHOOSING AN EXPERIMENTAL ROUTE AND DRIVING ENVIRONMENT

So that the experimental routes were not too simplistic and were representative of an everyday journey, there were a number of important features which were considered when selecting appropriate experimental routes within a suitable area to conduct the on-road trials. Future work within the driving navigation field could utilise this method to construct experimental routes which are designed to be suitably complex whilst lending themselves to post-trial environmental knowledge assessments:

1. **Participants should have no prior knowledge of designated test site.**

In line with the earlier work of Ishikawa & Montello (2006) and Ishikawa, Fujiwara, Imai, & Okabe (2008), it was important that all drivers who signed up to participate in each of the on-road trials had no prior knowledge of the Clifton area of Nottingham where each of the experimental routes was located. This was to ensure that any environmental knowledge which the drivers acquired could be attributed to the two experimental drives and the associated navigational method they were using, rather than any prior exposure.

2. **Participants travel routes twice, one week apart to replicate weekly travel to a meeting**

Building upon the earlier work of Oliver and Burnett (2008, September) who suggested that route exposure times within navigation research are often insufficient to build integrated spatial knowledge, a second drive was incorporated within the experimental design to increase each participant's environmental exposure time. It was hoped that this additional on-route time would promote driver engagement and encourage familiarity and the encoding of their spatial environment. This additional acquaintance and contact with an environmental is especially important to encourage the development of comprehensive survey knowledge which was examined as a part of this thesis.

3. Proximity of routes to main test site

The test area of Clifton, Nottingham was selected for a number of methodological and pragmatic reasons. Firstly, for practicality, experimental routes needed to be within fairly close proximity to the main test site (the University campus), promoting easy access to and from the routes for both the participants and researcher. Secondly, as Clifton is home to a competing universities campus it was anticipated that it would reduce the likelihood of prospective participants being familiar with this area. Finally, the area's roadways and environmental features allowed three routes to be developed which adhered to the constraints identified by Webber (2013), seen, and modified here within points 5, 6, 10 and 11.

4. Multiple routes

Drivers were required to navigate three consecutive routes during each test period. Similar to previous works which employed multiple routes within navigation paradigms (Ishikawa, Fujiwara, Imai, & Okabe, 2008; Huang, Schmidt, & Gartner, 2012) , utilising multiple routes within the experimental method ensured that participants approached portions of the routes from different directions, allowing participants to experience various environments in Clifton within a short driving time. It was anticipated that constructing routes in this way would foster the development of higher-level survey knowledge.

5. **All routes should be completed within approximately 45 minutes of driving time**

Following the earlier recommendations of Webber (2013) routes were constructed in a way which permitted participants to complete all routes (and the travel between each route) within a 45 minutes driving period. Each of the three routes utilised within this thesis could be completed by participants in around 10 minutes, allowing for five minutes travel time (under experimenter guidance) to the start point of the succeeding route. These time periods were selected so that routes were not too simplistic and provided a challenging navigation scenario to participants. Conversely, it was important that routes were not overly complicated to promote the development of environmental knowledge, allowing for comparison of navigational method.

6. **Routes should each intersect with one another along one distinct point**

Previous work (Oliver & Burnett, 2008, September) highlighted that incorporating route overlap and intersection along multiple points was advantageous to the development of participant spatial knowledge. Reasoning that in real life environments the development of a cognitive map involves significant time and multiple exposures. Therefore, the potential hindrance to cognitive map formation associated with the relatively short time scale which participants spent on-route could be overcome by careful route design which provided maximum route exposure within a short timescale. Following the recommendations of this work experimental routes were designed to intersect with one another along one distinct point on each route (3 route intersections in total). Distinctive environmental points were selected for route intersections to increase the likelihood that participants would identify the route crossover. Subsequently developing an understanding of how each of the routes related to one another and, as a result, how the environment is structured.

7. Clearly defined start and end points

Similar to the earlier works of Oliver & Burnett (2008), Webber (2013) and Gramann, Hoepner, & Karrer-Gauss (2017), each of the three experimental routes had a clearly defined start and end point which was communicated to participants prior to them commencing the routes and subsequent to their completion. Whilst participants were not informed of the battery of post-trial environmental knowledge tests, the clear separation of each route helped participants to see each drive as a distinct journey, which subsequently aided their performance on the iconic recognition tasks.

8. Different types of environments

Each of the experimental routes were placed through environments, characterised by a number of differing features along its course. As one of the objectives of this thesis was to explore how differing navigational methods impact driver environmental engagement, it was important that the driver was presented with different, distinct environments, as in previous navigation research (Burnett, 1998; Gramann, Hoepner, & Karrer-Gauss, 2017), which were representative of a journey through a town or village. Therefore, it was ensured that each of the below elements were prevalent, were possible, within each of the three experimental routes.

- Housing estates
- Highstreets
- Green spaces
- Mixture of A and B roads

9. Different junction types

Burnett (1998) highlighted the need to incorporate varying junction types within on-road navigation research to ensure that experimental routes were suitably complex and the navigational decision points which they contained, were representative of everyday driving. To ensure that each of the three experimental routes which were employed within the

methodology of this thesis adhered to these recommendations each experimental route path was directed through the junction types listed below:

- Roundabouts
- T Junctions
- Side turnings

10. Routes should contain a minimum of six decision points

Similar to the earlier works of Webber (2013) and Gramann et al (2017) a minimum of six decision points was included within each of the three experimental routes to ensure that they were not too simplistic, were of an adequate length and covered an appropriate distance for use within a driving navigation methodology.

11. The routes should be similar in terms of the number of salient landmarks or features

Each of the experimental routes contained a similar number of landmarks, ensuring that all drives were constructed to be equally engaging for participants. These landmarks and environment features were located throughout the course of route, as in earlier navigation research (Oliver & Burnett, 2008; Gramann, Hoepner, & Karrer-Gauss, 2017) serving to assist wayfinding at navigational decision points and acting as distinct environmental reference points for the driver (e.g. block of flats in the distance).

10.5 WIZARD-OF-OZ METHODOLOGY

The Wizard-of-Oz methodology utilised within this thesis represented a novel platform in this context allowing the researcher to observe and comment upon the behaviour of drivers who were engaged with a fully functioning, natural language digital driving assistant. The implementation of this approach allowed a range of user interactions and utterances to be examined and appropriately responded to, which would not be supported by current

speech-based system capabilities. Therefore, utilising this approach encouraged a free-flowing dialogue between system and user, limiting system misinterpretation and any 'out-of-domain' responses issued by the system when user requests would be beyond current system capabilities (e.g. "Please can you repeat", "sorry, I don't understand"). Indeed, Large et al (2017) highlighted the usefulness of the Wizard-of-Oz paradigm when exploring novel technology solutions, stating that such "*empirical observations (are) the best way to explore systems for which no complete a priori model exists*" (pg. 60).

To ensure that user interactions with NAV were representative of potential driver interactions with future natural language technologies, it was important that participants were convinced that they were interacting with a system rather than a human interlocutor. To ensure this, the professional actor, Pablo, who acted as the wizard throughout the on-road trial, had received prior training in the experimental environment and system responses which would be appropriate in line with the current experimental paradigm (e.g. as the focus of the study was navigation performance, the system was not permitted to play music or give news updates at the drivers' request, allowing the condition to be comparable to previous trials). Additionally, Pablo held extensive experience in simulating a digital driving assistant, having taken part in a number of similar, simulator-based research studies prior to commencing this work (Large, Clark, Quandt, Burnett, & Skrypchuk, 2017;Large, Burnett, Anyasodo, & Skrypchuk, 2016). This meant that he was capable of the ad-hoc formulation and delivery of high-functioning AI responses, in reaction to user requests.

Furthermore, great care was taken to uphold participant misdirection throughout this final study. For example, prior to their initial first drive, participants were briefed that the 'prototype' NAV system utilised a live visual feed from the in-car dash cam (positioned underneath the rear-view mirror) to issue them with context sensitive route guidance. Explaining the hardware in this way and presenting the system as a prototype meant that participants 'explained away' any system miscommunications as early development glitches, and were less suspicious of the hardware within the test vehicle

having been provided with a feasible explanation of how it assisted with system function.

> Providing the approach is well managed, the Wizard-of-Oz methodology is therefore capable of providing a more ecologically valid statement than other investigations into 'novel' technology, which may instead rely upon isolated exposure or self-reported, subjective rating scales to elicit results. For the current research, conclusions can be drawn with confidence regarding the likely ways that drivers will interact with a future natural language navigation system and these can be used to reliably inform the design and development of such systems. This approach is therefore of relevance to other researchers working in the field of voice interaction and the thesis as a whole is also likely to be of interest to the larger navigation and user experience (UX) community.

10.6 CONTRIBUTIONS OF THESIS

The main contributions of this thesis are detailed in table 10-1, highlighting the novel contributions to research which have been identified at different stages of this research. The contributions to knowledge include a number of methodological guidelines for on-road navigation research and the selection of appropriate experimental routes to support this work. In addition, a series of descriptive navigation models, presented within this thesis, represent novel illustrations which highlight the available support and interaction channels of active and passive navigational methods. The workload and environmental engagement implications of these active and passive navigation technologies are also discussed in terms of how the results obtained within this thesis, either support or contradict previous literature.

The contributions table also emphasises, the novel application of the Wizard-Of-Oz methodology, within the NAV on-road trial which simulated a garrulous passenger, issuing navigational information in a two way-exchange. Finally, a series of design principles are presented which draw upon the results of this thesis and previous literature recommendations to inform the development of future navigation NLIs.

Finding/Research	Novel Contribution	Chapter
Guidelines for appropriate route selection for an on-road navigational driving trial	This work presents a set of guidelines for the selection of *appropriate* navigational routes to examine on-road navigation. Guidelines are informed by the strategies employed within the methodology of this thesis and previous literature recommendations regarding the selection of appropriate routes within navigation experimental paradigms.	Chapter 10
Workload implications associated with the adoption of *passive* and *active* navigational methods	Previous work has suggested that the use of current passive navigation technologies is associated with lower initial levels of workload than active navigational methods. Investigation into increasingly active navigation technologies has suggested that this isn't necessarily the case, and suggests that drivers utilising either passive or active navigation technologies experience equivalent levels of initial workload.	Chapter 5 Chapter 7
Environmental engagement implications associated with varying navigational methods notable for their increasing interactivity	Previous work has highlighted the environmental disengagement and detrimental spatial knowledge implications of navigating using passive Satnav technologies compared to active navigational methods. However, much of this work has utilised landmark enriched turn-by-turn guidance or traditional paper map methodologies to represent active navigational methods. The work conducted within this thesis demonstrates the clear spatial knowledge benefits for *active* navigational methods which utilise two-way conversational language to deliver navigational instructions.	Chapter 6 Chapter 7
A series of descriptive models highlighting the level of available support and the environmental engagement implications of passive and active navigation technologies	A series of descriptive models, detail each of the navigational methods, examined within this thesis. The models are displayed on a 'engagement' continuum, which displays passive navigational technologies at one end and active at the other. Each of the utilised experimental methods are placed along this continuum according to the content of information they relay to the driver, the level of interactivity they permit, the driver's ability to engage with the navigational method and the subsequent impact on cognitive map formation.	Chapter 10
Methodology	Novel application of a Wizard-of-Oz methodology to explore driver interactions with a navigation NLI to yield rich insightful data in a real world navigational task and derive appropriate conversation prompts and dialogue for a natural language navigation system.	Chapter 9
Principles of design for the design of future natural language navigation interfaces	Based on the work of this thesis and previous literature recommendations, industry relevant recommendations are made for the design of future natural language navigation aids which support the user over the course of the navigation task and encourage an interactive, two-way navigation exchange between driver and system.	Chapter 10

Table 10-1 Novel contributions to knowledge arising from work conducted within this thesis

10.7 EXPERIMENTAL LIMITATIONS AND METHODOLOGY

The next section will discuss the limitations of the methodology employed within this thesis, subsequently reflecting upon the employment of an on-road paradigm in which to explore a number driving navigation methodologies.

10.7.1 Sample size & Generalisability

Whilst, the sample sizes of the navigational conditions detailed within this thesis were similar to those utilised within prior driving navigation research (Burnett & Lee, 2005; Forlizzi, Barley, & Seder, 2010), the selection of a relatively small number of drivers within each condition may not be fully representative of the driving population at large.

However, concentrating on the behaviour of a relatively small number of participants enabled greater in-depth analysis. Indeed, the level of analysis required for a larger investigation at this stage would not be practical given the number of participants required for results to be generalisable across the driving population. As the methodologies employed within this thesis involved a labour-intensive process of analysis, it was decided that a smaller sample size would allow for the level of depth necessary to detail how different navigational methods can influence a driver's cognitive map development and workload, whilst providing an initial indication of the behaviours and interactions exhibited participants in response an NLI. While this has allowed for an in-depth, comprehensive investigation into environmental engagement and workload, it could be argued that the conclusions drawn are specific to the pool of participants used within the four navigational conditions, and to the specific environmental and experimental context.

Future work, exploring the feasibility of natural language navigation systems should therefore involve a larger sample size in order to generalise driver interaction strategies and responses to system requests to the broader population. Defining the nature of driver interactions with a natural language system across a larger sample of the population could be done within a driving simulator, saving time and expense on the experimental setup and increasing experimental control. Moreover, from an interaction perspective, previous work (Large, Clark, Quandt, Burnett, & Skrupchuk, 2017; Large, Burnett, Anyasodo, & Skrypchuk, 2016) has found success in utilising this approach to examine driver interactions with natural language interfaces. However, as noted in chapter 3 this would rely on the development a fictional navigational scenario where the driver's experience of workload and engagement within the simulated environment would not be an accurate reflection of how they might respond within the real-world.

10.7.2 Individual differences in response to NLI

Within the NAV condition participants were observed interacting with the NLI a number of differing ways. Some participants treated the system as a loquacious in-car passenger, asking the system for additional information and responding each of the system outputs politely and in a timely manner. However, a number of participants' interactions with the NLI treated the system as a subordinate, issuing perfunctory responses, frequently ignoring system requests or issuing contradictory or blunt responses

Whilst participants' interactions with the NLI differed from driver to driver, stark behavioural differences were frequently observed between participants from differing cultural backgrounds. Previous literature has highlighted how preferences for navigational information differ from culture to culture. For instance, Mohd-Hasni (2012) and Large et al (2017) specifically examined how individuals from varying cultures differed in their preference for in-car navigational interfaces that varied in the information density

displayed, and demonstrated differences in information preference and communication strategies during wayfinding.

