Investigating Older Drivers’ Route Guidance Requirements to Inform the Design of Future In-Vehicle Navigation Systems

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Abstract

In-vehicle navigation has been identified as a key activity for maintaining the mobility and hence the independence and quality of life of older adults. However, few studies have directly investigated and tested route guidance requirements specifically for older drivers. This thesis addresses the knowledge gap using a range of quantitative and qualitative methodologies across three investigations.

A focus group investigation was undertaken first. Thirty older adults were recruited and themes of driving and navigation behaviour discussed. This research stage found older adults have difficulty planning and then navigating journeys, landmarks are used to navigate the road network and in-vehicle navigation systems (IVNS) are not deemed to be useable.

In the second investigation, current design IVNS were loaned to 22 older adults for a two-week period. During this period the participants detailed their experiences and attitudes of the loaned IVNS. In addition, in-depth interviews were undertaken. This investigation found that IVNS have usability issues for older drivers that need to be considered for the next generation of IVNS.

In the next stage, a driving simulator investigation with 30 older drivers was carried out. This phase of the research examined the navigational benefits of providing landmark-based route guidance information as compared to the traditional method of paper maps.

The study concluded that older drivers have difficulties with navigation through decline in memory and vision. The driving simulator investigation suggests that landmarks are effective at supporting older drivers with the navigation task; in particular, older female drivers. In addition, landmark-based route guidance information should be delivered through a combination of audio instructions and an icon-based visual display. Finally, the thesis outlines recommendations for the next generation IVNS for older drivers.

In loving memory of my mam, Margaret Emmerson

She always believed in me

The following journal paper has been published:

Emmerson, C., Guo, W., Blythe, P., Namdeo, A. and Edwards, S. (2013) 'Fork in the road: In-vehicle navigation systems and older drivers', *Transportation Research Part F: Traffic Psychology and Behaviour*, 21(0), pp. 173-180.

The following conference papers were published during the PhD:

Emmerson (2013) Turn where, dear? Older adults using in-vehicle navigation systems for the first time. UTSG 45th Conference, Oxford.

Emmerson, C, Blythe, P.T. Guo, A. Namdeo, A. Edwards, S. (2012) In-Vehicle Navigation Systems and Older Drivers. 19th Intelligent Transport Systems Congress, Vienna.

Emmerson, C, Blythe, P.T. Guo, A. Namdeo, A. Edwards, S. (2012) Using An In-Vehicle Navigation System For The First Time: A Case Study Of Older Drivers. International Conference on Aging, Mobility and Quality of Life, University of Michigan, USA.

Emmerson, C, Blythe, P.T. Guo, A. Namdeo, A. Edwards, S. (2011) Navigation and Older Drivers. UTSG 44th Conference, Aberdeen.

The following award was achieved during the PhD study period:

Best scientific paper at the 19th Intelligent Transport Systems Congress, Vienna.

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Chapter 1. Introduction

1.1 Background

Ageing of the world's population is a global structural change that is occurring for two reasons: people are living longer and, in developed countries, they are having fewer children (Hayutin, 2007). Consequently, worldwide, the number and proportion of people aged 65 and older is greater than ever before (Hayutin, 2007; ONS, 2011). Figure 1.1 illustrates the projected growth of the UK population. In 1984, 15% of the UK's population was aged 65 and over whereas by 2009, this figure rose to 16%, an increase of 1.7 million people (ONS, 2011). Yet, this is just the start of the 'age wave'; by 2034 it is projected that 23% of the UK's population will be aged 65 and over (ONS, 2011). Other countries will see a more rapid increase in their over 65s than the UK. For example, China's proportion of over 65s is predicted to more than double from 7% in 2005 to 15% by 2030 (Hayutin, 2007; Pison, 2009).

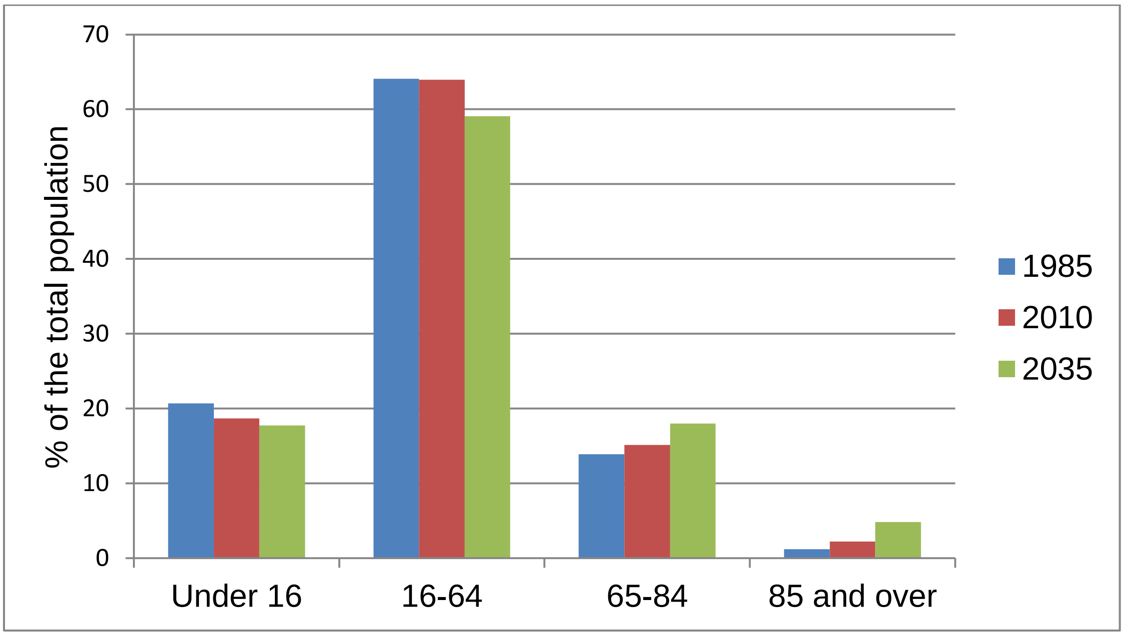


Figure 1.1 The past, current and predicted future age structure in the UK (Source: Office for National Statistics, 2011)

Significantly, one of the most striking characteristics of the UK's ageing population is the high percentage of people who will pass their 65th birthday as active drivers, and who will then expect to remain active for decades to come (Rosenbloom, 2010). For instance, on average one in every six UK driver was over the age of 60 in 2001. This is projected to increase to almost one in every four by 2030 (Rosenbloom, 2010).

1.2 Mobility of Older People

In the minds of many older adults, access to a car is equated with independence: the freedom to drive to the local supermarket; a doctor's appointment; or to simply run errands allows them to function independently (Craik and Salthouse, 2000; Metz, 2003). Moreover, as various studies have shown, staying mobile and 'getting out and about' enables older adults to continue to live independently and maintain their quality of life (Metz, 2000; Banister and Bowling, 2004). It is therefore perhaps unsurprising that the car is the dominant travel mode choice for the majority of this current and the next generation older people (Banister and Bowling, 2004). The UK National Travel Survey data shows that in 2010, over two thirds of all journeys by persons 60-69 were in a car and the majority of those were as a driver (Rosenbloom, 2010). In addition, older people travel substantially more than they used to. Banister and Bowling (2004) highlight in their UK study that the total number of journeys by older adults increased by 31% from 1995/96 to 1996/98. Over the same period, older adults' travel distance increased by 85%. The overall increase for the UK population, over the same time, was 2.6% for number of journeys and 26.5% for distance (Banister and Bowling, 2004).

With the increase in the number of older persons in the population, they now form a growing proportion of the expected increase in the demand for travel over the coming decades (Banister and Bowling, 2004). Additionally, successive generations of older people are more likely to be car dependent for mobility, and less likely to use alternatives, than previous older cohorts (OECD, 2001).This is due to future older adults' lifestyles being centred around car travel (Banister and Bowling, 2004; Eby and Molnar, 2009). The number of older people who hold a car driving licence has increased notably over the past decade. The UK National Travel Survey (DfT, 2010) indicates a rise from 63% to 78% in the proportion of people aged 60-69 who held a driving licence between the 1995 and 2009 surveys. Furthermore, the proportion of people aged 70 and over holding a driving licence increased, within the same period, from 38% to 54% (DfT, 2009). The increase in the percentage of older adults holding driving licences is expected to continue. In 2004 just over half of those aged 65 and over held a private car driving licence; in the same year approximately 89% of men and 77% of women aged 40-49 held a car licence in the UK (Rosenbloom, 2010). A significant factor in the growth of older drivers is the number of women holding driving licences. Between 1995 and 2009, the number of women aged 60-69 holding a car licence increased from 45% to 67%. This growth indicates that women are beginning to close the gap in the number of licences held with men.

As people age, there are functional declines that affect an individual's ability to drive (Mynatt and Rogers, 2001). Age related declines in strength, dexterity, vision, hearing, working memory and cognition can all affect driving a car (Salthouse and Siedlecki, 2007; Guo *et al.*, 2010). To adjust for these changes, older adults can reduce, modify or stop their driving in certain conditions, a process called self-regulation. This involves drivers being aware and evaluating their own functional abilities and adjusting their driving behaviour accordingly; allowing them to continue to drive but avoid conditions they find difficult (Charlton *et al.,* 2003). It has been found that older adults deliberately drive less in heavy traffic (Baldock *et al.,* 2006), at night and on unfamiliar roads (Ball *et al.,* 1998). Nonetheless, the potential of self-regulation for safe driving could soon be exhausted as it reduces individuals' flexibility to access work, personal business and/or social activities. Moreover, research has shown significant implications to older drivers' mobility and their wellbeing when they give up driving (Fonda *et al.,* 2001; Edwards *et al.,* 2009). Marottoli *et al.* (2000) found that when older adults cease driving it can result in increased levels of depression, especially in men. Other research has found that driving cessation can result in reduced integration with social networks (Mezuk and Rebok, 2008), and a sharp decline in health (Edwards *et al.,* 2009).

When older people cease driving, they become reliant on family and friends for their transport needs. (Kostyniuk and Shope, 2003). Rosenbloom (2010), for example, examined the role adult children have in the continued mobility of their parents in the UK. The study found that they were concerned about their parents' safety and the burden they would carry once their parents ceased driving. When older adults travel without a car, walking and using the bus are the dominant modes. However, significant mobility issues are clear for these forms of transport, as a typical journey using public transport will involve a walk to a bus stop. Walking is generally an unavoidable element of the journey but one that can cause significant issues (Metz, 2000). In 2009, 39% of persons aged 70 and over had problems walking or using the bus (DFT, 2009). Furthermore, the personal control in deciding where and when to go, on any transport mode, is very important to older persons (Kostyniuk and Shope, 2003). Public transport does not provide the same mobility, convenience, and security that a car can (Kostyniuk and Shope, 2003). Therefore, older people are generally unsatisfied with and in many cases reluctant to use public transport, preferring to rely on a private car for personal mobility (Kostyniuk and Shope, 2003; Dickerson *et al.,* 2007).