Although the literature has demonstrated a link between culture and navigation information requirements and communication strategies (Mohd Hasni, 2012, Jeon, Riener, Lee, Schuett, & Walker, 2012), it was decided to not specifically control for, or target a particular cultural affinity or background during participant recruitment. This was because the aim of the of this thesis was to explore driver environmental engagement and workload more generally, rather than investigate this from a specific cultural standpoint. Additionally, as participant selection was already bound by a number of recruitment requirements, reducing the participant pool further by only targeting a particular culture may have inhibited the recruitment of the required number of participants for each experimental condition.

However, as NLIs represent an emerging technology it is important that future work specifically considers individual differences, such as culture, gender, age etc. during driver interactions with speech-based systems, so that next generation system can be sensitive to variations in user preference and interaction strategies.

10.7.3 Replication of passenger gestures

Participants within the collaborative navigation condition and drivers within the informed passenger condition relied heavily on hand gestures to interpret verbal navigational guidance and communicate spatial information within issued wayfinding instructions. Participants acting as navigators within the Collaborative condition were frequently observed using accompanying hand gestures to pinpoint navigational turnings and highlight landmarks to ensure the driver identified and selected the correct roadway at navigational decision points.

Drivers frequently responded to the use of passenger hand gestures with a corresponding hand movement which allowed them to both

check their understanding of the information issued to them, and provide a confirmation to the passenger that they had correctly interpreted the information which had been issued.

Previous work has demonstrated how the use of gestures within spatial interactions can assist in both the communication and understanding of spatial information (Atit, et al., 2013; Alibali, 2005; Kang & Tversky, 2016). Therefore, it is possible that the omittance of such cues within the NAV condition may have hindered the drivers understanding of the verbal navigation information issued to them (although the navigational performance and environmental engagement measures suggest otherwise). Despite such hand movements increasing the clarity and communication of spatial information, it was decided that any attempt to replicate such movements using current technologies would not provide an equivalent interaction in terms of the precision and responsiveness of gestures performed by passengers within the driving cab, in a dynamic driving environment

Future work could assess the feasibility of augmented windshield displays or digital in-car avatars to simulate gestures within real time, such technologies would allow for accurate positioning and placement which correspond to the intended area of the driving scene, reducing the likelihood that imprecise gesture position would influence the inaccurate selection of roadway. Moreover, the anthropomorphism associated with the introduction of digital avatars, could offer additional social interaction benefits by facilitating the driver's interpretation of information and issuing personalised, precise multi-modal support (Okamoto & Sano, 2017, September). Initial explorations to explore such concepts could take place within a simulator environment to ensure that any issues associated with display washout would not impact the interpretation and understating of visual cues.

10.7.4 On road trials – Ecological validity Vs Experimental control

The decision to utilise a real, on-road environment to explore each of the navigational methods detailed within this thesis ensures that the resulting data benefits from having high ecological validity. Employing an ecologically valid method by utilising the same navigation tools which drivers may employ in a real-world setting (a commercially available Garmin satnav and an in-car passenger) and conducting the study in a naturalistic on-road environment, ensures that the resultant behaviours exhibited by participants during each of the experimental drives represent their natural interactions and navigational decisions, made when driving and following wayfinding guidance in an unfamiliar environment.

Whilst research conducted in the real world is able to generate generalisable results which are grounded in the situated task under examination there are also a number of challenges associated with experimental control and the implementation of identical conditions for each participant, within a dynamic and changeable environment. Within an on-road environment these challenges can include (but are not limited to) roadworks, changeable weather conditions, fluctuating traffic and seasonal change (of concern in a between subject's design conducted over the course of the year – see section 9.1 for dates of each conditions testing period). Whilst the nature of research in the real world means that experimental results will always be subject to confounding variables, a number of adaptations were made to the experimental methodology of this thesis to address this:

Traffic

Road trials were conducted outside of rush hour traffic so that some participants did not spend disproportionally longer on route than others. Conducting on-road trials between this window of 10am and 4pm meant that morning and evening rush hour traffic was avoided,

and all experimental trials took a similar amount of time to complete. As on-route times were similar for each participant, route learning could therefore be confidently attributed to the navigational method to which the driver was assigned rather than the time which the participant had spent on route.

Seasonal change

Each of the navigational conditions (Satnav, Informed Passenger, Collaborative, NAV) described within this thesis represents a separate on-road trial which was conducted throughout the three-year thesis period, at different points in the year. Conducting the road trials throughout the course of the year meant that participants sometimes travelled routes in differing seasons, depending on navigational condition. So that post-trial tests accurately reflected what participants had experienced whilst driving the images presented to participants within the landmark and route knowledge tests were changed to reflect the season in which the road trial was conducted (see appendix B). This was important as the presence or absence of foliage on trees, at the roadside could change the focal point of the driver on the junction approach. In summer, with an abundance of leaves the tree may be the focal point. However, in winter when the leaves were absent, the pub behind the tree may be what the participant had chosen to focus on. It was therefore imperative that images presented to participants during the post-drive evaluations reflected their immediate experience.

Roadworks

As part of the planning for each of the four road-trials, any planned and current roadworks were assessed along each of the experimental routes. Routes were driven to establish any planned road works which were expected to start over the arranged test period. Additional checks were then performed by consulting the Nottinghamshire council's website (https://nottinghamshire.roadworks.org/) which lists all roadworks and any likely delays. The test periods for each study were then planned around such works to avoid delays and

additional time spent sat in traffic on route which may have influenced the participants acquired spatial knowledge.

10.7.4.1 The preference of on-road trials over simulated environments within driving navigation paradigms

Whilst the above considerations went some way in limiting the effects of the confounding variables, associated with field-based studies, the changeable nature of the on-road environment means that they are unable to be designed out completely. Recently, due to the advancements in technology, the literature has recommended utilising a virtual environment to explore both human and driving navigation. Within a virtual reality (VR) environment participants are placed within a three-dimensional simulated space, which updates in real time in response to their manipulations (Azuma, 1997; van der Ham, Faber, Venselaar, van Kreveld, & Löffler, 2015). Virtual locomotion can then allow participants to move around this simulated world whilst remaining in a restricted physical space (Templeman, Denbrook, & Sibert, 1999). VR can therefore be a useful and versatile research tool, in which environments can be constructed with relative ease and controlled exactly to the experimenter requirements, ensuring each participant is presented with an identical environment each time.

However, navigating within a virtual environment lacks the same contextual cues associated with moving around within real world environments, with even the best virtual environments being criticised for being stark, deserted spaces (Spiers & Maguire, 2006). Additionally, previous work has suggested that, whilst landmark and route knowledge were at equivalent levels in participants who had learned an environment using either real world exploration or virtual means, for higher level survey knowledge, there are notable differences in acquired knowledge (Van der ham et al, 2015). Here, participants who learned an environment through real world exploration performed better than their virtual counterparts on

pointing and map-drawing tasks. Van der ham et al (2015) attributed such differences to the variation in locomotion between the two conditions. In a real environment locomotion is present, as individuals need to physically move through their driving environment to reach their goal, therefore adding an additional vestibular sensory input during learning. However, within a virtual environment locomotion is absent or limited, and whilst the virtual environment allows individuals to 'drive' routes it is difficult to replicate that same sense of journey for the individual whilst they remain sat in the same laboratory space throughout the drive. Subsequently, this means that the directional information and vestibular inputs derived from interactions and movements within the environment are missing. Therefore, whilst participants driving within a simulator may be displaced to a different visual environment from where they began, they lack the same directional, sensory information of how they got there.

As participants were being assessed on their acquisition of landmark, route and survey knowledge, it was important that the environmental knowledge acquired by drivers was an accurate reflection of how that particular method of navigation could impact a driver's environmental learning in the real-world. Therefore, despite concerns expressed in the literature regarding experimental control and work within the real-world, for the purpose of this thesis it was decided that the on-road environment would provide the most insight as to how drivers respond to each navigational method, whilst responding to the varying task demands of driving.

10.8 RECOMMENDATIONS FOR FUTURE WORK

Human factors research regarding in vehicle navigation systems represents a field which has shown a continuing interest and adaptation over the past twenty years. This thesis has explored how future systems could utilise the driver/passenger collaborative paradigm to inform natural language navigation systems, which would

issue environmentally embedded, interactive navigational support to drivers subsequently addressing the environmental engagement concerns associated with the use of current technologies. Research regarding system redesign provides a number of diverse solutions, including the use of vibrotactile impulses as a navigation aid and personalising system guidance to encourage safer driving and increased mobility within younger and older driving populations respectively (Bengler, et al., 2014). Although the personalisation of system interaction is discussed within this section in relation to the driver's social environment and context of use, the proposed recommendations for future work, will reflect upon those solutions which have the potential to enhance user interactions within natural language navigation systems, which simulate driver/passenger interactions.

10.8.1 Extension of NLI dialogue

It is proposed that by adapting of the methodology employed by Burnett & Oliver (2008) the dialogue of NLIs could be extended to highlight previously traversed areas, encouraging route familiarity. The authors made adaptations to a basic turn-by-turn navigation system design, incorporating a range of additional features; including landmarks, compass bearings and previously traversed routes. Additional information was communicated to the driver either visually (compass bearings/previously traversed routes) via the systems visual interface, or through the systems auditory route guidance instructions (landmarks). Findings revealed that users of the learning-oriented system displayed better memory for driven routes when compared to those drivers navigating using the basic turn-by-turn system. There was also evidence that participants utilising enhanced guidance developed more complete cognitive maps, subsequently drawing more detailed sketch maps of the traversed virtual world.

Incorporating this information within a NLIs dialogue would require subtle changes to the language utilised by the system, to highlight to the user that they are travelling along the same section of road as a

previous, prior journey. A number of participants within the collaborative condition were observed making similar modifications to their navigational guidance, where portions of the routes intersected, meaning that participants travelled sections of some routes twice, on the same experimental drive. In such instance's participants were seen making subtle adjustments to the language within navigational prompts e.g. the use of the word 'again', and also reframing subsequent guidance to explain how the upcoming navigational manoeuvre would differ from their previous encounter.

Participant 8: Drive 1 – Route 3

Passenger: So, we're going to go past the leisure centre *again* but this time we're going to carry on just after it (gestures) *rather* than carry on.

Participant 1: Drive 1- Route 3

Passenger: There's Iceland again, yeah (gestures). So effectively we're going to get to the leisure centre *again* but *instead* of going straight on past it, we're gonna turn right just after it.

Participant 14: Drive 1 – Route 3

Passenger: So, we keep going straight, heading for that big block of flats *again*.

Making such adjustments to NLI system language would allow researchers to determine whether highlighting the previously traversed routes of drivers, within system verbal prompts, encourages a better memory of the areas through which they have travelled.

Another additional modification, proposed within earlier literature, suggests that the landmark information incorporated into verbal navigation prompts, could be adapted to appeal to driver interests and preferences to encourage enhanced engagement with the driver's environment. Gramann, Hoepner, and Karrer-Gauss (2017) examined whether modified navigation instructions supported incidental spatial

knowledge acquisition. Using a virtual driving environment, the authors instructed participants to navigate through urban and suburb environments following the assistance of either a traditional turn-by-turn system (control group), or one of two modified systems. Modified systems utilised traditional turn-by-turn guidance at decision points in additional to either (i) personally irrelevant landmark information, or (ii) landmark information which had been tailored according to participants' individual preferences regarding food, hobbies and interests.

Gramann et al (2017) found that, whilst the driving performance of participants did not differ significantly between navigational conditions, significant improvements were observed in both of the modified navigation conditions, across each of the three measures of spatial learning. Those participants receiving modified guidance performed significantly better on subsequent unaided navigation of the initial route, landmark recognition tests and sketch map drawings, indicating that the addition of verbal landmark cues is able to assist a driver's spatial learning.

Future work could build upon these findings to examine whether the incorporation of personally relevant landmark information impacts spatial knowledge acquisition across more complex routes, representative of everyday journeys. Additionally, the landmarks at which drivers are offered this additional, subjective information could be limited to those which the literature has deemed to be 'good' landmarks. That is, additional information, shaped by driver preference, could be issued at those landmarks which are visible to the driver from a distance, are likely to be a permanent fixture within that environment, are unique and in contrast to their surrounding environment and are placed at a useful location within the environment (i.e. close to a navigational decision point).

Creating a subjective navigation experience for drivers at selective landmarks, on more complex routes would allow researchers an insight into the most effective ways to implement landmark guidance to drivers with differing spatial abilities and preferences.

10.8.2 Include broader survey knowledge information into wayfinding guidance

In addition to modifying verbal navigation prompts to highlight previously traversed routes and issuing enhanced, personalised landmark information to encourage spatial knowledge acquisition. The literature has also proposed that broader survey knowledge information could be incorporated into wayfinding guidance to encourage a deeper understanding of the driver's wider environment and how the placement of areas within urban spaces are interconnected.

Lynch (1960) carried out a number of early influential studies to determine what aspects of a large-scale environment people contain within their cognitive maps, and found that people tend to categorise their environment into five types of elements.

- *Paths* – defined as the channels along which people move e.g. streets, footpaths etc.
- *Nodes* – defined as the points where several paths meet e.g. junctions.
- Landmarks - defined as external reference points which are easily distinguishable from a distance. Towers, monuments certain buildings and bridge are all examples are types of landmarks
- *Districts* – defined as medium-to-large areas of an environment which the observer can mentally "go inside of", and are easily distinguished as having some common characteristics e.g. city centre, old town, business district.
- *Edges* – defined as the linear elements which are not considered as paths, they are usually, but not always the boundaries between two different district or areas e.g. rivers, walls, fences.

The work within this thesis has argued for the incorporation of landmark information into *verbal* navigation prompts, suggesting that modifying a systems' verbal dialogue by incorporating environmental references, alongside current node and path information, can enhance a driver's spatial learning. However, recent work by Thorn (2018) has

suggested that, rather than modifying a systems' verbal outputs, it is the addition of supplementary visual information (e.g. augmenting a *visual* map view to incorporate additional district and edge information) which could support a driver's spatial knowledge acquisition, at a deeper level of understanding.

Thorn (2018) utilised an augmented map view to highlight the range of distinct regions within the suburb of Petone in Lower Hutt, New Zealand. Participants were provided with either an augmented or a standard map view (control), on a tablet device and were requested to follow guidance through a pre-defined, experimental route. The route for the driving task was comprised of eighteen navigational choice points along a 4.1km path. The control group was issued navigational prompts at each of these choice points, with participants receiving the additional augmented guidance being issued with a further ten instructions containing enhanced regional information. All participants were guided through each of Petone's six regions on route. Those participants receiving additional, augmented guidance had access to each of these regional boundaries via their augmented map view, with additional information being issued to them upon entering or exiting each of these defined regions. On completion of the test route, participants were asked to complete a series of navigational exercises which saw participants being dropped at a number of predefined locations and shown an image which they were required navigate to, via the fastest route.

Participants receiving the additional regional information demonstrated superior task completion rates (lower actual, or near-miss navigation errors) over those participants receiving standard guidance, suggesting that incorporating pre-defined regions to navigation instructions does impact on drivers' understanding of their wider environment.

Future work could build upon these results and the findings within this thesis to explore how the incorporation of additional environmental elements within route guidance can impact on driver's cognitive map formation. Such guidance may be issued to drivers using

an augmented map view, administered via visual interface or full windscreen augmented reality (AR) display. A concept previously proposed Kim and Dey (2009, April) who suggested that full windshield navigation displays could remedy the decline of spatial cognition in the elder driving population. Alternatively, this information could be relayed to drivers through the verbal route guidance of NLIs, using modified system language to notify drivers of their entry and exit through predefined city districts.

10.8.3 Use of AR to simulate passenger gestures

Whilst the NLI interface, administered via Wizard-of-Oz methodology, was successful in simulating the dialogue and navigational instructions of a loquacious in-car passenger. Spatial hand gestures represent an integral element of the navigational exchange between driver and passenger which the NLI was unable to replicate. Hand gestures are frequently used to convey spatial information, within human interactions, where these habitual movements are usually intended to enhance or supplement their communicative statements (Allen, 1997).

The literature has suggested that the use of gestures to support spatial language can have benefits for both the speaker and the addressee. For the speaker, the action of producing gestures assists with the conveyance of spatial information, such movements represent communicative actions which can facilitate the swift expression of thought, allowing the speaker to quickly draw the addressee's attention to an area, or feature within the environment, without the requirement for a lengthy verbal description.

Alternatively, the presence of gestures in verbal descriptions assists the addressee by helping them to separate relevant from non-relevant environmental information. In this respect, "gestures help to organise the conversational space into a salient foreground and an unrepresented, diffuse background" (Atit, et al., 2013, pg 5).

The performance of gestures was frequently seen, between driver and passenger, within the collaborative navigation condition. Passengers commonly utilised hand gestures and head nods, alongside verbal navigation information, to highlight a landmark or pinpoint the location of a required navigational manoeuvre, within the driver's wider environment. When gestures were utilised to highlight navigational turnings, drivers would frequently meet the passenger's gesture with a counter gesture. Here, they driver would point, or gesticulate toward the area outside of the vehicle to verify that their interpretation of the passenger's prior gesture was correct. This interaction served as a confirmation that both driver and passenger were referring to the same environmental point or roadway.

These non-verbal exchanges were observed frequently between collaborative driver and passenger pairings, enhancing the verbal route instructions issued by the passenger by directing the drivers gaze toward an area of driving the environment, which was germane to the accurate completion of the upcoming navigational manoeuvre. Such interactions are able to assist drivers during navigation as they can be issued quickly, either in response to additional driver questioning (regarding the location of a manoeuvre) or in support of verbal navigation instructions. The speediness such interactions subsequently benefits driver navigational performance by allowing drivers to react quickly within the dynamic and changeable road scene where they may be travelling at speed.

Despite the use of spatial gestures being an integral component within human navigation and the conveyance of spatial information (Alibali, 2005). Such gestures were not replicated within the NAV experimental condition due to technological and time constraints (see section 10.4.3). Moreover, as one of the main aims of this thesis was specifically how verbal route guidance (notable for its interactivity and its landmark based information), could impact a driver's navigational performance and environmental engagement, the other non-verbal components observed within human navigational interactions were

outside of this focus and therefore, were not replicated within NAV system interactions.

Future work may consider how the addition of system 'gestures', could enhance the navigational performance of drivers and their interpretation of verbal route instructions. Such gestures may build upon the previous work of Bolton, Burnett and Large (2015) who utilised a head-up-display to highlight key environmental features within an 'area-of-interest' box. Utilising this approach at navigational decisions points, resulted in drivers making more accurate navigational decisions compared to those using a traditional-turn-by-turn display. Future work could build upon these findings, utilising an NLI alongside full windshield display to highlight areas of interest or roadways to indicate pertinent environmental and route information to the driver. Providing the driver with a secondary, visual representation of route information, which corresponds directly to the environment outside of the vehicle, could assist navigational decision making, helping to reduce navigational uncertainty in instances where there is an absence of landmarks, where junctions may be located close to one another, or where roadways or turnings may be hidden from the drivers' view.

10.8.4 Context of use variables & the user experience

Finally, future work may consider exploring important context of use variables which may impact a driver's navigational performance, cognitive map development or their willingness to spontaneously engage with an NLI.

Previous literature has discussed how those individual differences amongst drivers, related to their sense of direction and personal wayfinding strategies, can play an integral role in cognitive map formation and navigational performance. Baldwin (2009) found that in drivers with a poor sense of direction, auditory route guidance facilitated cognitive map formation over visual map displays. Conversely, those drivers with a good sense of direction tended to use

survey style strategies when navigating and instead benefitted from allocentric maps, containing a north up feature. Interestingly, Baldwin (2009) found that when both auditory and visual map navigation styles were presented concurrently to participants with a good sense of direction, it caused confusion, subsequently disrupting their navigation performance.

Previous work has also demonstrated how a driver's gender (Saucier, et al., 2002) and age group (May, Ross, & Osman, 2005) can impact upon their cognitive map formation and their preference for auditory, landmark-based information or visual, allocentric map information (Dabbs Jr, Chang, Strong, & Milun, 1998). Due to the plethora of individual differences between drivers, future work may examine the benefits and associated compromises that the employment of a natural language navigation interface would have for each of these groups. For example, based on the current literature recommendations, use of the NAV NLI system may be most appropriate for older drivers, individuals with a poor sense of direction or females (Edwards, Emmerson, Namdeo, Blythe, & Guo, 2016, Cherney, Brabec, & Runco, 2008, Ward, Newcombe, & Overton, 1986), as previous literature has found that, for these groups, auditory, landmark based route guidance is the preferred and most beneficial interaction method for cognitive map formation and accurate route following.

In addition to the individual differences which have been shown to impact navigational performance and cognitive map development. It is important that future work considers any barriers related to a driver's willingness to spontaneously engage with an NLI. As discussed in the earlier limitations section (section 10.7.2) those participants who took part in each of the studies, detailed within this thesis were recruited from Nottingham university campus, and were therefore staff members or students.

As today's universities are increasingly global, with Nottingham holding two of its three campuses in Asia, participants were made up of individuals from a number of different backgrounds and cultures. Whilst this was unlikely to have influenced their driving ability and

navigational performance (all participants were required to hold a UK driving license and have experience of driving on UK roads), the participants' cultural background may have influenced their willingness to spontaneously engage, and shaped the nature of those interactions with the NAV NLI system, in the final on-road trial. Indeed, driver interactions with the NAV system revealed a number of differences between those participants of different cultures, both in their tendency to engage with the system and the politeness observed within those interactions. However, due to the limited sample size it would be inappropriate to make determinations regarding culture and enjoyment with an NLI based on these limited observations.

However, previous literature has shown that an individual's culture can influence their perception, judgement and decision making. Moreover, Cyr and Trevor-Smith (2004) demonstrated that the cultural background of users can influence interface preferences and subsequent perceptions. For example, user preferences for website features such as layout, symbols, navigation and the use of colour have been shown to vary across cultures therefore a large number of interface elements need to be considered so that systems are designed appropriately for their target culture.

Greek (a high UA culture) and Dutch (a low UA culture) cultures expressed preferences for those interfaces which were tailored according to their cultures' uncertainty avoidance (UA) characteristics. The concept of UA was first put forward by Hofstede (1980) who suggested that cultures vary in their degree of UA. Cultures with a high UA (e.g. Greek culture) are associated with higher anxiety, stress, avoidance of ambiguity and preference for rules and are outwardly more expressive than their low UA counterparts (e.g. a Dutch culture). In turn, they hold a preference for interfaces with a high UA, which offer frequent confirmations, give explicit instructions and a limited number of choices. Conversely, low UA cultures tend to experience less stress, are more accepting of deviations from the norm and demonstrate less outward emotion. Therefore, they prefer interfaces

which allow more free flowing interactions, more flexible navigation and present them with a variety of choices.

The findings of Dhillon et al (2011) demonstrate how an individual's culture can influence their predilection for interface style. Future work could therefore build upon this and examine how an individual's cultures shapes NLI interactions, subsequently exploring how NLI interfaces can be tailored to consider a cultures UA within user interactions e.g. the interface could detect the users UA (based on expressiveness) adapting its communication style to promote efficient, satisfying interactions.

Another context of use variable which may determine how users interact with an NLI is the social environment of the vehicle. Drivers who are happy to engage with an NLI whilst driving alone may be unwilling or feel self-conscious about interactions when there are in-car passengers present. Additionally, it is important to consider how the verbal interactions between in-car occupants may be affected if they interfere with system proficiency and driver/system interactions. For example, it is important that drivers are able to control their level of system interaction according to their mood or the cars' current social environment. Without the ability to manipulate and shape the degree of interactivity drivers may become frustrated or unwilling to use a system if conversations between in-car occupants are interrupted or stunted as a result of the systems presence. Future work, could therefore consider how varying vehicle use cases and the cars' social environment can influence the driver's willingness to engage with the system and how the nature of these interactions changes according to each use case.

Finally, future work could utilise within subjects designs' to examine how a driver's overall user experience is influenced according to whether they are interacting with an active or passive navigation system. The work within this thesis utilised a between subject's design, comparing how driver workload and environmental engagement were influenced by varying methods of navigation across different participant groups. Due to post-trial environmental

knowledge tests, participants were only permitted to take part in one of the four experimental conditions to ensure that any environmental knowledge gained was a direct result of the exposure and navigational method utilised during the road trial.

Removing the focus on environmental knowledge measures, a within subject's design could compare the user experience implications of interactions with active and passive methods of navigation. Providing an insight to the perceived strengths and weakness of each methodology from the same user perspective.

10.9 CLOSING REMARKS

The research presented within this thesis demonstrates clear benefits and potential for a natural navigation system employing conversational language with landmark-rich information (in preference to distance descriptors) delivered at navigational choice points. Reported results show that such a system ensures that the navigation task remains 'active', thereby enhancing environmental engagement and supporting a long-term perspective in the development of spatial knowledge, but does not demand the elevated workload traditionally expected with increased navigational activity. In addition, it offers the flexibility to tailor interactions (as a collaborative passenger might) whilst also providing the capacity to incorporate real-time updates (information that is less likely to be available to a passenger).

Moreover, delivering navigational advice in this manner also offers the capacity to further enhance route knowledge by incorporating and communicating information from connected vehicle technologies, which could provide real-time route information to the driver, such as current or estimated traffic delays or congestion, obstructions in the road or accidents ahead, in a similar, colloquial manner.

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A

APPENDIX A: PARTICIPANT PRE-TRIAL PAPERWORK

SATNAV & INFORMED PASSENGER CONDITION

Ethics Application & Approvals

A copy of ethics application document (with subsequent approvals) for the Satnav and informed passenger condition can be accessed using the link or QR code below:

https://www.dropbox.com/s/5vzfuh0j3y3086y/Ethics%20Application%20and%20Approvals%20-%20Satnav%20and%20IP%20study.pdf?dl=0

Participant Information Sheet (Satnav and Informed Passenger Condition)

1. Thank you for taking part in this study. Please take some time to read this information sheet carefully and feel free to ask any questions that you may have.
2. The purpose of this study is to allow us to study how an individual's need for navigation assistance can fluctuate throughout a journey. Miss Vicki Antrobus, who is currently a Human Factors postgraduate from the University of Nottingham, will conduct and act as the lead researcher on the study.
3. In this study, you will be either be working alone and driving along three predefined routes with the navigational assistance of a satellite navigation device or you will be assisted along the route by a passenger who will issue you with the appropriate navigational information to move through the routes. Whilst the passenger, acting as your navigator will issue set navigational prompts you are encouraged to prompt for any additional information which would help or enhance your journey. The routes which you will travel will incorporate a variety of different road and junction types (e.g. roundabouts, T-Junctions, traffic lights) to reflect an everyday journey. Whilst dependent on traffic the driving task will not exceed 60 minutes.
4. Prior to your arrival today you were asked to complete the Santa Barbara Sense of Direction Scale. This was to ensure that you are a confident navigator as only drivers who are confident navigating in an unfamiliar environment have been selected for participation in this study.
5. Please note that you should always drive in a way that is comfortable to you and your most important task is to drive safely.
6. If at any time you feel uncomfortable or unsafe please inform the experimenter who can drive you back to the ITRC building.
7. Your performance of the navigating task will be video recorded. The results of the study will be used solely for the purposes of this research. Data will only be accessible by people directly involved in

the study and images will not be used without your permission. To maintain confidentiality, participant consent forms will be stored separately from results and image data.