1.3 Navigation and Efficient Route Guidance

Navigating a car journey can be a very demanding task on the driver. Every journey undertaken in the car will involve navigation to some degree. There are a wide range of tools and methods that can support drivers to navigate journeys. For example, road signs; roads markings; published maps and online route planners. Research has long shown that drivers, regardless of age, gender, race or driving experience can have difficulties in planning and following routes (which affects fuel consumption and time taken) (Burns, 1999; May *et al.,* 2005). In particular, older drivers' have been found to have significant difficulties with navigating an unfamiliar journey (Dingus *et al.*, 1997; Mallon and Wood, 2004; Wood *et al.*, 2009; Anstey and Wood, 2011). Older drivers may find planning a journey and then way-finding that route particularly difficult through perceptual (vision) and cognitive (divided task attention and working memory) declines (Salthouse and Siedlecki, 2007). It is therefore unsurprising to find that navigation has been identified as a key component for maintaining the mobility and hence the independence and quality of life of older adults (Burns, 1999; Goodman *et al.,* 2005).

Research has found that navigational difficulties do affect older drivers' mobility, they will reduce the amount they drive on unfamiliar roads and to unfamiliar locations (Charlton *et al.*, 2003; Bryden *et al.*, 2013). Caird (2004) suggested that one reason older adults do self-regulate their driving to avoid unfamiliar roads is due to a fear of losing their way. It is perhaps fair to say that every driver has felt frustration and anxiety when they have taken a wrong turn and ended up lost and stressed. Paper maps are the traditional source of navigation information for a car journey (Burnett, 1997). In addition, using a printed map while driving or on the roadside during a journey have been found to be prevalent in older drivers (Bryden *et al.*, 2013). Although, this may be a result of printed maps being the only navigational tool available for a number of years. Nonetheless, Petchenik (1989) highlighted that paper maps are not necessarily the best tool for navigation, despite the obvious fondness for them by drivers. Additionally, Streeter and Vitello (1986) found that many people have difficulties in accurately reading maps when driving.

As many people find using maps difficult it is not surprising to find that drivers will use pre-prepared notes or sketches for journeys (Parkes and Martell, 1990). In a questionnaire survey, Bryden *et al.* (2013) found that 33% of older drivers would use written instructions or a drawn map to navigate. However, when these notes provided inaccurate information or were confusing to the driver then this method cannot adequately compensate for the difficulties found with the printed map (Srinivasan, 1999; Waters and Winter, 2013).

1.4 Role of Technology

Advancements in information technology, intelligent transport systems (ITS), and telecommunications have paved the way for technology to provide positive enhancements to the transport environment. Under the umbrella of ITS there are a wide range of technology solutions to address travel needs. Within this range of technology solutions, in-vehicle information and support systems are an importance facet. Systems that provide route guidance have the potential to provide significant support to older drivers (Caird, 2004; Dickerson *et al.*, 2007; Eby and Molnar, 2009; Eisses, 2011). The purpose of route guidance systems is to offer a technological solution to driver navigation. Systems that provide this type of information are called in-vehicle navigation systems (IVNS). They are arguably one of the most recognisable forms of ITS.

1.5 Technologies for Route Guidance Systems

Modern IVNS (also known as route guidance systems) perform two fundamental task of navigation: pre-trip planning and way-finding instructions.

Generally, IVNS will use the global positioning system (GPS) satellite constellation to determine its location. With this information, the system can then perform a route calculation and selection using its on-board road map database. They then present a series of map overviews and turn-by-turn instructions to drivers. The information is traditionally provided through a combination of auditory instructions and a visual display (Baldwin, 2002; May and Ross, 2006).

The first IVNS reached the commercial market in the late 1980s and was a built-in system by Electro-Multivision in Japan (Akerman, 2010). This system and many after it were pioneering but actually static in nature; meaning they were not linked to GPS. The technology progressed to include GPS in the early 1990s and started to emerge on the wider market. At this stage they were only built into high-end luxury cars as they were seen as an expensive optional extra. Over time the technology has developed, following Moore's Law (Moore, 1965; Schaller, 1997), reducing in size, cost and significantly increasing in functionality and computing capability. As a result, there are now built-in versions and nomadic devices that can be attached to windscreens, and more recently relatively high-quality route guidance systems on smart phones. The price of these systems has significantly decreased over time and functionality increased making them available to a greater number of drivers, not just those with high-end luxury cars.

1.6 Older Adults and In-Vehicle Navigation Systems

IVNS deliver a range of navigational information through a combination of audio information, usually based on distance-to-turn information, and a complex visual map-based display. The map-based display is shown on a LCD screen and shows the location of the system, i.e. the car it is in, at the centre of a digital map. The map then moves around this centre point to provide information to the driver. The quality and depth of information displayed varies across each manufacture. Crucially, older adults are often less successful at interacting with technology then their younger counterparts (Mynatt and Rogers, 2001; Wood *et al.*, 2005; Pak *et al.*, 2008; Barnard *et al.*, 2013). This is significant as IVNS are designed for the mass market and do not take into account any specific characteristics of user groups (Eby and Molnar, 2009; Musselwhite and Haddad, 2010).

Numerous researchers report that the 'one size fits all' approach to IVNS may not be appropriate for older drivers (or indeed other sub-categories of the driving population), and that further research is needed on their route guidance requirements (Baldwin, 2002; Vrkljan and Polgar, 2007; Birrell and Young, 2011). Dickerson *et al.* (2007) published a research program for advancing safe mobility of older drivers, highlighting the potential of advanced technology, for instance IVNS, in maintaining and enhancing the safe mobility of older adults. Thus, potentially assistive technologies have to take into account the unique requirements of older adults. This includes taking care with the design and understanding the functional capabilities of older drivers (May *et al.,* 2005; Dickerson *et al.,* 2007; Eisses, 2011).

The most recent data from the Office for National Statistics (2007) suggests that only 6% of over 65s who own a car also own an IVNS. When compared to other age groups this is considerably low:

- 16 to 24, 15%;
- 25 to 44, 45%;
- 45 to 54, 17% and
- 55 to 64, 17%.

Although this only gives a very general overview, it does provide an indication that those aged 65 and over form a very small market share of overall users. Research from other countries produces similar findings. Surveys in Australia and the U.S. found that only one in ten older drivers own and use an IVNS for unfamiliar journeys (Tison *et al.*, 2011; Bryden *et al.*, 2013). This is despite older drivers facing significant problems with navigation.

1.7 Statement of Problem

Navigation is a fundamental component of driving. It is therefore important to explore ways to provide better support in this driving task to maintain the independent mobility for older drivers. Currently IVNS are not thought to provide sufficient support in assisting older drivers to navigate the road network. Consequently, there is a need to identify older drivers' route guidance requirements, and then study if these requirements can improve the navigational performance of older drivers.

1.8 Approach to the Thesis

Previous research on route guidance requirements (Alm, 1993; Burnett and Joyner, 1996; Burnett, 1998; Michon and Denis, 2001; May *et al.,* 2003; May and Ross, 2006) has shown that there is a wide variety of potential information that can be provided to drivers to improve their navigation. Additionally, how that information is presented varies (Liu, 2001; Baldwin, 2002; Dalton *et al.*, 2013). Research has ranged from solely providing distance-to-turn audio prompts (turn right in 200 meters) to navigational-based turning guidance in vibrating seats (Van Erp and Van Veen, 2004; Davidse *et al.*, 2009).

However, older drivers' route guidance requirements and the delivery of the requirements have rarely been studied. With the increase in the number of older drivers it is important that either future IVNS take into account the specific requirements of older drivers or that a dedicated system is developed for them; allowing older drivers to maintain their independent and safe mobility. Consequently, the motivation of this research is to develop an improved understanding of what information should be provided to older drivers and whether this can support them in the navigation task of driving.

1.9 Potential Benefits

This study will provide an improved understanding of the navigational information older drivers require and whether it provides improvements to their navigational performance. The results from this research will therefore help to inform the future design of IVNS. For car and device manufacturers (OEMs), this study will also reiterate the importance of considering older adults' specific needs in the design of technology. For transport researchers, this study should support the validity of considering older adults and their varied difficulties when tackling transport issues. Improvements in the design of IVNS to take into account the specific requirement of older adults additionally have the potential to benefit drivers of all ages. The results and knowledge gained through this research will therefore benefit car manufactures, IVNS and IVS developers, transport researchers and, ultimately, older drivers of today and in the future.

1.10 Aims and Objectives

This research has two aims:

- To identify older drivers' route guidance requirements; and
- To study older drivers' specific route guidance requirements, by investigating their navigational performance within a simulated driving environment.

Additionally the research has the following objectives:

- To investigate how older drivers currently navigate their journeys;
- To understand what difficulties older drivers currently experience when navigating on the roads;
- To determine what route guidance information older drivers prefer and why;
- To investigate whether current in-vehicle navigation systems provide adequate support to older drivers;
- To investigate the most appropriate method of delivering route guidance information to older drivers;
- To assess the effectiveness of providing landmark information in the route guidance; and
- To provide recommendations for the design of future IVNS for older adults.

1.11 Structure of Thesis

To address the research aims and objectives, one literature review and three investigations were undertaken. These were each tailored to address the aims and objectives and differed in method and procedure. Figure 1.2 shows, in general terms, the main thread of the thesis. Figure 1.2 matches the study's aims and objectives to either existing knowledge or to the investigations undertaken. Each of the investigations have coloured lines linking them to the objectives and aims they influenced. This demonstrates how each investigation was not undertaken in isolation but provided findings that shaped the direction of the study. Each investigation has a line linking it to Chapter 7, which provides the recommendations for the design of the next generation of IVNS. As the study progressed, the perspective moved from a general overview and became more specific.