8. Kindly be informed that the data collected in this study will be securely stored in either a locked cabinet or a password protected file on University of Nottingham secure servers. Only Miss Vicki Antrobus, who is the lead researcher, and personnel directly involved in the study, will have access to the data. The data will be solely used for the purpose of the study. All the information will be kept on file for a period of 7 years, in line with current practices at the University of Nottingham, after this time all data will be securely destroyed.
9. Participation in this study is completely voluntary and you may withdraw from the study at any point in time. Should you withdraw prior to the completion of the study, the collected data will be treated in accordance to the guidelines described in item 8. There is no consequence for withdrawal from the study.
10. To maintain your confidentiality, your name will not be used during the study. Instead, you will be provided with a participant identity number.
11. The following personnel can be contacted should you have any further query.
    - Lead Researcher: Vicki Antrobus vicki.antrobus@nottingham.ac.uk
    - School of Engineering Research Ethics Officer: gary.burnett@nottingham.ac.uk
    - Jaguar LandRover Research Lee Skrypchuk lskrypch@jaguarlandrover.com
12. If you do not have any further queries, please sign on the Participant Consent form on the following page. Once again, thank you for taking part in this study.

COLLABORATIVE PASSENGER CONDITION

Ethics Application & Approvals

A copy of ethics application document (with subsequent approvals) for the Collaborative passenger condition can be accessed using the link or QR code below:



https://www.dropbox.com/s/7mmo2lbk8hvk9uy/Ethics%20Application%20and%20Approvals%20-%20Collaborative%20study.pdf?dl=0

Participant Information Sheet (Collaborative Passenger Condition)

1. Thank you for taking part in this study. Please take some time to read this information sheet carefully and feel free to ask any questions that you may have.
2. The purpose of this study is to allow us to study how an individual's need for navigation assistance can fluctuate throughout a journey. Miss Vicki Antrobus, who is currently undertaking a PhD in Human Factors at the University of Nottingham, will conduct and act as the lead researcher on the study.
3. In this study, you will be driving along three predefined routes in the Clifton area of Nottingham. You will be directed along these routes by the passenger with whom you signed up to the study. Your passenger has be trained in these routes prior to your drive today and is therefore able to issue you with navigational information to move you through these routes accurately. However, should you make any navigational error at any point in the drive, the experimenter will issue you with navigation information to direct you back onto the correct path, where the passenger will resume the role of navigator. The routes which you will travel will incorporate a variety of different road and junction types (e.g. roundabouts, T-Junctions, traffic lights) to reflect an everyday journey. Whilst dependent on traffic the driving task will not exceed 60 minutes.
4. Please note that you should always drive in a way that is comfortable to you and your most important task is to drive safely.
5. If at any time you feel uncomfortable or unsafe please inform the experimenter who can drive you back to the ITRC building.
6. Your performance of the navigating task will be video recorded. The results of the study will be used solely for the purposes of this research. Data will only be accessible by people directly involved in the study and images will not be used without your permission. To maintain confidentiality, participant consent forms will be stored separately from results and image data.
7. Kindly be informed that the data collected in this study will be securely stored in either a locked cabinet or a password protected file on University of Nottingham secure servers. Only Miss Vicki Antrobus, who is the lead researcher, and personnel directly involved in the study, will

have access to the data. The data will be solely used for the purpose of the study. All the information will be kept on file for a period of 7 years, in line with current practices at the University of Nottingham, after this time all data will be securely destroyed.

8. Participation in this study is completely voluntary and you may withdraw from the study at any point in time. Should you withdraw prior to the completion of the study, the collected data will be treated in accordance to the guidelines described in item 7. There is no consequence for withdrawal from the study.
9. To maintain your confidentiality, your name will not be used during the study. Instead, you will be provided with a participant identity number.
10. The following personnel can be contacted should you have any further query.
    - Lead Researcher: Vicki Antrobus vicki.antrobus@nottingham.ac.uk
    - School of Engineering Research Ethics Officer: gary.burnett@nottingham.ac.uk
11. If you do not have any further queries, please sign on the Participant Consent form on the following page. Once again, thank you for taking part in this study.

NAV CONDITION

Ethics Application & Approvals

A copy of ethics application document (with subsequent approvals) for the NAV condition can be accessed using the link or QR code below:

https://www.dropbox.com/s/s3q7gyismmrfp3j/Ethics%20Application%20and%20Approvals%20-%20NAV%20Study.pdf?dl=0

Participant Information Sheet (NAV Condition)

1. Thank you for taking part in this study. Please take some time to read this information sheet carefully and feel free to ask any questions that you may have.
2. The purpose of this study is to allow us to study how an individual's need for navigation assistance can fluctuate throughout a journey. Miss Vicki Antrobus, who is currently undertaking a PhD in Human Factors at the University of Nottingham, will conduct and act as the lead researcher on the study.
3. In this study, you will drive along three predefined routes in the Clifton area of Nottingham and will be following the navigational assistance NAVAI: A prototype natural language navigational interface developed by a major vehicle manufacturer. This auditory only interface equipped with a forward-facing road view and a cab-view of the driver will issue you with personalised, timely navigational information to guide you through the routes safely. This prototype system, acting as your navigator will issue set navigational prompts. However, as the system can see and hear you, you are encouraged to prompt for any additional information which would help or enhance your journey. The routes which you will travel will incorporate a variety of different road and junction types (e.g. roundabouts, T-Junctions, traffic lights) to reflect an everyday journey.
4. Please note that you should always drive in a way that is comfortable to you and your most important task is to drive safely.
5. If at any time you feel uncomfortable or unsafe please inform the experimenter who can drive you back to the ITRC building.
6. Your performance of the navigating task will be video recorded. The results of the study will be used solely for the purposes of this research. Data will only be accessible by people directly involved in the study and images will not be used without your permission. To maintain confidentiality, participant consent forms will be stored separately from results and image data.
7. Kindly be informed that the data collected in this study will be securely stored in either a locked cabinet or a password protected file on University of Nottingham secure servers. Only Miss Vicki Antrobus, who

is the lead researcher, and personnel directly involved in the study, will have access to the data. The data will be solely used for the purpose of the study. All the information will be kept on file for a period of 7 years, in line with current practices at the University of Nottingham, after this time all data will be securely destroyed.

8. Participation in this study is completely voluntary and you may withdraw from the study at any point in time. Should you withdraw prior to the completion of the study; the collected data will be treated in accordance to the guidelines described in item 7. There is no consequence for withdrawal from the study.
9. To maintain your confidentiality, your name will not be used during the study. Instead, you will be provided with a participant identity number.
10. The following personnel can be contacted should you have any further query.
    - Lead Researcher: Vicki Antrobus vicki.antrobus@nottingham.ac.uk
    - Supervisor: gary.burnett@nottingham.ac.uk
11. If you do not have any further queries, please sign on the Participant Consent form on the following page. Once again, thank you for taking part in this study.

PAPERWORK ISSUED TO ALL PARTICIPANTS

PARTICIPANT CONSENT FORM

Understanding how a driver's need for navigational assistance fluctuates throughout different journeys.

Researcher's name: Vicki Antrobus

Supervisor's name: Dr Gary Burnett, Dr David Large

- I am a licenced driver for UK roads
- I have read the Participant Information Sheet and the nature and purpose of the research project has been explained to me. I understand and agree to take part in this study.
- I understand the purpose of the research project and my involvement in it.
- I understand that when I act as a driver, it is my responsibility to drive safely in accordance with the rules of the road.
- I understand that I may withdraw from the study at any stage and/or request deletion of my data and that this will not affect my status now or in the future.
- I understand that while information gained during the study may be published, I will not be identified and my personal results will remain confidential.
- I would be happy for my video data to be used in research presentations, where this content would be required for conference presentations I understand that I would be contacted explicitly for approval.
- I understand that only Miss Vicki Antrobus, who is the lead researcher and personnel who are directly involved in the study shall have access to the study data. The data will be stored securely during the study period and will then be held by The University of Nottingham for a period for seven years, after which time it will be securely destroyed
- I do not have any known health related problems that might influence my driving performance.

Signed …… (Research participant)

Name …… **Date** ……

Demographic Questionnaire



Gender:

Male: ☐

Female: ☐

Age:

☐ **Years**

For how many years have you held a full driving license?

☐ **Years**

What is your approximate annual mileage?

☐ **Miles**

What is you preferred route planning method (please tick all which you use)?

SatNav (e.g. TomTom, Garmin) ☐

Smart phone application (e.g. Waze) ☐

Smartphone map application ☐

Route planner (e.g. AA route planner, googlemaps) ☐

Paper maps ☐

IF using a dedicated portable device to navigate do you utilse 3D maps?

Yes: ☐

No: ☐



How frequently do you use a navigation device when travelling new routes?

Always: ☐

Occasionally: ☐

Never: ☐

Do you use a navigation device in areas which you are familiar with?

Yes: ☐

No: ☐

Occasionally: ☐

Example recruitment poster

Participants Needed

Understanding how a driver's need for navigational assistance fluctuates throughout different journeys



Meet: Downstairs in ITRC building

Location: ITRC Building, Engineering block, University Park, University of Nottingham

Date: The trial will be on Tuesday 1st August – Thursday 21st August

Duration: 2.5 hours (spilt into 1 and 1.5 hour slots over 2 consecutive weeks)

In order to take part you must:

- Be available to participate in the road trial over Two Consecutive Weeks
- Have a University Drivers Permit
- Not be familiar with the Clifton area of Nottingham
- Be aged Over 21
- Drive steadily; obey road rules and speed limits.

You are invited to take part in an on-road user trial which is investigating how a driver's need for navigational assistance can fluctuate throughout a journey. The results of the trial aim to provide initial input for the development of intelligent interfaces for future in-vehicle systems.

The trial will involve driving along three predefined routes in the Clifton area of Nottingham over TWO consecutive weeks (please select one time slot and register using your email and I will you contact to arrange the second session). For completion of the study you will be compensated with **£30 worth of Amazon Vouchers** for your time.



Post-trial Consent Form

Thank you for participating in this study. Your time and effort is greatly appreciated.

Please sign below to confirm the following details:

I have received an Amazon voucher for my participation ☐

I have been informed of the true nature of the study and will not share this information with other potential participants ☐

Signed(participant)
……

Date
……

Information on obtaining a university drivers' permit

Part of the requirements for the study is that participants have a university driving permit but this is relatively quick and simple to sort. The registration process itself is quite straight forward: participants fill out a drivers' permit application (https://driverspermits.nottingham.ac.uk) and download a summary of licence record (https://www.gov.uk/view-driving-licence). You should then email a copy of both sides of your driving licence along with the licence record to the permit administrator (whose details will be sent in a confirmation email after filling out the drivers' permit application). The permit administrator will usually be able to approve the application immediately, although where there are issues they may forward the application on to a member of the insurance team over at Kings Meadow. Once the application has been approved participants will receive an email with a permit code and expiry date and are then insured to drive the vehicle.

Apparently a driver's permit can be granted the next day for people with a UK driving license (there seems to be more insurance issues for non UK licenses) and for those who have held their license over one year.

I have also attached the study flyer just for additional info. Please get in touch if you have any questions Vicki.antrobus@nottingham.ac.uk

B

APPENDIX B: POST-TRIAL ROUTE LEARNING TEST MATERIALS

ROUTE ONE – WINTER IMAGES.

Images used to examine participant route knowledge. Participants were required to place images in the order in which they were travelled. Images displayed here follow route order (e.g. top left and top right image represent junctions 1 & 2)



ROUTE ONE – SUMMER IMAGES.

Images used to examine participant route knowledge. Participants were required to place images in the order in which they were travelled. Images displayed here follow route order (e.g. top left and top right image represent junctions 1 & 2)



ROUTE TWO – WINTER IMAGES.

Images used to examine participant route knowledge. Participants were required to place images in the order in which they were travelled. Images displayed here follow route order (e.g. top left and top right image represent junctions 1 & 2)



ROUTE TWO – SUMMER IMAGES.

Images used to examine participant route knowledge. Participants were required to place images in the order in which they were travelled. Images displayed here follow route order (e.g. top left and top right image represent junctions 1 & 2)



ROUTE THREE – WINTER IMAGES.

Images used to examine participant route knowledge. Participants were required to place images in the order in which they were travelled. Images displayed here follow route order (e.g. top left and top right image represent junctions 1 & 2).



ROUTE THREE – SUMMER IMAGES.

Images used to examine participant route knowledge. Participants were required to place images in the order in which they were travelled. Images displayed here follow route order (e.g. top left and top right image represent junctions 1 & 2).



C

APPENDIX C: PARTICIPANT TRANSCRIPTS & ROUTE LEARNING MATERIALS

NAV NATURAL LANGUAGE ROUTE INSTRUCTIONS

A copy of the NAV natural language route instructions for each of the three experimental routes (with accompanying junction images) can be accessed via this link & QR code:

https://www.dropbox.com/s/xnpmqt9iwb2e44n/NAV%20Natural%20language%20route%20instructions%20-%20ALL%20routes.pdf?dl=0

NAVIGATIONAL TRANSCRIPTS

Due to the word count limitations of this thesis Collaborative passenger and NAV participant transcripts are not incorporated into the main body of this document. However, they can be accessed following the links or QR codes presented below.