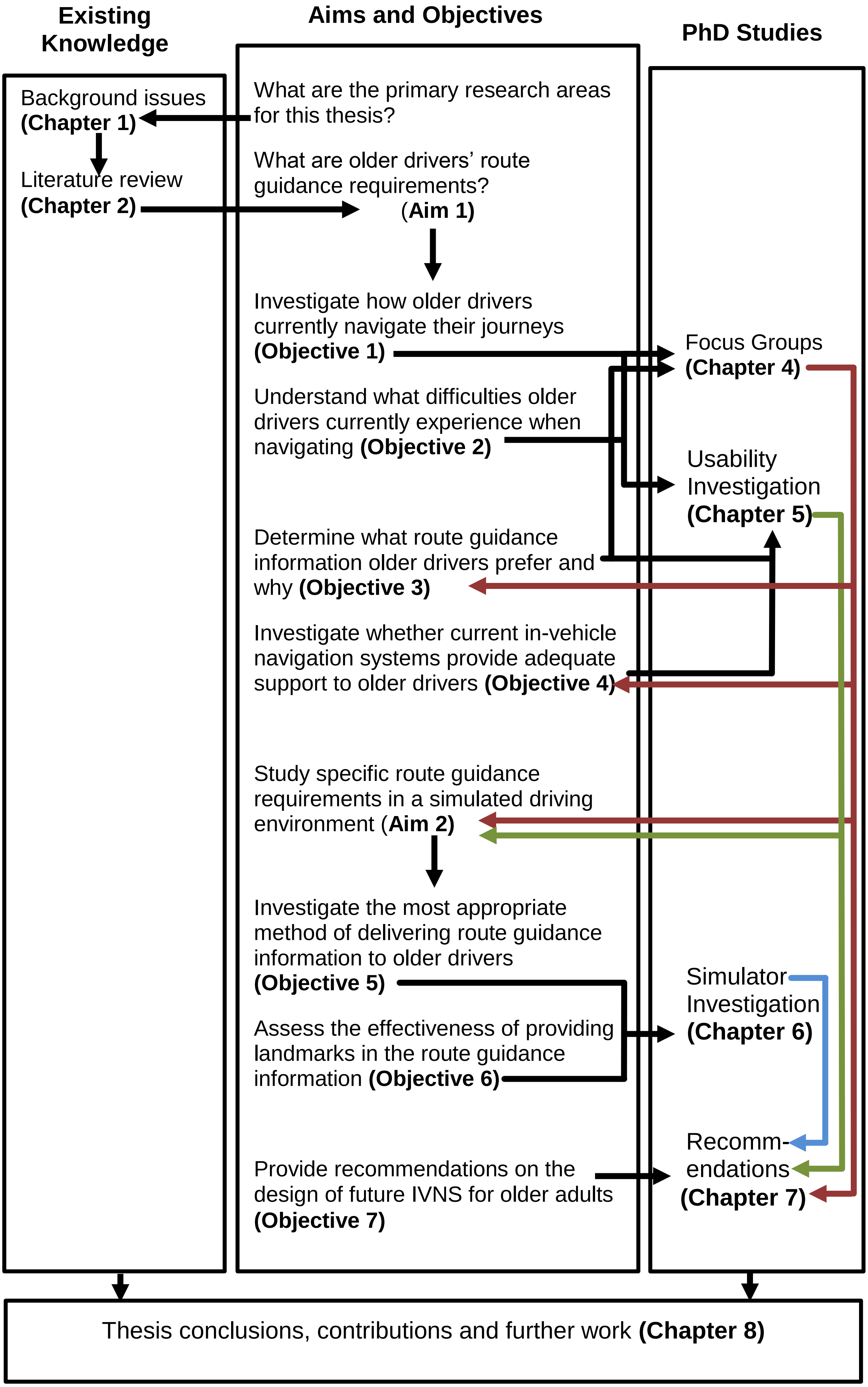


Figure 1.2 Overview of the thesis

Chapter 2. Literature Review

This literature review consists of four sections, each covering a specific sub-topic, and a summary of the highlights and insights found. The first section provides a review of existing models that describe the relationship between navigation and driving. The second section describes the research on older drivers and navigation - this includes the age-related declines that affect navigation and the effective use of IVNS. The route guidance requirements of drivers are described in the third section, while the fourth section reviews how this information should be presented to the driver. Finally, a summary of the literature review is provided, providing a platform to take forward to the methodology and experimental design.

2.1 Overview of the Driving Task and the Role of Navigation

Individual's navigation, in its broadest sense, is to travel safely, efficiently and independently from one point to another (Burns, 1999; May *et al.,* 2005). Navigation involves two distinct but interrelating themes: pre-trip planning and way-finding. Pre-trip planning encompasses the navigational preparations people make before undertaking a journey, whereas way-finding can be defined as the on-trip decision making process the driver is required to undertake during a journey to reach the destination (Burns, 1999).

Driving and navigating are two distinct but related tasks. It is important to consider them in isolation but also how they relate to each other. The literature proposes that driving can be viewed as three tasks structured in a hierarchical model. The key within this approach is that driving is regarded as a complex process that involves a number of small tasks that combine into the overall driving task (May and Ross, 2006).

For the purposes of providing an overview of the driving task, Michon's (1985) model has been used extensively across academic disciplines (Ranney, 1994; May *et al.*, 2003; Rakotonirainy and Steinhardt, 2009) – see Figure 2.1. Michon's (1985) hierarchical model viewed 'navigation' as an integral element across each level. This is a result of navigation occurring for every journey undertaken, whether familiar or unfamiliar.

At the top of the hierarchically model is the ***strategic*** level (Figure 2.1). This level comprises the planning of the driving journey ahead and includes decisions on route selection and what time to set off. These decisions are largely derived from the driver's own knowledge of the local area and generally do not require any new information. Importantly, the strategic level task occurs before the car journey starts and therefore may not be constrained by time. Thus, for local trips, it may only take a matter of minutes, whereas for unfamiliar journeys this stage may take several hours. The ***tactical*** task focuses on the manoeuvres and immediate goals the driver faces whilst driving, for instance overtaking, turning and speed selection. Tasks at this level are generally completed based on the strategic level requirements and the prevailing situation – for example interaction with other road users. The decisions occur in a matter a seconds and are implemented in the final level. The ***operational*** level is essentially the moment-to-moment operation of the vehicle, and includes the physical control of the vehicle. For example the turning of the steering wheel, pressing of the brake and changing gear. The decisions made at this level are implemented within milliseconds and depend on the immediate prevailing situation. These decisions are time-critical so that any delays in the execution of actions may have safety-related implications for example, when turning the steering wheel or pressing break to avoid a collision.

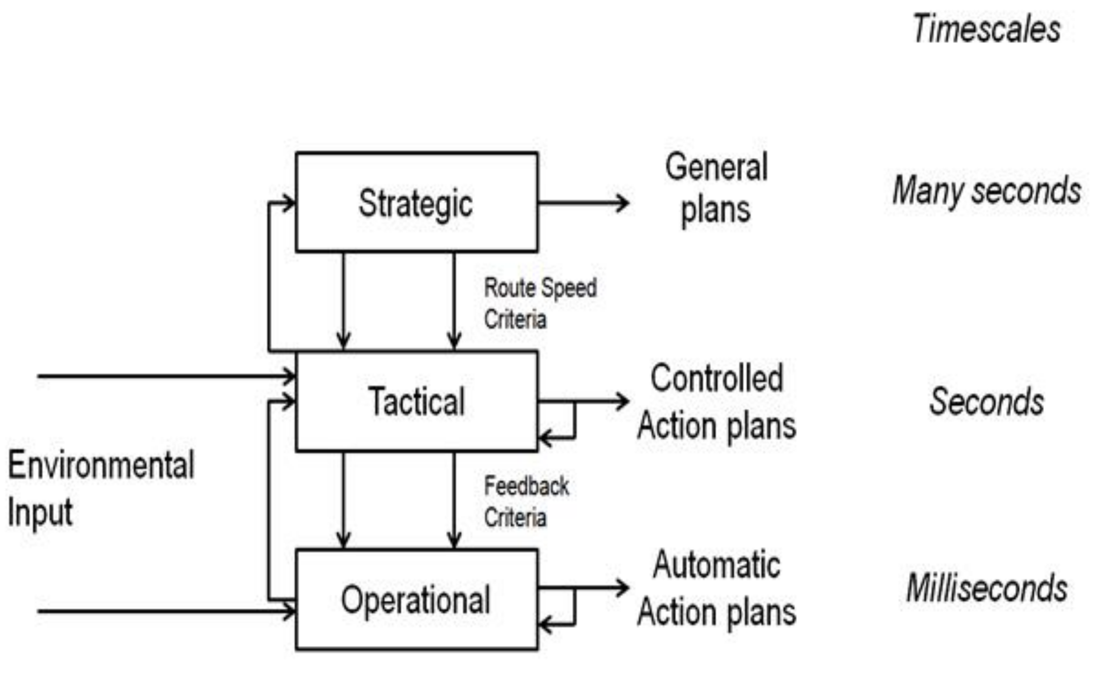


Figure 2.1 Hierarchical structure of the driving task (Michon, 1985)

Michon's model provides a strong overview of the driving task. However, the limitation of Michon's model is that it does not consider the drivers' processing of information whilst driving. Expanding on the work of Rasmussen (1986) a number of authors have attempted to analyse driving-related tasks (Lansdown, 1997). They have merged the sub-tasks of driving by three modes of information processing:

1) Knowledge-based processing – occurs when actions must be planned. For example, planning an unfamiliar journey. This level requires considerable attention from the driver;
2) Rule-based processing – applies to familiar situations where pre-learnt rules for behaviour choices are used. For instance, driving round a roundabout. This level requires average attention from the driver; and
3) Skill-based processing – is highly automatic behaviour that is controlled by subconscious routines. For example, changing gear. This level requires minimal attention from the driver.

Michon's model and Rasmussen's adapted modes of information processing can be combined to produce a matrix of driving tasks – see Table 2.1 (Hale *et al.,* 1990). The shaded grey area indicates the information drivers use to navigate an unfamiliar area. This clearly illustrates that when driving on an unfamiliar journey the strategic and tactical components of the driving task requires information processed from the knowledge and rule based level. Therefore, the operational task of Michon's model and the skill-based task of Rasmussen's model are not ones that could to be considered for this study.

		Levels of driving task		
		Strategic	Tactical	Operational
Levels of information processing	Knowledge	Planning unfamiliar trip	Using a paper map en-route	Using vehicle controls for the first time
	Rule	Choosing between two familiar routes	Following passenger instructions en-route	Using unfamiliar vehicle controls
	Skill	Daily commute	Negotiating familiar junctions	Turning steering wheel at junction

Table 2.1 Matrix of driving-related tasks on an unfamiliar journey (based on Hale *et al.,* 1990)

2.1.1 *Understanding the Navigation Task With and Without an IVNS*

Section 2.1 introduced the three levels of the driving task: strategic, tactical and operational. As illustrated in Table 2.1, navigation is imbedded into the strategic and tactical levels.

At the strategic level drivers require information on estimated journey time and current traffic conditions (Streff and Wallace, 1993). At the tactical level, the needs are different as drivers require information on direction of movement, landmarks, road signs and road layout to assist in the decision making of where and when to turn (Streff and Wallace, 1993). The relative merits of and how the information is provided are critical to the usability of a route guidance system and will be covered in detail in Section 2.4.

First, however, it is important to consider how humans navigate their environment and more specifically how they navigate when driving. There have been a number of different theoretical models that have outlined how humans navigate their spatial surroundings (see Hölscher *et al.,* 2011 for a review). The most relevant ones to this thesis are the models that consider navigation within the context of driving. Within these models the use of a cognitive map is prevalent.