Collaborative transcripts can be accessed via this link & QR code:



https://www.dropbox.com/s/onciawmfn39hpi5/Collaborative%20Transcripts%20%20-%20Cilfton%20road%20trial.docx?dl=0

NAV participant transcripts can be accessed via this link & QR code:



https://www.dropbox.com/s/j6p30nqghpda0c1/NAV%20Participant%20Transcripts.docx?dl=0

COLLABORATIVE ROUTE LEARNING MATERIALS

Prior to commencing the on-road trial collaborative participants were trained in experimental routes and told to make navigational notes to help them guide their drivers. Training consisted of issuing participants with a highlighted map and a series of videos which were filmed from the drivers cab perspective. Videos feature audio commentary, which used the same navigational script as the informed passenger trials. These route learning materials, discussed in more detail in section 4.1.3 (page 102), can be accessed via this link and QR code:



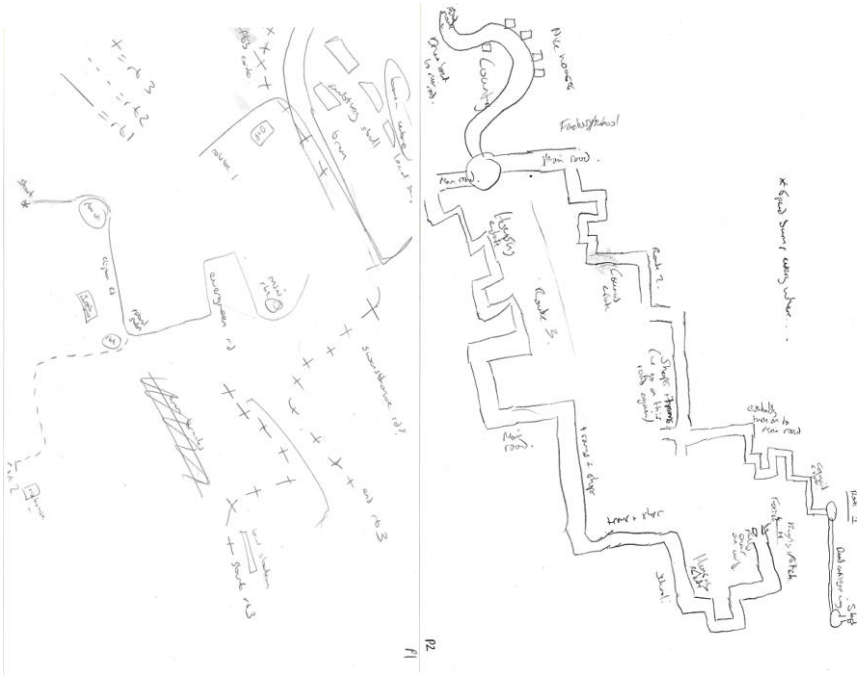
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D

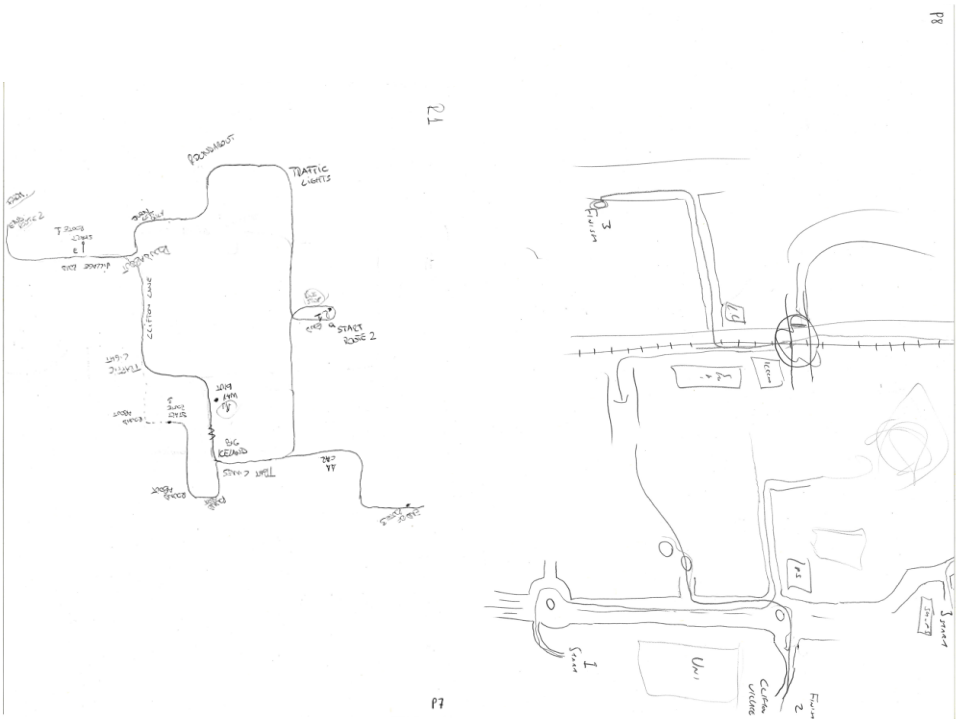
APPENDIX D: PARTICIPANT SKETCH MAPS

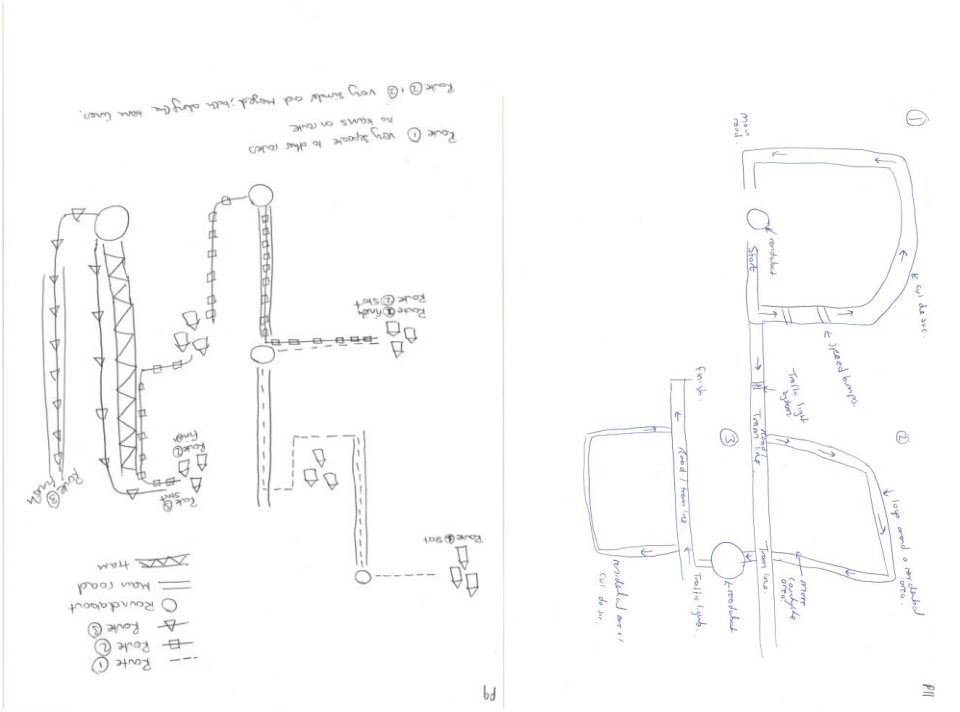
Appendix D provides all participant sketch maps from each of the four navigational conditions. Maps are segregated according to experimental condition.

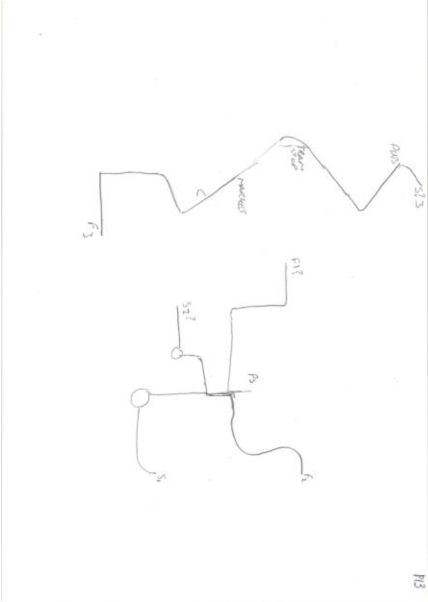
SATNAV SKETCH MAPS

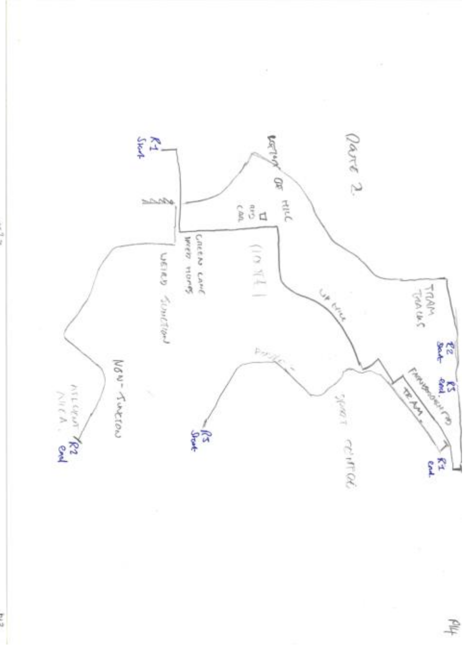


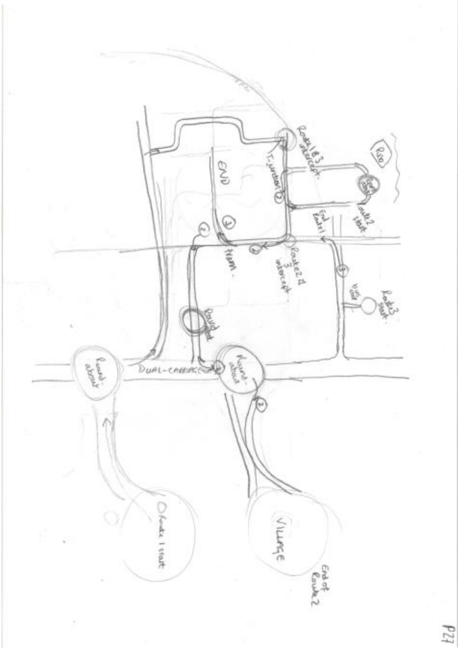
Route 1
Route 2
Route 3
Start
Finish
Toilets
Cafe
Shop
Gate
Car park
Trail
Path
Footbridge
Steps
Bridge
Viewpoint
Bench
Picnic area
Information board
Start Route 2
Start Route 3
Finish Route 3
Finish Route 2
Finish Route 1
Start Route 1
Route 1
Route 2
Route 3
Start
Finish
Steps
Path
Bridge
Footbridge
Viewpoint
Bench
Picnic area
Information board
Toilets
Cafe
Shop
Gate
Car park
Trail
Start
Finish
Steps
Path
Bridge
Footbridge
Viewpoint
Bench
Picnic area
Information board
Toilets
Cafe
Shop
Gate
Car park
Trail