A cognitive map allows humans to represent their spatial environments, and their corresponding ability to use the representations to move from place to place within the mapped environments (Kitchin, 1994; Chown *et al.,* 1995). The majority of research in this area was based upon the pioneering work of Kevin Lynch. Lynch (1960) determined what aspects of a large-scale environment people contain within their cognitive maps, and found that people seem to categorise their environment into five elements:

- ***Paths***: channels that people move, e.g. streets;
- ***Nodes***: points where several paths meet, e.g. junctions;
- ***Landmarks***: external reference points which are easily observable from a distance, e.g. towers, certain buildings;
- ***Districts***: medium-to-large sections of an environment, which the observer mentally enters and are easily recognised as they have some common features, e.g. University campus; and

- ***Edges***: linear elements that serve as boundaries between districts, e.g. rivers or walls.

Figure 2.2 provides an illustrated breakdown of the five elements people use in cognitive maps. Within car navigation, it is generally agreed that paths, nodes and landmarks are the most frequently used (Daimon and Kawashima, 1995). This will be covered in detail in Section 2.4.

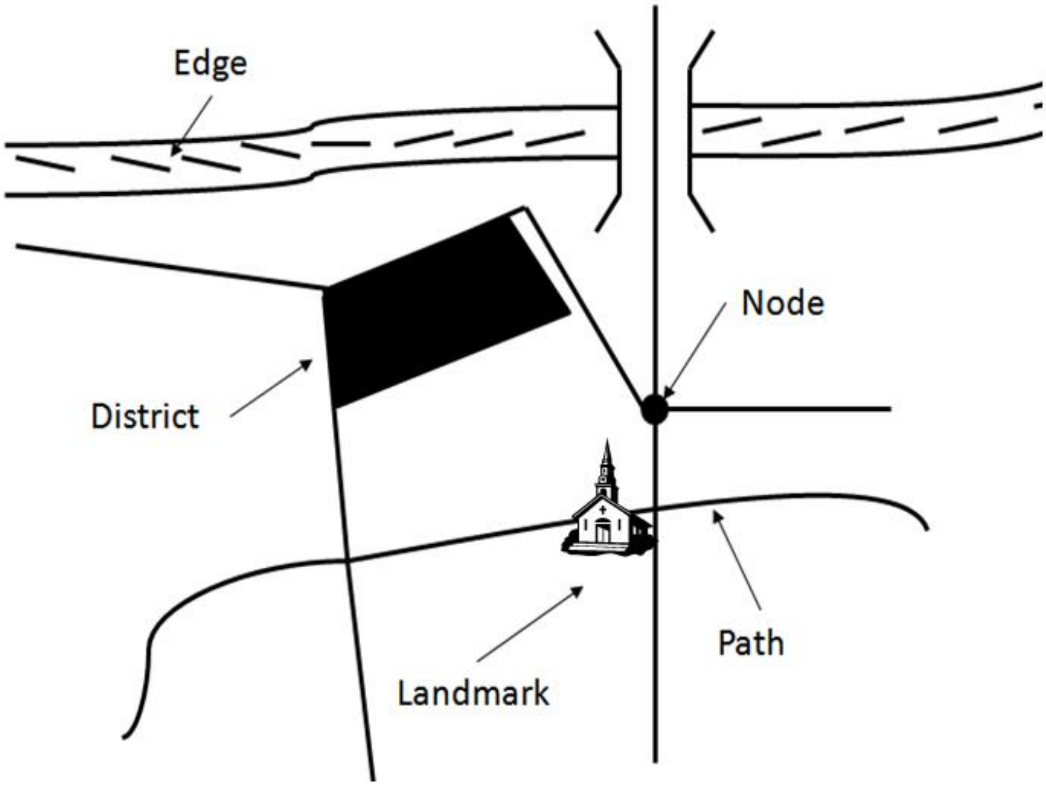


Figure 2.2 An example of components of a cognitive map (based on Daimon *et al.,* 2000)

A number of models have included the cognitive map in describing the navigation task from the driver's perspective. Figure 2.3 outlines Burns' (1998) model of way-finding, which is structured around Wickens (1992) model of information processing. This model indicates that when drivers encounter a decision point, which can be referred to as a node, a decision has to be made. This decision is directly influenced by either the information from the drivers' cognitive map – one that has been derived from the pre-trip planning stage and includes the use of landmarks, paths and nodes – or their perception of the environment (road signs and markings). Burns (1998) argued that drivers may use the information from the prevailing situation, i.e. road signs, road markings, to inform the decision in conjunction with their own cognitive map. However, for frequently travelled routes the use the information provided at the roadside becomes unnecessary. This model re-confirms in a more structured navigation context the driving task and information-processing drivers undertake.

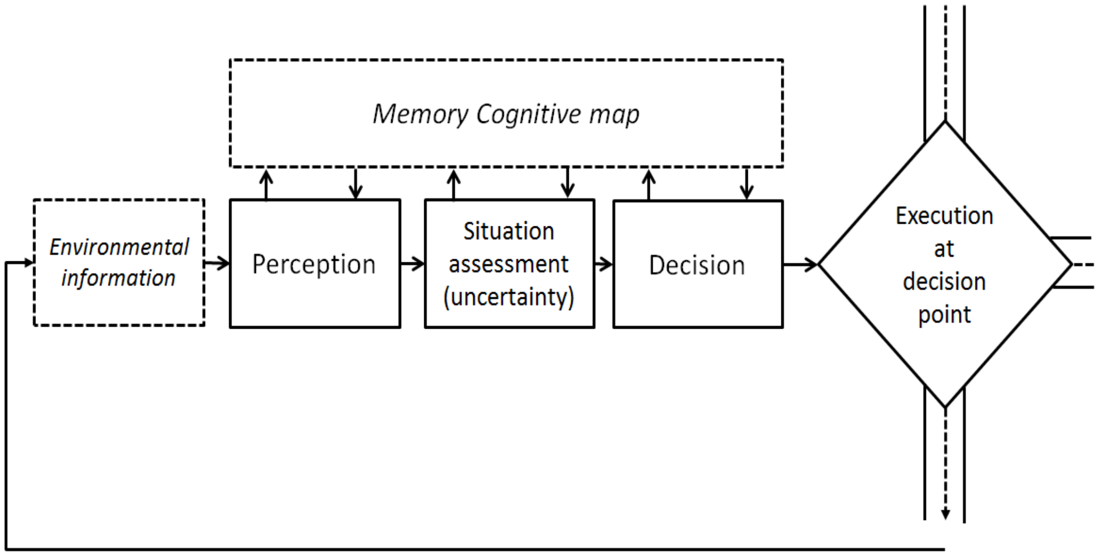


Figure 2.3 Model of way-finding while driving (Burns, 1998)

Burns (1998) indicates the general way-finding task, but does not take into consideration the potential influence of IVNS on this. Daimon and Kawashima (1995) conducted a study where the cognitive processes in route selection were extracted and analysed with five student participants. The students would plan routes by verbally describing their thoughts actions and reasoning. This was then transcribed and a verbal protocol analysis undertaken. The results where compared to the five elements of Lynch's cognitive map (Daimon and Kawashima, 1995). This research is of particular interest as the process was compared for both a paper map and a first generation IVNS. The results showed that regardless of using a paper map or a navigation system the participants fundamentally set 'sub-goals' at junctions (nodes) where they had to make a turn and then plan the route to the next junction. This process was repeated until the final goal, i.e. the end destination is reached (Daimon and Kawashima, 1995).

The study found a significant limitation with the use of maps to plan and then way-find a journey as published paper maps cannot provide the user with their current location. Daimon and Kawashima (1995) proposed that when drivers use an IVNS, which provides its current location, a different cognitive processing would result. When driving without an IVNS the driver will observe landmarks and keep them in their working memory or in a ‘buffer’ as Daimon and Kawashima (1995) described. Therefore, during driving, they will search for landmarks along the route and determine their current location – see Figure 2.4. They will then locate themselves within their cognitive map.

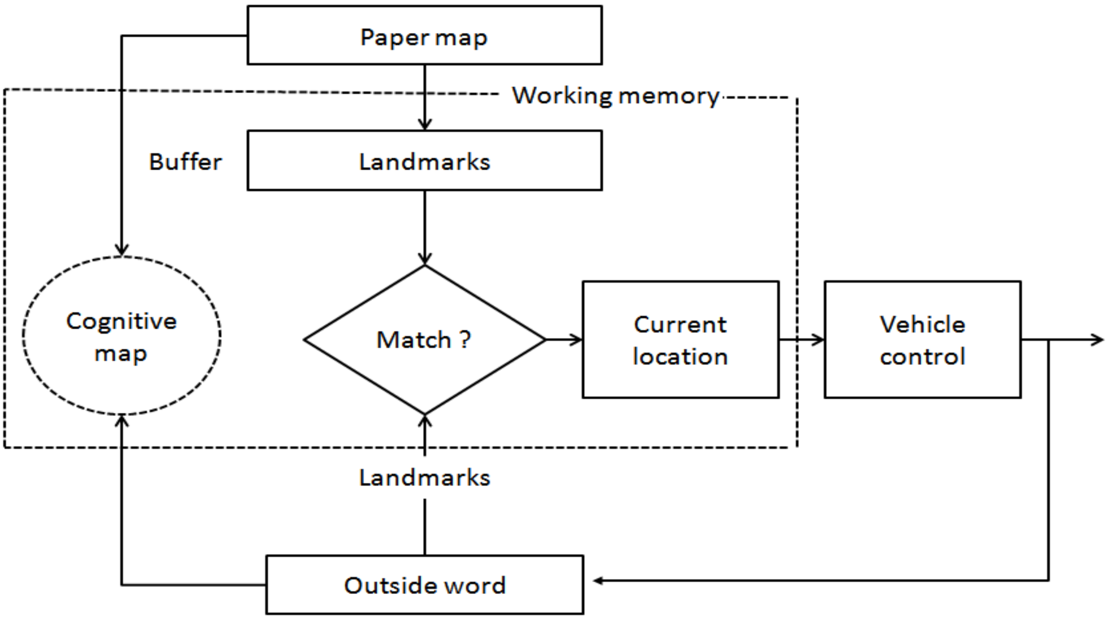


Figure 2.4 Driver's cognitive process for determining current location when using a paper map (Daimon and Kawashima, 1995)

The same cognitive process was analysed with five students when they used a navigation system. IVNS provides a current location on the map-based display along with the estimated arrival time and distance to next turn. Daimon and Kawashima (1995) hypothesised that drivers mainly extract and refer to the information of path, node and location from a first generation IVNS. However, this information is not kept in the working memory as the information was displayed on the visual screen at all times. Drivers will still search for landmarks or paths but determine that they are on the correct road through observing the visual display, reducing the need for a cognitive map – see Figure 2.5. The reduced cognitive workload is the greatest difference between Figure 2.4 and 2.5.

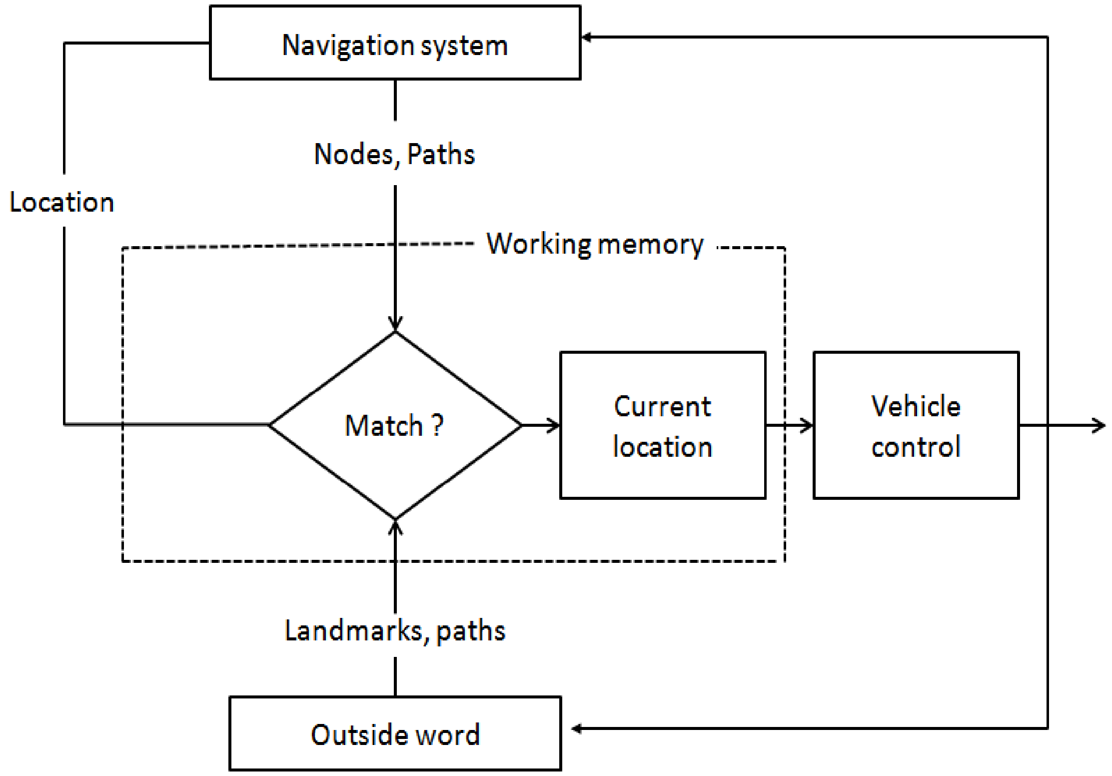


Figure 2.5 Driver's cognitive process for determining current location when using an IVNS (Daimon and Kawashima, 1995)

2.2 Ageing Drivers: Their Mobility and In-Vehicle Navigation Systems

Section 2.1 highlighted the key elements of navigation within driving, which are the strategic and tactical tasks of Michon's model. Yet, to further understand the route guidance requirements for older drivers it is import to consider their current mobility, the effect of ageing on driving and navigation, the potential gender difference within navigation, their current use of IVNS, and safety concerns of using IVNS.

2.2.1 *Older Drivers' Mobility*

The introduction to this thesis has drawn attention to older adults' reliance on a private car for their mobility needs. Generally, older people are considered to be safe drivers (Langford *et al.,* 2006; Langford *et al.,* 2008; Rosenbloom, 2010). There has been a recent increase in research focusing on the accidents attributed to older drivers and their general safety on the roads. The types of accidents and driving styles of older adults differ from younger and middle aged drivers. Boufous *et al.* (2008), for example, linked police and hospital records in Australia and found that on rural roads, the presence of complex intersections, road speed limit, and driver’s error can all be identified as independent predicators of injury severity. However, to consider all drivers over the age of 60 as responsible for a high proportion of accidents is misleading. For example older drivers under the age of 70 have lower accident rates than their younger counterparts (aged 60 and under) (Hakamies-Blomqvist *et al.,* 2002; Langford *et al.,* 2006). This may be explained by their increased caution and experience behind the wheel (Banister and Bowling, 2004), but they do have a high death rate and serious injury rate due to their fragility (Hakamies-Blomqvist *et al.,* 2004). Furthermore, Clarke *et al*. (2010) examined UK road casualties in three UK counties and found that drivers aged under 70 appeared to suffer similar crashes as those from any age group. Yet, beyond 70 years of age the number of crashes caused by themselves increases. Those aged 85 years or more appeared to be over four times more likely to have contributed to a crash than when they were deemed to have been innocently involved, highlighting the importance of not treating older adults as a homogenous group (Clarke *et al.,* 2010).

2.2.2 *Ageing and the Effect on Driving and Navigation*

There is an agreement in the literature that as a person ages their abilities, in a wide range of areas, will decline but not in a uniform or predicable way. Ageing can be attributed to functional declines in physical, sensory and cognitive abilities (Mynatt and Rogers, 2001). The implications of ageing can be found to influence a wide spectrum of daily tasks. Driving and navigation tasks are no different. When comparing older people to younger adults, older adults take longer to make similar movements, their ability to maintain continuous movements decline, and their coordination is disrupted (Mynatt and Rogers, 2001). These declines affect the operational level of Michon’s model of driving tasks. This is the second by second overall control of the vehicle. Therefore, ageing makes what the majority would consider simple tasks, like turning the wheel or changing gear more demanding. Although these physical declines do affect the control of the vehicle they do not affect navigation (as shown in Section 2.1) so will not form a part of thesis.

Ageing is also associated with changes in all sensory abilities. The declines in vision and hearing have been the most studied. This is particularly useful as these are the most important senses for driving and using IVS (Guo *et al.*, 2010). Colour vision, contrast sensitivity and visual acuity all decline with age (Mynatt and Rogers, 2001; Owsley *et al.*, 2013). The decline in vision has obvious implications for driving. There have been numerous studies to investigate the declining eyesight of older adults. Owsley and McGwin (2010) produced a comprehensive review of vision and driving. They found that declines in visual acuity (which is the difficulty to see colour contrasts or sharply defined edges (Staplin and Hunt, 1999)) particularly affects driving performance. This aspect of sight reduces the ability to clearly read road signs and dashboards. Therefore, this implicates on drivers using the prevailing environment for assisting in the way-finding task. Owsley and McGwin (2010) do stress that age-related visual impairments could affect older drivers' ability to detect relevant events and objects on the roadside, and to utilise the dashboard information. Yet, they concede that technologies can assist with these declines but that the research is in its infancy for example, heads-up displays (HUD) (Kim *et al.*, 2011).

Just as vision decreases with age so does hearing. This includes the loss of absolute sensitivity, difficulty detecting sounds of high frequency, and changes in pitch and speech perception (Mynatt and Rogers, 2001). The decline in hearing ability is important to consider, especially when reviewing how current route guidance information is delivered to older drivers (see Section 2.4 for further details of research in this area).

The field of cognitive ageing has aimed to understand the basic cognitive changes that accompany the normal ageing process (Craik and Salthouse, 2000; Park and Schwarz, 2000). The research within cognitive ageing has found that although some abilities do decline, many actually remain intact well into people's eighties. There are no accepted rules with any declines associated with ageing. In general, however, aspects of memory (particularly working memory), online reasoning ability, and aspects of attention which require attending to more than one source of information all show age-related decline (Craik and Salthouse, 2000; Park and Schwarz, 2000; Mynatt and Rogers, 2001). Relevant abilities to driving and navigation that do show limited declines into old age are some aspects of memory for example, in the case of recall of well-learned and habitual information (Mynatt and Rogers, 2001).

It is now important to reflect on how ageing and the associated declines in the senses and cognitive ability influence navigation. In general, navigation is seen as a straightforward and effortless task as it is so common. Yet it involves multi-level cognitive processing and therefore has attracted much theoretical and practical interest (Ishikawa *et al.,* 2008). Older adults have been found to perform worse than younger participants in a variety of spatial learning and memory tasks (Iachini *et al.,* 2009). These age-related declines in spatial learning and memory have been found to create challenges for older adults in accurately forming a mental representation of a spatial environment, and thus efficiently navigating such environments (Forlizzi *et al.*, 2010; Kim *et al.*, 2012; Yamamoto and DeGirolamo, 2012). Therefore, older adults have difficulties in planning a journey from memory. Moreover, older adults will often want to avoid certain situations like heavy traffic, driving at night or driving on unfamiliar routes - a process called self-regulation (Charlton *et al.,* 2003). This makes planning a journey even more cognitively demanding. Therefore, older drivers often plan alternative ways of achieving their goal or adapt their behaviour in order to reach the required destination (Metz, 2000; Metz, 2003; Banister and Bowling, 2004). Burns (1999) conducted a survey of UK residents and found that older drivers go on significantly fewer trips and drive less on unfamiliar roads when compared to younger cohorts. This research supported a study by Rabbitt *et al*. (1996) that found older drivers prefer to avoid heavy traffic conditions, unfamiliar places and unfamiliar routes as they age. Furthermore, in a study in the U.S. Sixsmith and Sixsmith (1993) highlighted that age related navigation difficulties was one of the most significant reasons for reduced driving or for driving cessation. Further research has suggested that older drivers can find navigation particularly difficult due to the decline in their cognitive, perceptual and motor skills (Burns, 1998; May *et al.,* 2005).

Bryden *et al*. (2013) conducted a large-scale survey with 534 older adults (aged 65 and over). This examined their way-findings strategies and navigational behaviour. From this sample, 60% of the older drivers reported difficulties with way-finding. When reviewing the respondent’s way-finding strategies for an unfamiliar journey the authors’ found that using a map while driving was the most popular (61.9%). Reading a map while on the roadside was second (55.1%) and reliance on memory (38.2%) third. 33% of older drivers would create written instructions or a drawn map to assist them. While only 9.9% would use an IVNS. Moreover, this research found that when older drivers have difficulties with way-finding they are likely to use a passenger to assist them in the navigation task.

Section 2.1.1 highlighted the importance of cognitive maps in locating oneself within an environment. The use of cognitive maps relies on several processes that contribute to spatial cognition, for instance memory, attention, perception, mental imagery and decision-making (Liu *et al.*, 2011; Bryden *et al.*, 2013; Dalton *et al.*, 2013). Liu *et al*. (2011) conducted an online survey with 634 volunteers that aimed to investigate age and gender difference in the use of navigation strategies, including cognitive maps. The study analysed the responses with a two-way analysis of variance (ANOVA) and found that older participants performed worse than younger participants in all navigation strategies. Yet the ability to form cognitive maps was found to be most difficult for older adults. In addition, men were found to be better than women at forming a cognitive map. The results are supported by a study by Iaria *et al*. (2009), in which they concluded that older adults require more time to form a cognitive map than younger people. Moreover, older adults were found to require more time and make more errors when using a cognitive map for navigation when compared to younger adults (Iaria *et al.,* 2009).