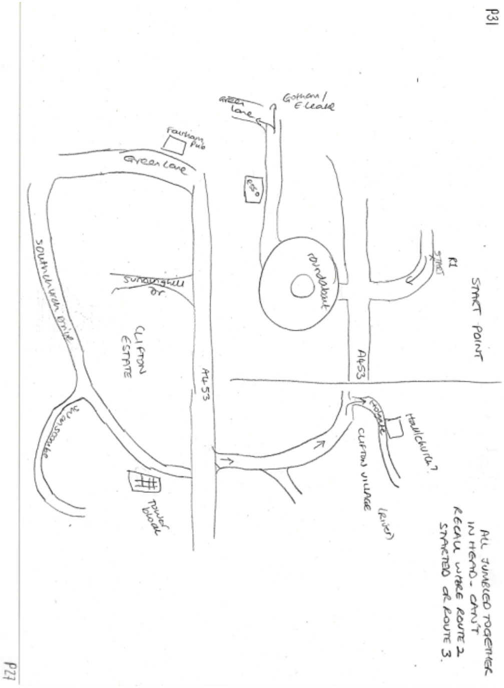




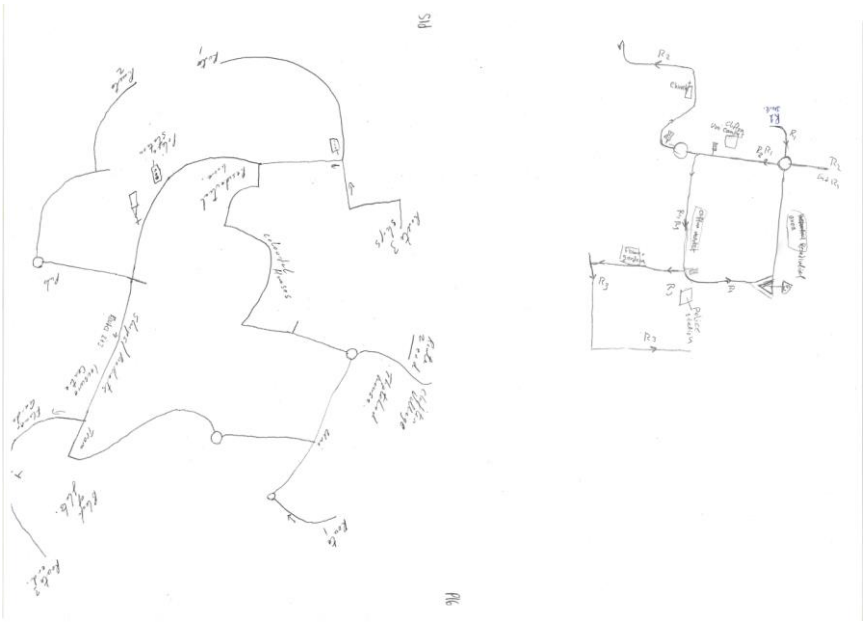

P13

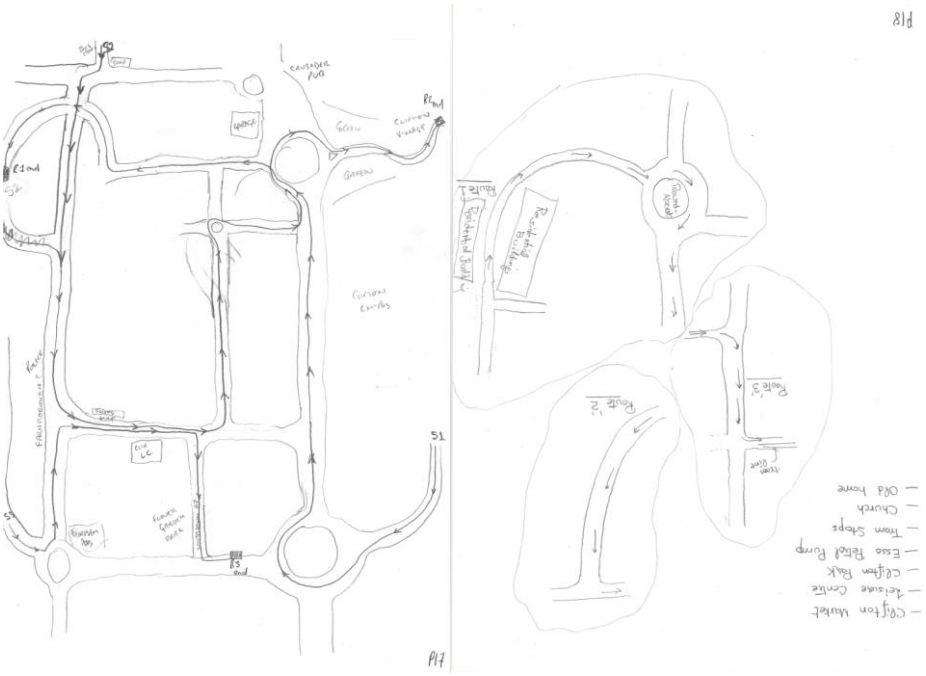

ROUTE 2
TRAM TRACKS
NON-STATION
SPORT CENTRE
P14

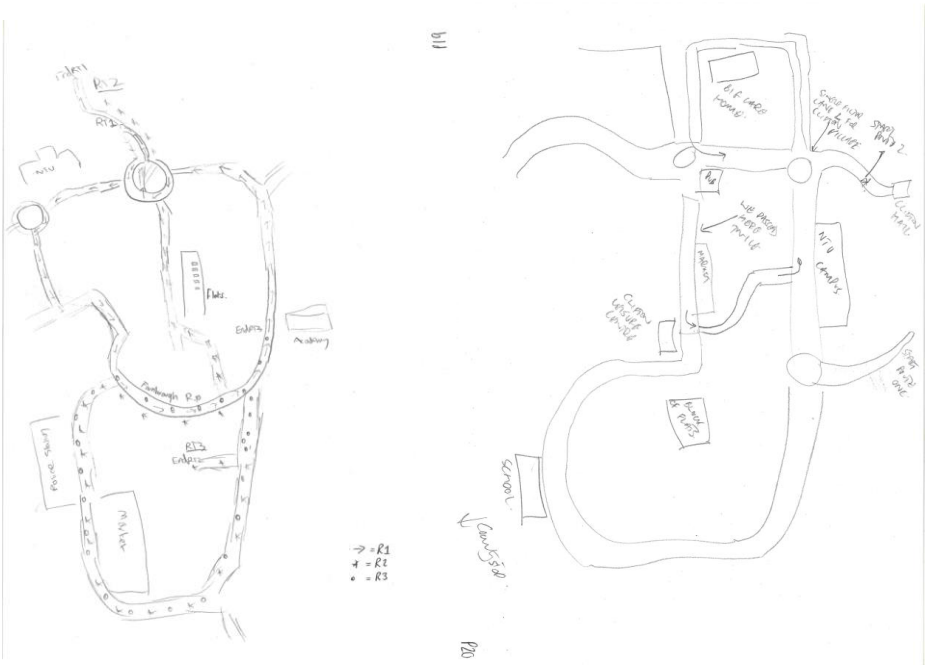

END
Village
DUAL-CARRIAGEWAY
P27

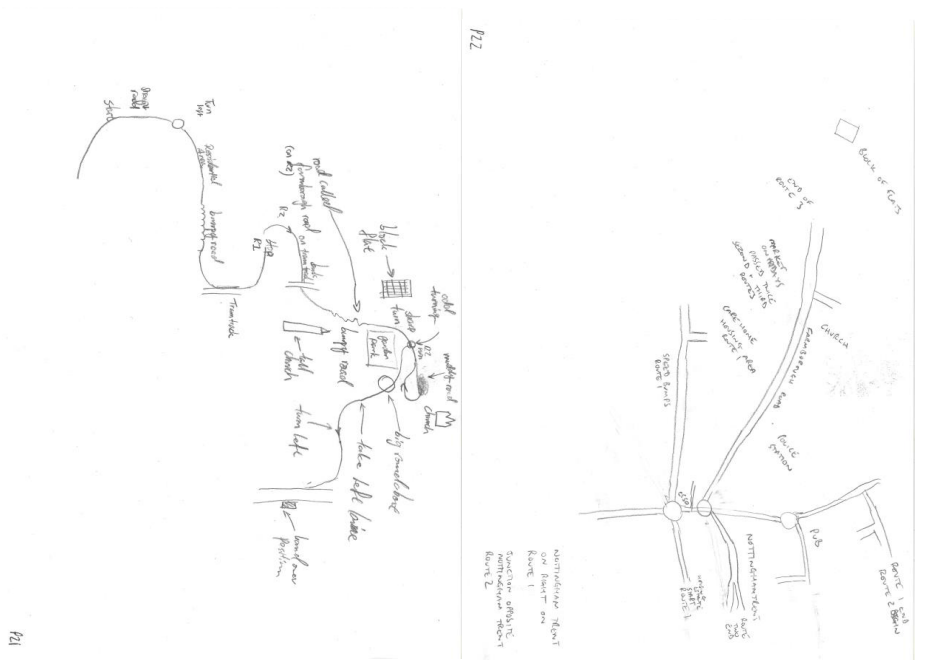

START POINT
roundabout
A453
CLIFTON ESTATE
CLIFTON VILLAGE
Green Lane
Southchurch Drive
ALL JUMBLED TOGETHER IN HEAD - CAN'T RECALL WHERE ROUTE 2 STARTED OR ROUTE 3.
P31

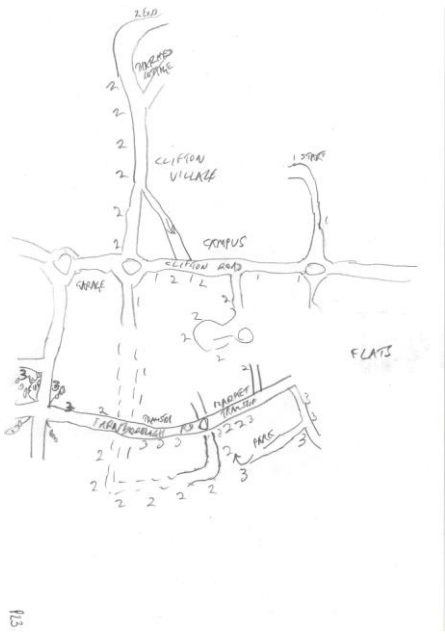
INFORMED PASSENGER SKETCH MAPS

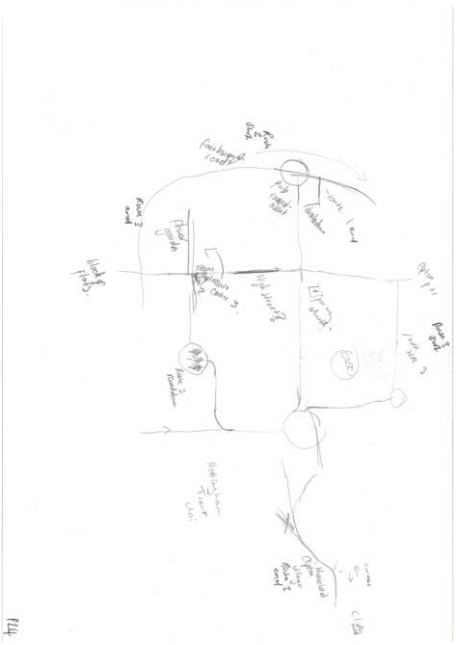


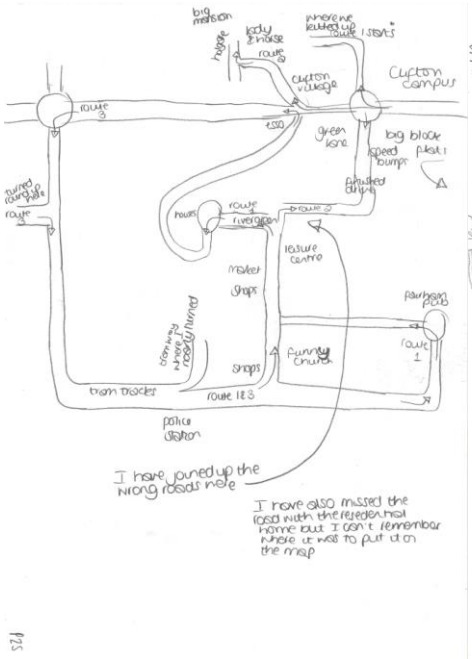


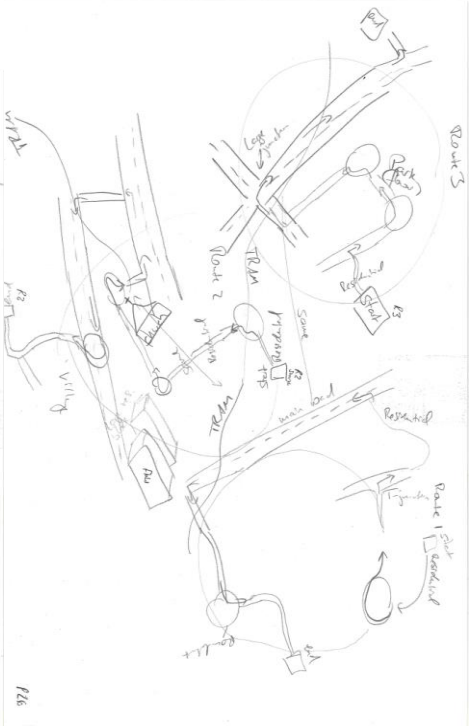


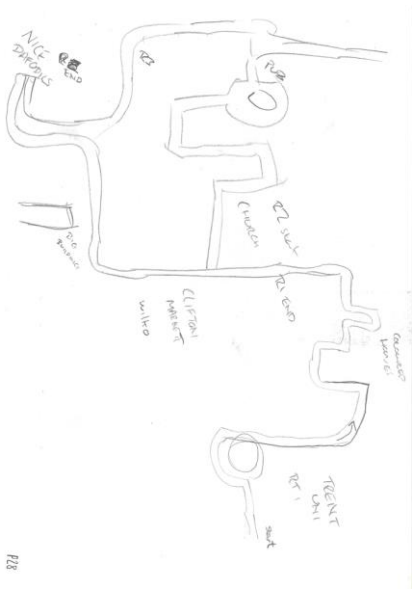



CLIFTON VILLAGE
CAMPUS
CLIFTON ROAD
FLATS

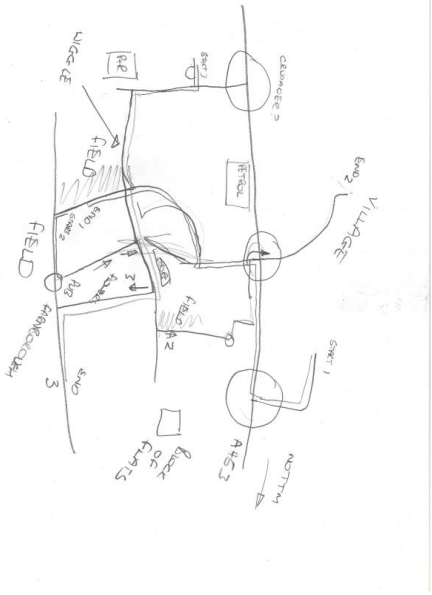



big mansion
lady in house
route 3
where we started up
Clifton village
Clifton campus
route 1
ESSO
green lane
big block
speed bump
flooded drive
route 2
leisure centre
market
shops
pawnbroker
funny church
shops
train tracks
route 1&3
police station
I have joined up the wrong roads here
I have also missed the road with the residential home but I can't remember where it was to put it on the map


Route 3
Route 2
Route 1
TRAIN
Residential

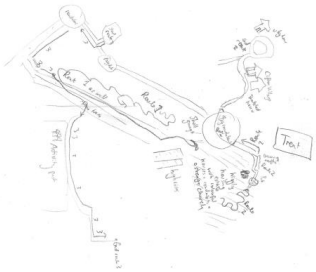

NICE SPRINGS
CLIFTON MARKET
TRENT LANE
TRENT

P28

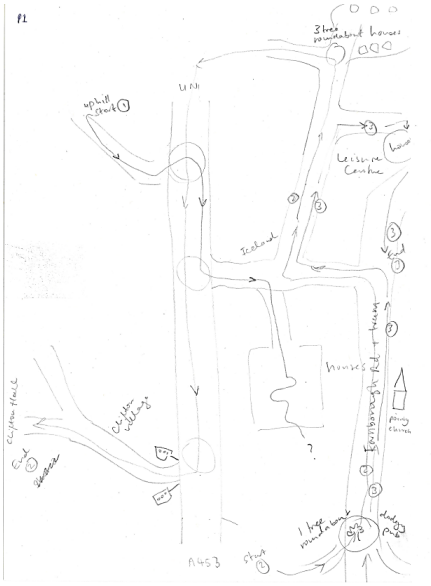

FIELD
FIELD
VILLAGE
FARMHOUSE
A453
NOTTM

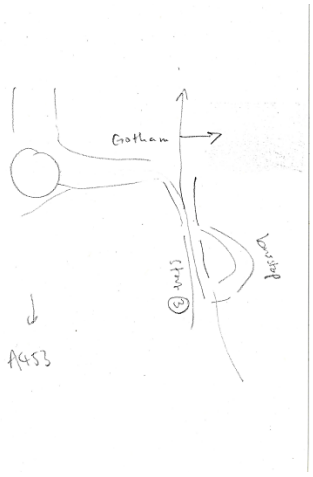
P29

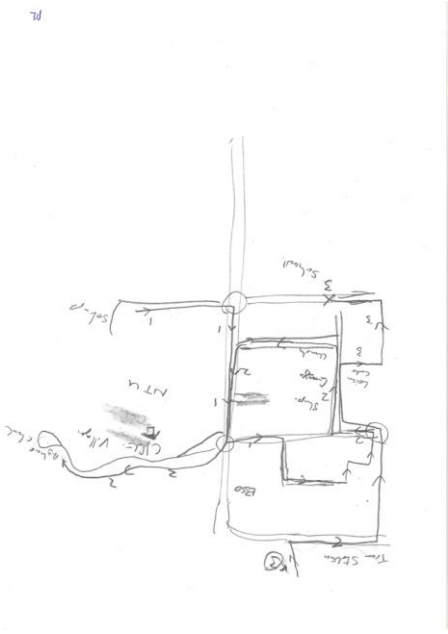
P30

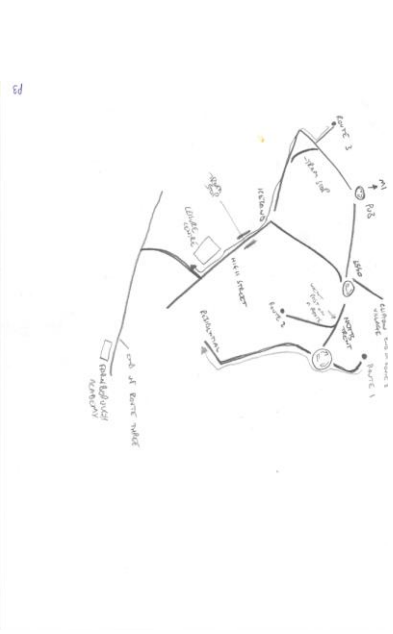

Trent

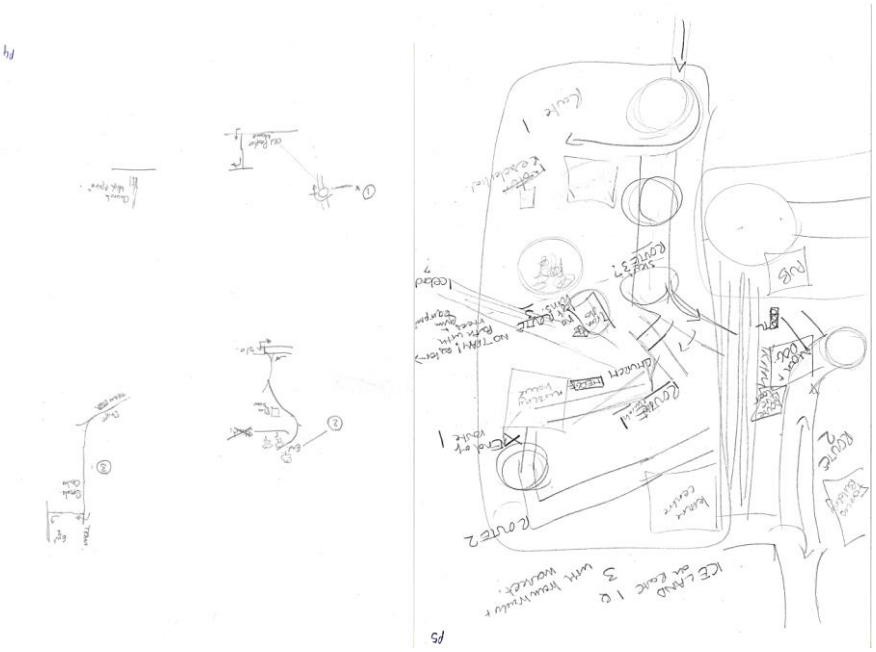
COLLABORATIVE PASSENGER SKETCH MAPS

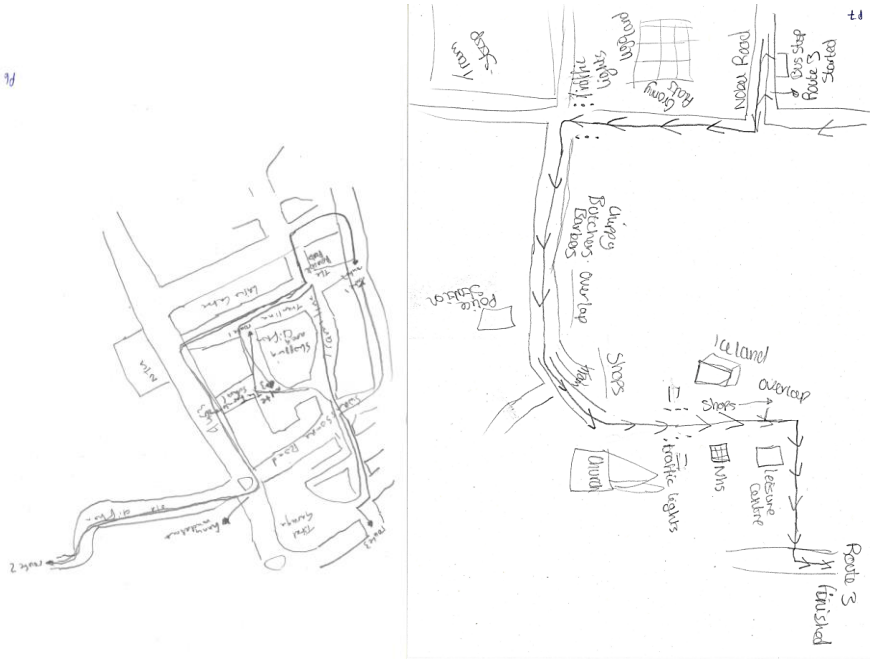


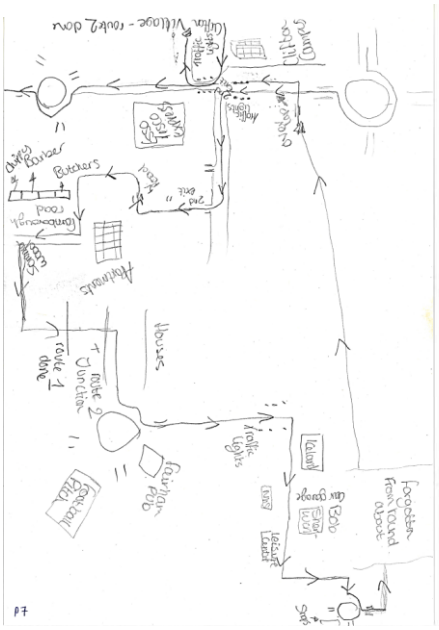


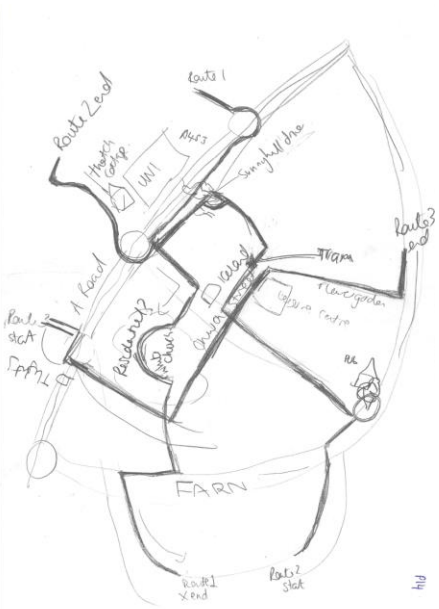


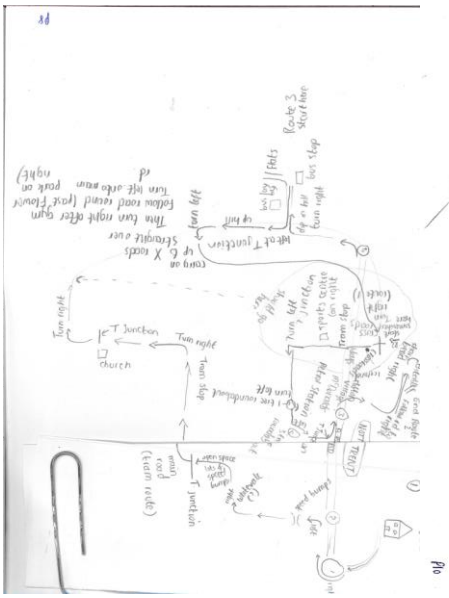


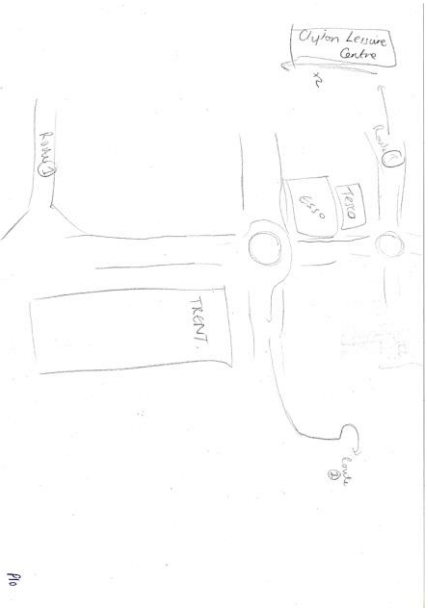


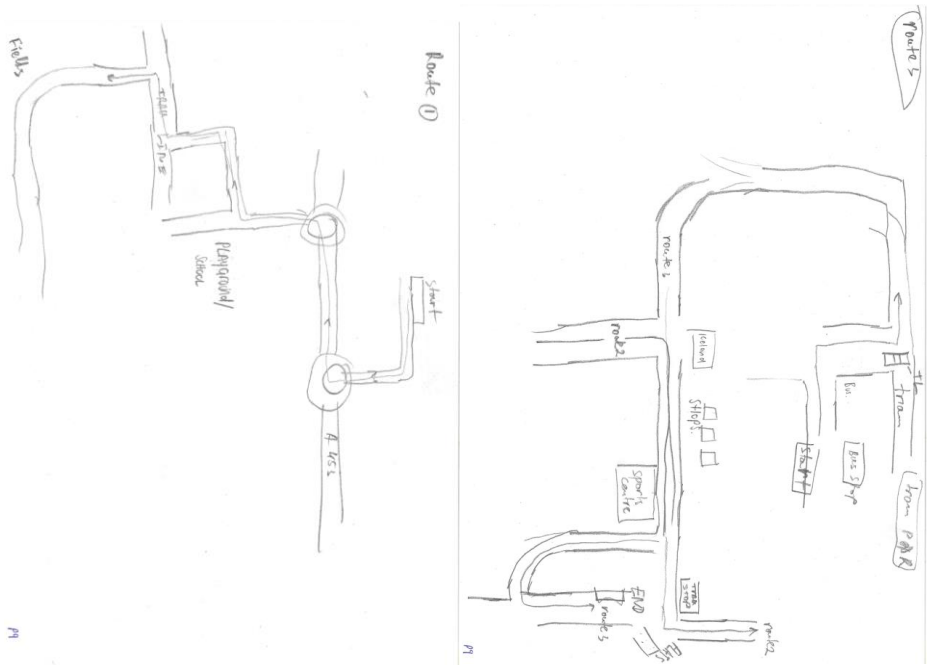


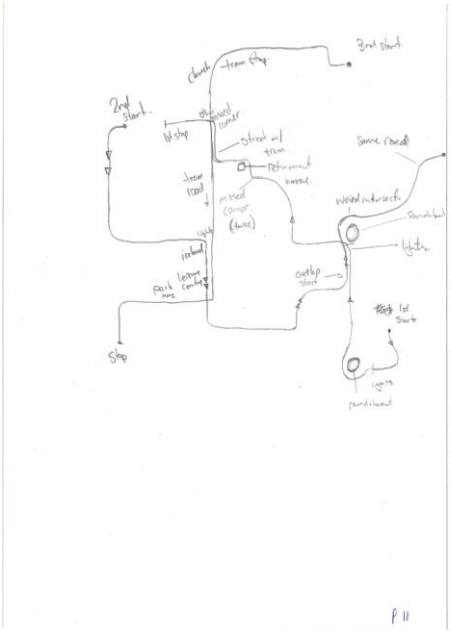

Village - route 2 down
Butchers
Houses
T Junction
route 1
route 2
Traffic Lights
Bus stop
Bus stop
Junction from round about
Church
P7

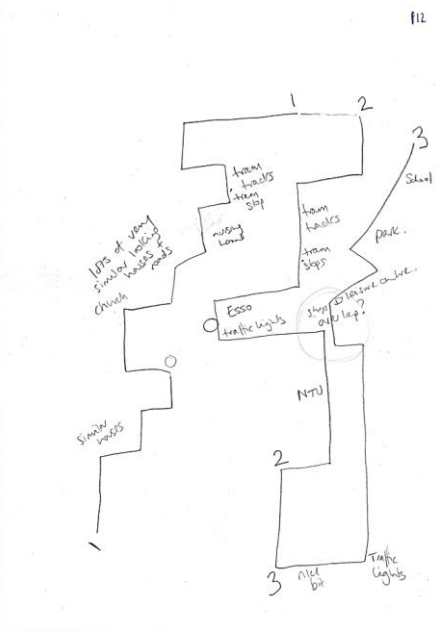

Route 2 end
Route 1
Uni
Tram
A road
Route 2 start
Route 1 end
Route 2 start
EARN

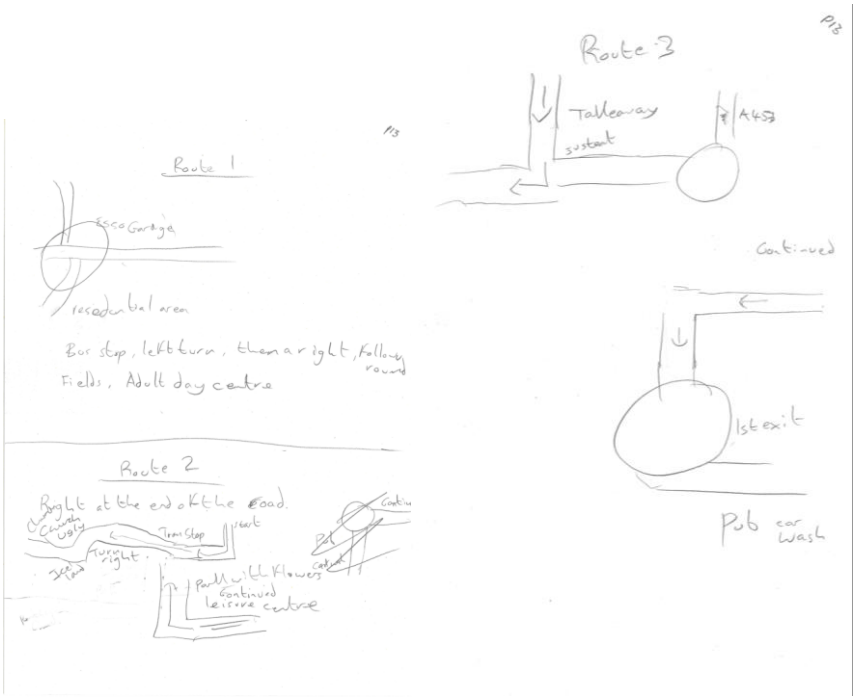

Route 3 start here
bus stop
Hats
bus stop
turn right
left
up hill
left T junction
turn right
T junction
Turn right
church
Turn right
Turn left
Turn left
Turn left
T junction
Turn right
P8