In conjunction with a cognitive map, Section 2.1 indicated the use of the prevailing environment to inform the decision making process at each navigational decision point. Decline in the senses, especially vision, and working memory makes reading and then processing road signs or road markings more difficult as we age. In an on-the-road assessment, older adults were found to make a significant number of errors when asked to report road markings and traffic signs as they drove (Kim *et al.*, 2012). Older drivers have been known to compensate by driving slower and leaving larger gaps in their headway. This allows them more time to notice and read the road signs (Hakamies-Blomqvist *et al.,* 2004). Additionally, older drivers have been found to drive with a passenger so they can become the eyes and ears of the driver; allowing the driver to simply focus on the sole task of controlling the vehicle (Kostyniuk *et al.*, 1997; Bryden *et al.*, 2013). Nevertheless, Burns (1998) from a survey found that ‘signs and information’ were the most frequently reported cause of getting lost. In fact 83% of 1184 respondents blamed poor road signs for their navigation problems, whether this is poor highway design or a more complex reason is unclear.

2.2.3 *Older Adults' Use of IVNS*

IVNS are generally considered beneficial to older drivers as they assist with the strategic and tactical tasks of driving (Burnett and Lucas, 2010). Yet, the greatest attention older adults and IVNS have received has been surrounding their ability to interact with the system. This research has largely revolved around the age-related factors that affected the use of these systems (Burnett, 1998; Eby and Molnar, 2009):

- ***Perceptual changes*** – for example, reductions in visual field, static and dynamic acuity, depth perception, increases in glare sensitivity, time required for lower light-levels and dark adaptation, and poor hearing.
- ***Cognitive changes*** – for instance, reduced spatial ability, greater problems in tasks involving divided attention, attention switching and selective attention.

Research undertaken by Lui (2001) has found that older drivers experience greater visual demand with in-vehicle displays than younger drivers do. Additionally, Zhang *et al*. (2012) found that older drivers are prone to make more navigational errors as task difficulty and display complexity are increased.

Therefore, it is apparent that given the difficulties with older adults navigating car journeys and using technology, there is a clear need for IVNS to consider this. However, current research has found that IVNS do not take into account older driver's needs. Pauzie (2003) suggests that current IVNS are difficult to use by older adults and generally do not meet the needs of older drivers; highlighting that the present configuration of information delivery and complex visual displays of IVNS are not suitable for older drivers. Dingus *et al.* (1989) found that, on average, older drivers had longer glance durations to the display when compared to the younger drivers. This finding has been supported by additional research. In a simulator study where older and younger drivers followed a route from an IVNS, older driver's mean glance duration was 0.98 seconds compared to the younger driver's average of 0.84 seconds (Zhang *et* *al.,* 2012). An on-the-road trial found that older drivers mean glance towards a moving map based display to be 1.08 seconds compared to the younger participants 0.83 seconds (May *et al.,* 2005). In addition, older drivers have been found to take longer to read and then understand the instructions provided by the screen than drivers under the age of 55 (Pohlmann and Traenkle, 1994; Dingus *et al.,* 1997). As older drivers glance at the screen for longer than any other user group this has significant safety implications. Mourant et al. (2001) who conducted a study examining the use of IVS with ten older and younger drivers, further investigated this issue of safety. The authors found that in-vehicle displays, including ones used for IVNS, in their current format are not appropriate for older drivers. They concluded by suggesting that the in-vehicle displays are not useable due to age-related declines in vision rather than cognitive processes. They highlighted that the provision of information, in this form, affects the safe control of the vehicle. Moreover, a study by Rakotonirainy and Steinhardt (2009) found that older drivers have difficulties with the dual tasks of driving and following a navigation route. Pak *et al.* (2008) highlighted that IVNS need to reduce the demand on workload and spatial ability for older drivers. In addition, it has been found that older drivers may not trust the information presented and route guidance information was not presented in enough time before having to make a turning (Mahmud *et al.,* 2009).

A review of the usability of IVNS in 2000 by Burnett (2000) found that they are far from effective at providing route guidance information to its users (and not just older people). In particular, there were three key areas that the author felt needed to be addressed in the future:

- **Voice interface** – there is need for a wider range of information for all vehicle navigation systems;
- **Display interface** – there is need of higher positions of display which may lead to head-up-displays (HUD) being the most beneficial solution; and
- **Control interface** – those navigation functions that are likely to be used by the driver during a journey should be readily accessible.

Burnett (2000) further highlighted the importance of effectiveness, efficiency and satisfaction when reviewing the usability of IVNS. This will be discussed further in Section 3.3.4.

Perhaps surprisingly there have been only a limited number of published studies on the real world use of IVNS. A recent study with 40 drivers from America found, unexpectedly, that subjects predominantly reported using their IVNS for familiar destinations (Lo *et al.,* 2011). However, the data was self-reported and it could be possible that they were more likely to recall familiar journeys. Baldwin and Reagan (2009) conducted a study to investigate the difference in navigational strategy that may occur with age. The authors found the navigational information provided for younger adults would not be optimal for older adults. Older adults were found to benefit from auditory route guidance systems aids but rely more on map-based and cardinal heading information relative to younger adults.

As older drivers have been found to have significant difficulties with using IVNS an interesting finding on how they use them was produced by Kostyniuk *et al.* (1997). In their observational based study, the authors found that older couples used IVNS more commonly. Team navigating was evident through their conducted focus group sessions where the secondary person, either a friend or a partner, would act as an extra pair of eyes on the road ahead. The research found that if older adults were to benefit from IVNS then it would take two people to use one device. Furthermore, it was suggested that IVNS could be an adequate replacement for human co-pilots if designed in the right manner (Kostyniuk *et al.,* 1997; Kostyniuk and Molnar, 2008).

However, it is worth noting that the majority of the research on IVNS was carried out and published in the early 1990s to coincide with the emergence of the first generation of IVNS and again in the late nineties when IVNS became a more commercial proposition and affordable to the mass market (Burnett, 2000c). Since then, IVNS technology has progressed dramatically (in terms of functionality, form and size of units and affordability). Therefore, further research is required to verify the usability of the current generation of IVNS and their suitability for older drivers.

2.2.4 *Gender Difference in Navigation Behaviour and use of IVNS*

The research highlighted so far has indicated that there are significant problems for older drivers with navigation and using IVNS. Yet, the literature has also indicated that there may also be gender issues in navigation behaviour and use of IVNS.

Research has found that older women in particular are keen to adopt in-vehicle technologies (Yannis *et al.,* 2010). One of the key reasons is that female drivers have a desire to maintain their independence, and technology is one way to achieve this. However, given the low ownership of IVNS in the older driver age bracket there are clear barriers to use. Current literature is not clear on what are the barriers.

In terms of driving behaviour that relates to navigation, research has found that older women are more likely to reduce time driving on unfamiliar roads when compared to older men (Peel *et al.,* 1995; Burns, 1999; Ragland *et al.,* 2004; Siren and Hakamies-Blomqvist, 2009). In a large-scale survey, Bryden *et al*. (2013) found that 14% of older drivers actively avoid unfamiliar routes. Moreover, older female drivers are four times more likely to report avoidance than men. A U.S. longitudinal study conducted between 1992 and 1995 showed that those older woman who restrict their travel distance from home have an association with an increase in mortality and frailty (Xue *et al.,* 2008). Moreover, older women with even a slightly restricted travelling behaviour were associated with a higher risk of becoming frail (Xue *et al.,* 2008).

Turano *et al*. (2009) conducted a study that aimed at investigating whether sense of direction was associated with the amount people drove. Over a thousand participants aged over 67 took part in the study. The results showed that a poorer sense of direction was significantly associated with restricting the frequency and distance older females drove. They concluded that perceived spatial/navigational ability does play an important role in older women's driving restrictions. Furthermore, Turano *et al*. (2009) proposed that as men have higher spatial confidence and lower spatial anxiety than women they therefore have little difficulty or stress with navigation. This would mean that navigation does not influence their driving behaviour to the same degree that it does for women. Additionally, Lawton (1994) found that women are more likely than men to report anxiety about navigation. This increased anxiety has been found to affect their driving behaviour, with a reduction on travelling on unfamiliar routes (Lawton, 1994; Burns, 1999). Kozlowski and Bryant (1977) suggest that people with a good sense of direction derive self-esteem from their ability to find their way about the environment. Research has found that males perform better at spatial orientation than females, proposing that there may be gender based differences (Voyer *et al.,* 1995; Cutmore *et al.,* 2000).

Lawton (1994) examined the difference between men and women's way-finding strategies. Although the research did not focus on older adults, it does provide relative results. The study found that men use orientation strategy, where an individual's position is tracked in relation to geographical reference points, whereas, women prefer route strategy with the focus on learning the route or particular key features on the route. The means that women generally prefer to learn a route before setting off. This became more evident as women in the Lawton study were less likely to undertake a shortcut while way-finding unless the shortcut was part of the pre-trip planning. Further studies have examined the differences of map reading ability between the genders. Males have been found to perform better with map tests then females (Henrie *et al.,* 1997). Although the studies have focused on gender and not age, the results seem to suggest that females rely on local features that have to be learnt over time. Males on the other hand, approach maps from a global perspective (Coluccia and Louse, 2004; Coluccia *et al.,* 2007).

Another study explored the relationship between older drivers, their passengers, and the potential implications of IVNS on their driving safety. In total, 22 married couples were interviewed with all the males identifying themselves as the driver. The findings showed that in later life the driving task was a shared activity between the driver and passenger (Vrkljan and Polgar, 2007). When driving in unfamiliar locations and in demanding conditions, for instance city centres, then the passenger would become a co-pilot. This would mean reading road signs and looking for required exits; becoming the eyes for the way-finding task while the driver focused on driving. All the participants had never used an IVNS before and expressed concern that it may cause a distraction (Vrkljan and Polgar, 2007). These results could provide a potential new area for research to explore within older drivers and IVNS. The study concluded that this form of duel navigation could be included into future IVNS to assist ageing couples in their continued driving.

More recently, Lin and Chen (2013) conducted a study with 64 participants, aged 18-30, to assess potential gender difference of IVNS visual screens. In particular, to assess the usability of 2D and 3D IVNS screens. The study found that the genders do possess difference in visual spatial capacity as males were found to outperform females in locating points and planning routes on the displays. This resulted in the male participants rating the usability of visual navigation display to be higher than females. Additionally, 3D provided no advantage over 2D screens and, in fact, proved detrimental to females.

When examining the difference in use of IVNS by gender, research has produced some intriguing results. For example, Kostyniuk *et al*. (1997) conducted focus group interviews with 18 drivers over the age of 64 who had substantial experience with IVNS. Males were found to be the dominant drivers in the focus groups. The participants indicated that changes in the road environment made navigation more difficult as they aged. Moreover, they preferred driving with a human co-pilot rather than relying on their IVNS system. Yet the act of the co-pilot had developed from map reading skills to relaying the information they obtained from the IVNS to the driver.

The findings from this section could have significant implications for future application of IVNS. There are clear navigational differences between the genders that may influence the route guidance requirements and how that information is presented. In addition, there may be a need for an IVNS designed for older adults providing a greater level of support to older female drivers. Further research is required to understand the potential gender difference for the design and use of an IVNS for older adults.

2.2.5 *Safety Aspects of Using IVNS*

The relative merits of older adults using an IVNS can be summarised as:

- Current and future generation of older adults are car dependent;
- Older adults have significant problems with navigation;
- These difficulties result in older drivers reducing or limiting the amount they drive on unfamiliar roads;

- This negatively impacts on their mobility and thus their well-being;
- It is particular evident in older women; and
- Safely maintaining older adults' access to their private car is a growing requirement which technology can provide support in.

IVNS therefore have the potential to provide support to older adults. However, there are possible safety issue with the use of IVNS, not only for older drivers but also for all drivers, which needs to be considered. There are two key issues to review when considering safety and IVNS: workload and distraction.

In-vehicle information systems (IVIS), which includes IVNS, have been shown to increase driver workload and cause distraction (Birrell and Young, 2011). A recent simulator study by Birrell and Young (2011) evaluated the impact of smart driving aids on workload and distraction with 25 participants. They found that real-time delivery of smart driving information did not increase driver workload or adversely affect driver distraction. In fact mean speed was found to be more consentient. However, the research paid no attention to age. One of the reasons why older drivers could be especially prone to distraction from an IVNS is because of the ageing impairment found in perception and attention. Fofanova and Vollrath (2011) conducted a simulator study to examine the effect of age on driving performance as well as the potential compensation strategies adopted by older drivers under distraction. A total of 20 participants were recruited, 10 middle-aged and 10 older. The study found that the older participants were worse in all conditions, in time pressured and non-time pressured tests, compared to younger ones. Moreover, older drivers took significantly more time to respond to items in the dual task conditions without time pressure. The authors argued that older drivers abandoned the secondary task and focused on the control of the vehicle. In this scenario, the ability to follow navigational information from an IVNS was affected.

Kim and Son (2011) have undertaken research on the safety issues of using an IVNS through on-the-road trials. Trials were conducted with 40 participants in three age groups: younger (20-29); middle-aged (40-49); and older (60-69) under five driving tasks. Kim and Son (2011) found that older drivers were significantly different in the time they took to complete tasks through NASA-TLX scores (a measure of workload, see Section 3.3 for further detail). Older drivers needed more time to complete even the most basic task when compared to younger drivers. Kim and Son (2011) suggested that user interface does not adequately take into account the increased time it takes older adults to complete tasks with IVS. Finally, the study reported that older drivers did become distracted when completing the more complicated tasks.

Horberry *et al*. (2006) conducted a driver simulator study that examined the effects of distraction upon driving performance for drivers in three age groups. Thirty-one participants took part in the study: 10 were younger drivers (under 25 years old); 11 were middle-aged (aged 30-34); and 10 were older drivers (aged 60-77). The study aimed at investigating in-vehicle distraction and possible distraction caused by environmental complexity – visual clutter on the roadside. The study found that all participants lowered their mean speed while interacting with the in-vehicle display. Moreover, the older driver participants lowered their mean speed limit to a greater extent than other age groups. A significant finding was that older drivers had a lower speed in complex conditions than the other two age groups (Horberry *et al.* 2006). The reduction in speed was thought to be an attempt to compensate for the increased workload that occurred when the older participants used an IVNS.

2.3 Information Requirements for Route Guidance

Information requirements will differ according to what stage of navigation the driver is undertaking (either pre-trip planning or way-finding). Research dating back to the nineteen eighties has shown that drivers have problems in planning and following efficient routes (Davis and Schmandt, 1989; Burnett and Joyner, 1996). Furthermore, the strategic level information requirements will be different to that of the tactical level on Michon's model. This section will explore the information requirements at both levels. The research of this area can be disassembled into those that have aimed to generate suitable information types and those that have tested them.

2.3.1 *Route Guidance Requirements*

The literature has highlighted a range of different research methods used to understand drivers' route guidance requirements. One of the fundamental aspects within the research in this area is the acceptance that humans have developed cognitive maps to help them navigate (Kitchin, 1994). Researchers have used drivers' cognitive maps to elicit the information types required for route selection and guidance. Lynch's seminal work on how humans view their surroundings is prevalent in a number of studies. Although there is one relevant study that undertook a different approach to cognitive maps that is worth considering.

Chown *et al.* (1995) explored how human's way-find their cognitive map and found that it can be broken down into four component problems:

- ***Landmark identification***: Landmarks are vital in determining orientation and current location. The problem with landmarks in way-finding is to separate out distinctive objects which can be used in pre-trip planning and then recognised when travelling the route;
- ***Path selection***: Choosing a route to a required destination. If the route is not direct then the journey can be divided into a number of different journeys. It is likely that this will involve the use of landmarks; meaning the path will be created by travelling passed each landmark in turn;
- ***Direction selection***: Choosing the correct direction in which to travel. For those destinations that are not in sight, then this becomes more problematic. The series of turns and number of them will result in many changes in directions. Consequently, the starting direction is rarely enough for the entire journey; and
- ***Abstract environmental overview***: Although not essential for successful way-finding, this provides an overview of the environment in which the journey will take place. Additionally, the overview makes large-scale reasoning about the environment simpler.

Chown *et al*. (1995) argues that solutions to the first three are essential to human way-finding, and that all four are individually separable but all need to be addressed for successful way-finding. When examining the work by Lynch (1960) (see Section 2.1.1) and Chown *et al*. (1995) it is evident that the most notable difference is that the information of districts and edges in Lynch's work is not covered by Chown *et al.* (1995). This can be explained through the difference in scope between Lynch and Chown's research. Lynch attempted to identify how people develop cognitive maps whereas Chown assessed how humans navigate their cognitive maps. For this study, it is important to assess older drivers' cognitive maps as there is no clear evidence if they are different to the findings proposed by Lynch.

The four solutions outlined by Chown *et al*. (1995) are supported by a study in which 44 students were asked to either sketch a map or write down verbal directions indicating how to reach their university from their house (Obata *et al.,* 1993). The use of sketch maps was first used by Lynch (1960). A participant is asked to draw a map of a specific area on a sheet of paper, based on memory. The method is frequently used in research on cognitive maps and is explored in more detail in Section 3.2.3 (Daimon *et al.,* 2000). The sketch maps are then analysed and categorised according to pre-determined categories, predominantly Lynch's (1960) five elements. Obata *et al*. (1993) found that limited information was noted which were classified as districts or edges on Lynch's cognitive map elements.

Whether researchers have adopted Lynch or Chown's components of cognitive maps, one of the key elements of both are the use of landmarks. The importance of landmarks as a tool to understand your spatial surroundings and then navigate that environment has been well documented in the literature (Nothegger *et al.,* 2004; Roger *et al.,* 2011). Landmarks have been found to be a key navigational requirement for both stages of navigation (Klippel *et al.,* 2003; Richter and Duckham, 2008; Waters and Winter, 2013). Moreover, landmarks have been found to be beneficial within the navigation task compared to traditional methods; especially when landmarks are located in close proximity to the navigational decision point (Dennis, 1997; Lovelace *et al.,* 1999; Michon and Denis, 2001).

May *et al*. (2003) conducted an empirical study of the information requirements a driver needs in an urban environment. This study attempted to eliminate participants' cognitive maps by focusing on the information needs in the context of being a driver on an unfamiliar route. 36 participants took part in the study, and these were split into two groups depending on local knowledge of the roads. This was significant as those who had limited local knowledge were shown videos of routes and asked to identify the information that they would need to navigate successfully. The participants who had any knowledge of the filmed routes were shown schematics of the route instead. These were designed to just show enough information for them to identify their requirements. In total three routes were shown to the two groups and the data analysed. The authors found that landmarks were the most common form of information being used by both groups. However, due to the number of items included within the landmark category then this result could have been expected. Nonetheless, May *et al*. (2003) argued that landmarks are a very prominent way to navigate in the UK. Although landmarks did feature heavily in the information requirements, so did junction descriptions, lane information and direction signs. Interestingly in terms of current information provided by IVNS, distance-to-turn information was perceived to be of little value.

Schraggen (1990) conducted a road-based trial with 24 drivers, where the aim was to gain insight into how drivers navigate under typical road conditions and explore what difficulties they encounter. This was therefore not an investigation into how people use their cognitive maps but rather what types of information drivers need on route. This also differs from May *et al*. (2003) as it takes place on-the-road rather than through videos or schematic maps. Schraggen (1990) instructed his participants to plan the journey and then verbally explain what information they were looking for during the journey. This information was recorded and categorised to Kuiper's theory of spatial knowledge rather than Lynch's (Schraggen, 1990). The analysis revealed that a slight difference occurred from the pre-trip planning information to information attained during driving. Table 2.2 outlines the information that was required during both tasks of navigation:

Categories	Pre-trip planning (%)	Way-finding (%)
Street names	51	42
Road signs	11	14
Landmarks	12	17
Topological knowledge	23	23
Metric knowledge (e.g. distances to turn)	3	4

Table 2.2 Information required at the two stages of navigation (Schraggen, 1990)

The results are in stark contrast to May *et al*. (2003) study. This may be a result of geographical location - Schraggen (1990) road trials were conducted in Holland. Geographical factors have been found to influence navigational behaviour (Daimon *et al.,* 2000). Additionally, it also may be the result of the driver being behind the wheel rather than the subjective position of watching a video or viewing a map. The issue of drivers using their cognitive map to navigate was removed by Schraggen (1990) by only using drivers with no previous experience of the area. Even though street names were used extensivly in both stages of navigation, the study found that reliance on street names for way-finding increased navigational errors. However, this was a study to investigate how drivers navigate in a new environment whilst using traditional strategies. The use of street names would have been a primary source of navigational information and earlier sections of this review have identified the potential problems older drivers have with reading road signs. Additionally, it has been noted that road signs can only be partially visible, inaccurate, misleading, or perhaps not even present and therefore it can be expected that increase navigational errors will result (AA, 2011).

Streff and Wallace (1993) conducted a survey with over 2,700 drivers in the state of Michigan with the overarching aim to analyse drivers' information use and preferences on the roads. The results were then compared to a first-generation IVNS and comparisons made. Streff and Wallace (1993) asked a wide range of questions concerning information provision. However, unlike other studies they did not disaggregate their findings to any categorisation scheme but rather investigated the potential preference differences. The participants were asked to indicate (from a list) all of the sources of trip information that they used. The results showed a wide variety of information. The most popular information service was maps (86.4%) and a roadside sign (76.7 %) was the third most popular. The results should be considered with caution as the question did not specify the trip purpose or type. Therefore, walking and public transport could have been included, which is perhaps why a travel service (81.1%) was the second most popular choice. When the participants were asked to select a statement that best describes their confidence in driving oneself to desired locations, 44% agreed that they are good at finding their way in familiar areas with minor troubles in unfamiliar areas. When the results were tested for statistically significant differences in confidence levels in respect of demographic details the results showed that driving confidence is significantly associated with gender.