Clifton Leisure Centre
Route 1
Route 2
Tram
Esso
TRENT
Ends

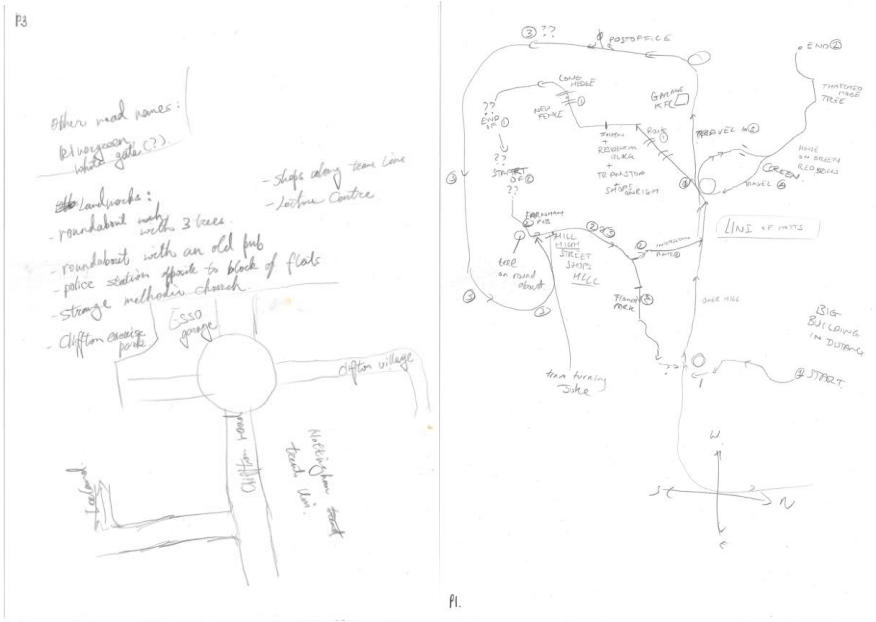

Fields
Route 1
Playground
School
Start
A 452
Route 2
tram
Bus
Shops
Sports Centre
Tram Stop
Bus Stop
Tram Park
Route 3
Route 2
Route 1
P9
P12

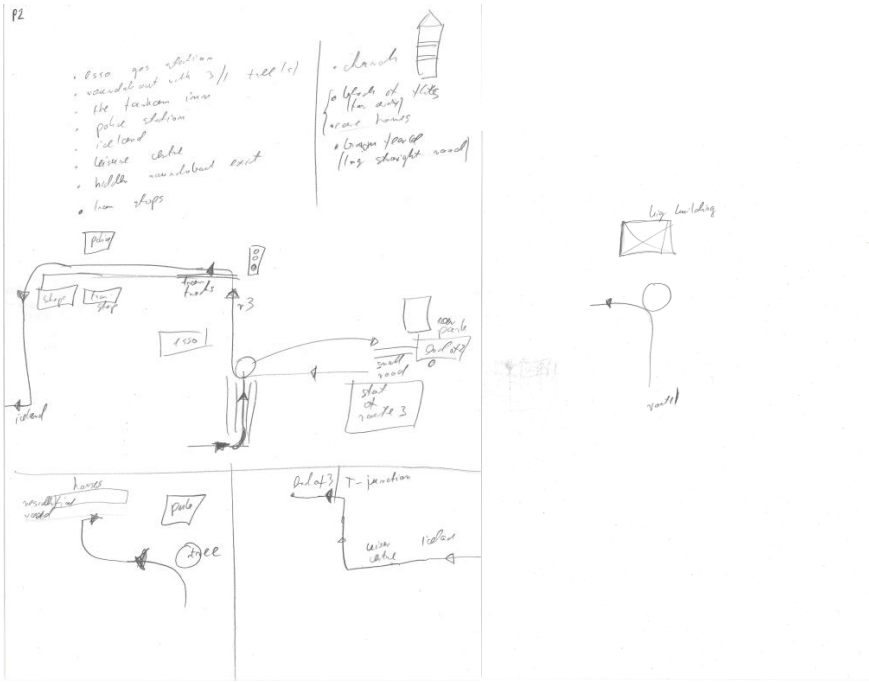

3rd start
church
tram stop
2nd start
bus stop
playground
street wi
tram
Retirement
homes
same road
tram road
passed
corner
(twice)
woodland/trees
church
Park
Tram Stop
Shop
3rd Stop
lights
roundabout
P11

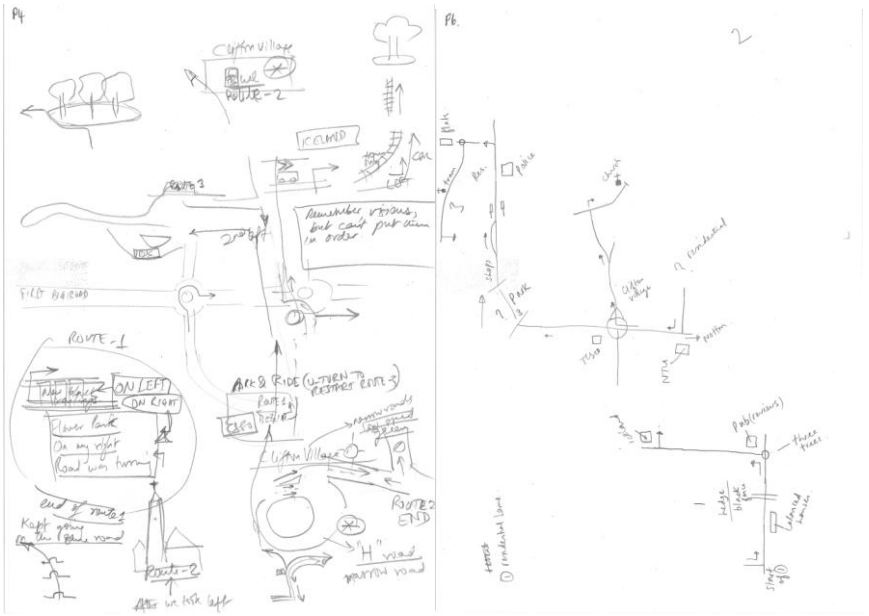

1
2
3
tram tracks
tram stop
tram tracks
tram steps
School
park.
lots of very
similar looking
houses and
roads
crunch
Esso
traffic lights
NTU
similar houses
2
3
Nice bit
Traffic Lights

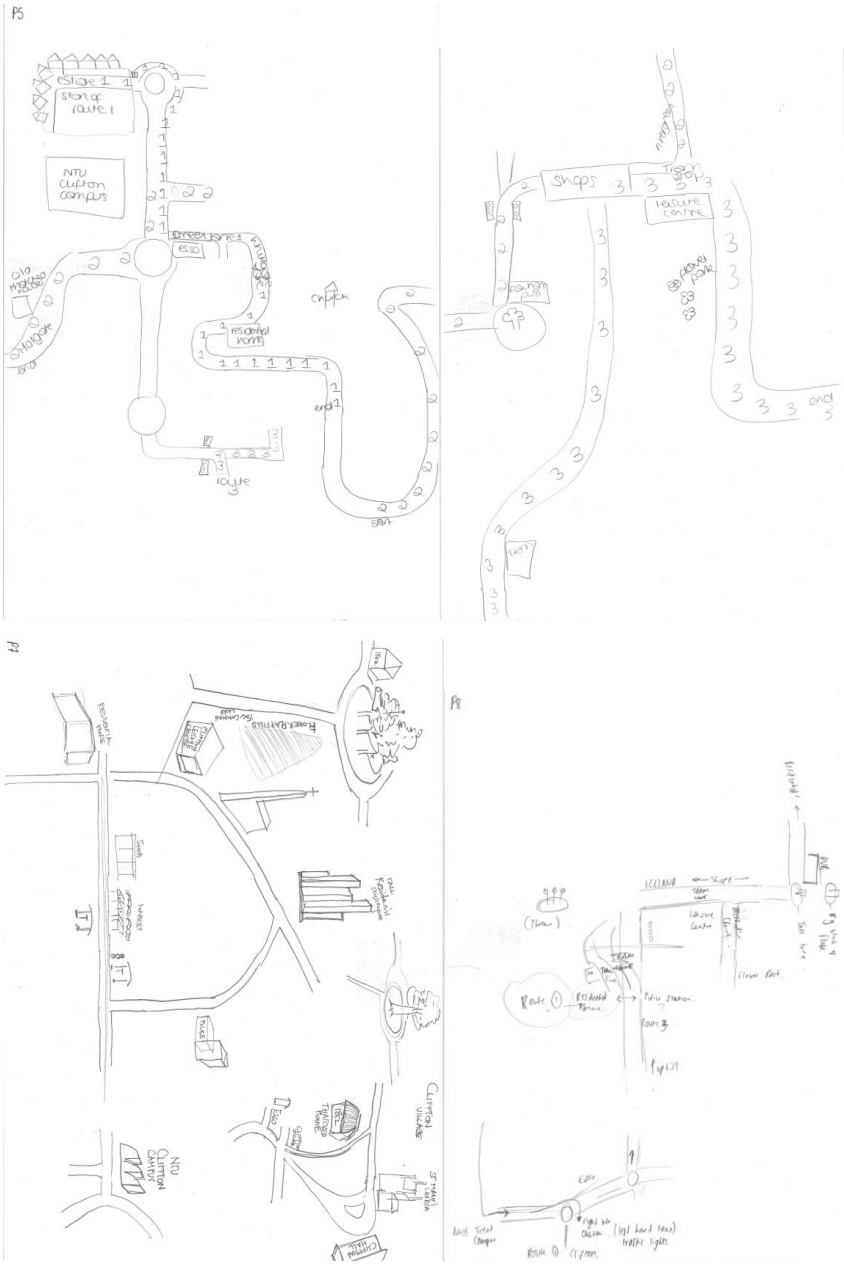


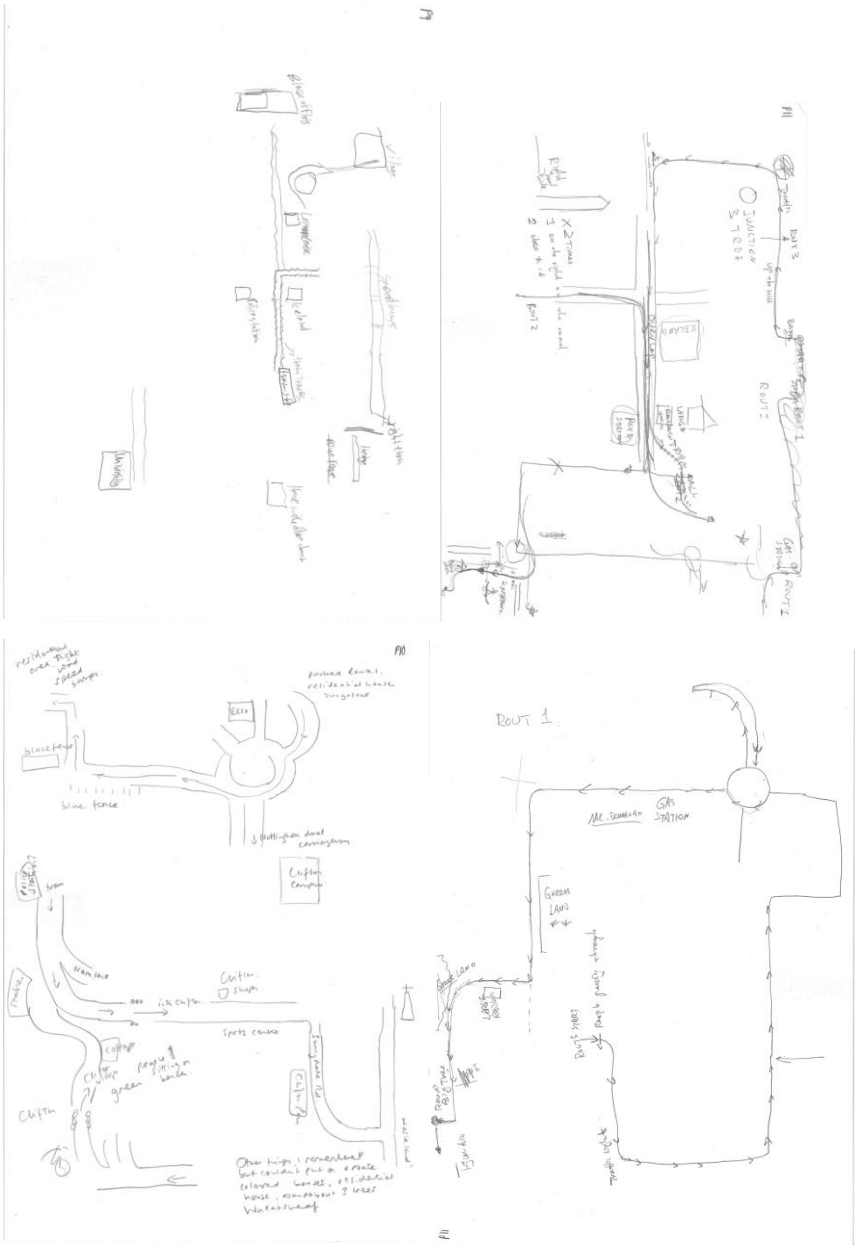
NAV PARTICIPANT SKETCH MAPS




P2
• esso gas station
• roundabout with 3/1 tree (c)
• the fareham inn
• police station
• iceland
• leisure centre
• middle roundabout exit
• lion shops
• church
• bagan (on left of this area) with houses
• bagan (on left) has straight road
Big building
Parking
Shop
Train Stop
Trees
x3
Esso
Small road
Start of route 3
Iceland
Houses
Pub
Tree
End of 3
T-junction
Main cable


P4
Cliffe Village
Start
ROUTE-2
ICELAND
ROUTE 3
Remember arrows, but can't put them in order
FILEY BAYROAD
ROUTE-1
ON LEFT
ON RIGHT
Flower bank
On my right
Road with turning
Kraft
Route-2
Ack & Ride (U-turn restores route 3)
Route 3
Cliffe Village
Route 2
END
"H" road
P6.
2
Pub
Bus
Trees
Church
Cliffe Village
Pub (arrows)
Three trees
Hedge
Bridge
Tunnel entrance
Fences
Industrial land


P5
start of route 1
NTU Clifton campus
Shops
leisure centre
P7
NTU Clifton campus
P8


P9
P11
P10
P11
ROUT 1
Green Lawn
Sports centre
Cliffs
Blue fence