Winsum (1993) examined what route selection criteria drivers have. He argued the studies have found time-savings, distance, traffic conditions, safety and scenery have all appeared to be important in route choice. Yet, the current findings have been unable to address the context of the network, distance of trip between origin and destination, demographic characteristics and trip motive. Winsum (1993) conducted a study with 49 drivers where they would plan a long journey from point A to B four different ways. All the participants were familiar with the area but the distances between points were large enough to allow different routes to be planned. Of the four routes each participant planned, they were asked to explain what makes them travel that way over another. A decision analysis study found that total time of the route strongly influenced the preference of the route. Total distance and time waiting at traffic lights strongly determined the total travel time. In addition, road types (in terms of condition) also were considered important, as this would affect the arrival time. The results were used to create a route selection algorithm for a navigation system with ‘waiting time for giving right of way’, ‘waiting time for traffic lights’, ‘road type’ and ‘distance’ key factors. The algorithm resulted in a route that 82% of the participants would have chosen as their primary route (Winsum, 1993). When only distance was taken into account, the routes planned only accounted for 41% of the primary routes chosen. The results strongly suggest that people select routes beyond distance alone. In addition, there were no statistical differences between gender, age, trip type, education level and driving experience.

A study was conducted by Hölscher *et al*. (2011) aimed to assess how drivers’ plan routes. They found for the first time that different planning and navigation conditions lead to different way-finding strategies. In the first study, 12 participants were asked to navigate from one edge of a district to the other. They were not allowed assistance and were asked to plan verbally, the shortest route and then navigate it; explaining their decisions at every turn. The participants were walking rather than driving in both studies but comparisons can be made between the two as the focus was on planning a journey through a road network. It was found that when participants planned the route during navigation (strategic task on the move), it resulted in more turns and a greater number of streets but a more efficient route overall. The second study with 12 participants allowed them to plan the route before travelling and then navigate it in the same verbal manner. Hölscher *et al*. (2011) found that the routes chosen where longer and focused on the major roads when compared to the first study. This resulted in the authors arguing that when navigating as you go rather than planning before a journey resulted in more efficient and flexible route choices. It was suggested that this was because the participants in the first study were able to choose diverse routes and adapt for conditions. Thus the participants were able to use the environmental information on the roadside to assist them. They additionally commented that visual feedback – i.e. landmarks in affirming the directional selection was important. The results are supported by research that examined 20 London Taxi drivers' process of way-finding (Spiers and Maguire, 2008). The study found that drivers in a well-known urban environment employ a number of way-finding strategies. The ability to plan a route, on the move, with only the basic direction known was evident. The participants would travel street by street towards the goal, and only partially plan the entire journey before they set off (Spiers and Maguire, 2008). However, the effectiveness of this approach – i.e. the driven route being the quickest and shortest was not examined. Thus, it is still not clear if this approach is an efficient method to navigate.

2.3.2 *Information Testing - Landmarks*

The literature review so far has suggested that there is a strong requirement from drivers, including older adults, for the inclusion of landmarks in the route guidance information. Before considering the studies that have tested the inclusion of landmarks in the route guidance information it is first worth considering what a landmark actually is and why it may be of benefit to drivers.

In his seminal work, Lynch (1960) described landmarks as external reference points that are easily observable. Other researchers have provided alternative definitions, but what is consistent amongst researchers is that landmarks are considered a useful form of navigational information primarily as they are part of human's cognitive map (cognitive maps were reviewed in Section 2.2). Moreover, landmarks are a useful form of information as they are more prevalent across an urban environment. However, if landmarks are to be used successfully in the provision of navigational information they should be visible in all conditions and seen at a distance (Green and George, 1995; Burnett, 2000b; Goodman *et al.,* 2004).

The most important research to-date on this topic has been by Burnett *et al*., (2001). The authors conducted a study with 32 participants (16 male, 16 female; age range 22 to 60) in which they were asked to write down detailed route plans for an unfamiliar journey. This aimed to understand the characteristics of what makes a 'good' landmark for navigation. Each participant's transcripts were coded and counts undertaken of the frequency of landmark mentions. From this point, the transcripts were assessed and reviewed for the reason for selecting landmarks. Additionally, the contextual differences of the landmark types were assessed. From this analysis Burnett *et al*. (2001) produced, a table that outlined five characteristics that are useful for navigation purposes - see Table 2.3. Table 2.3 shows the characteristics of 'good' and 'bad' landmarks. Indeed, to the best of this author's knowledge, a more comprehensive review of landmarks classification in route guidance research is not available.

Attributes of valued landmarks	**Good landmarks**	**Poor landmarks**
Permanence - the likelihood of the landmark being present, either in ●Form (shape/size) or ●Label (name, logo, etc.)	Churches, Woods, Monuments, Schools	Factories, Shops, Petrol Stations
Visibility - whether the landmark can be clearly seen in all conditions	24 hr. petrol stations	Post-boxes, Street names
Usefulness of Location - whether the landmark is located close to navigational decision points	Traffic lights, Corner shops	Rivers, Railway lines
Uniqueness - the likelihood of the landmark not being mistaken for other objects/features, either due to: ● A highlighted individual appearance ●Being located apart from landmarks of same type	Bridges, Roundabouts, Railway stations, Parks	Repairs garages, Traffic lights
Brevity - the conciseness of description associated with a landmark	Traffic lights	Large white house on the left

Table 2.3 Characteristics of landmarks for navigation (Burnett *et al*., (2001)

To confirm the findings from Burnett *et al*. (2001), two studies have adopted the research findings: May *et al*. (2005) and May and Ross (2006). May and Ross (2006) conducted a study in which 48 drivers (all aged over 21 – no age range provided) used a state-of-the-art DVD-based satellite navigation system that provided visual navigational arrows and verbal landmark instructions, as well as a visual map overview. In total, the route had 37 decision points, which were defined as a location where the driver had more than one navigation option. As the navigation system used was off-the-shelf the researchers' recorded additional verbal landmark instructions. The instructions included 'good' and 'poor' landmarks (based on Burnett *et al*., (2001) findings) and distance-to-turn information. All the participants drove the same experimental route that was designed to be navigationally challenging. The participant's driver safety, navigation performance, workload, confidence, attitude and visual glance behaviour were measured. The road trial found that when good landmarks were used, navigation performance, driving performance and driving confidence increased. When the distance-to-turn information was used then visual glances increased towards the navigation screen. May and Ross (2006) additionally found that there was no impact on subjective workload when providing different navigational information to the driver. The authors concluded that future navigation systems should adopt a hybrid approach where distance-to-turn information is used when an adequate landmark is not available.

The findings were expanded upon by an additional on-the-road trial. The study was conducted by May *et al*. (2005) with 32 participants of which 16 were aged 55 and over (no age range provided). The aim was to investigate the benefits to older and younger drivers in providing landmarks within the audible route guidance information. The landmarks were again selected upon the criteria of Burnett *et al*. (2001). The study found that the use of landmarks for both older and younger drivers reduced the time spent glancing at the visual display, reduced navigational errors and positively influenced driver confidence. The authors' concluded that the inclusion of landmarks could have significant benefits for older adults.

Burnett (1998) produced a list of the top ten scoring landmarks for use in the UK, based on a number of studies. These included questionnaires and navigational-based road trials. The author further highlighted that this list was influenced by geographical location. Drivers' navigational behaviour and preference has been found to be influenced by their geographical location. Thus, a UK driver might consider a pelican crossing a landmark, whereas someone from Japan may not (Daimon *et al.,* 2000). The top ten are:

1. Traffic lights
2. Pelican crossing
3. Bridge over road
4. Hump-backed bridge
5. Petrol Station
6. Monument
7. Superstore
8. Street name sign
9. Railway station
10. Church

The use of landmarks within route guidance has also being identified to be particularly useful to older people in a study by Goodman *et al*. (2005). The authors conducted a study with older adults using a specially designed system that included landmarks. The investigation focused on pedestrian navigation but the results are relevant to this study as it involved older adults and landmarks. In total 32 participants took part in the trial, 16 of whom were aged over 60 and 16 were aged between 19 and 34. The participants navigated two routes around Glasgow University Campus, one with a standard paper map and the other using a hand held navigation device. Goodman *et al*. (2005) found that a system that bases its navigation guidance around landmarks can significantly outperform a paper-based map. In addition, the authors found that their system design significantly reduced subjective workload (through a Raw Task Load Index (RTLX) – see Section 3.3.1.2) and was positively received by the participants. The 16 older people were found to derive more benefit from the systems than the younger users. Interestingly, when examining the information delivery the use of speech instructions on their own were less effective than text or photographs (Goodman *et al.,* 2005). The study found that landmark-based route guidance information can provide benefits to older drivers navigation, albeit pedestrian navigation. However, the effectiveness of landmarks in car navigation for older drivers is not clear.

2.3.3 *Information Testing - Road Signs*

Reading and processing information from road signs is an issue for ageing drivers (Owsley, 1999). The decline in vision, specifically visual acuity, affects the ability to read road signs. However, there has been limited research into providing the information through an in-vehicle display.

Moreover, Musselwhite and Haddad (2010) explored older drivers' needs through a qualitative study finding that road signs are regarded to be a distraction. A compensated method for this problem has been highlighted where older drivers undertake a journey with a co-pilot who read the road signs for the driver (Kostyniuk *et al.*, 1997; Vrkljan and Polgar, 2007).

2.3.4 *Information Testing - Auditory*

As highlighted in the earlier sections ageing is accompanied by a wide variety of impairments. Perhaps one of the most overlooked age-related declines, in relation to driving, is hearing loss as auditory ability is not generally considered an integral requirement of safe driving as much as visual decline. Hearing decline results in increased pure-tone thresholds, difficulties in speech perception and greater susceptibility to the adverse effects of noise and reverberation form the environment (Baldwin, 2002).

IVNS rely heavily on the auditory channel (May *et al.*, 2003; May *et al.*, 2005). Thus, hearing ability will significantly affect a driver's ability to use an IVNS or any IVS. Baldwin (2002) reviewed the difficulties older people face with hearing and found those in their 60s have pure-tone detection thresholds that are on average 13 dB higher than those in their 20s. However, driving inherently results in background noise that will affect those results. Moreover, background noise will vary according to vehicle model and condition, driving conditions and road type. For instance, interior noise levels will rise with car speed (Baldwin, 2002).

Currently IVNS primarily use auditory information for providing way-finding information. A study by Coren (1994) found that older adults, those aged 60 and above, preferred speech stimuli to be presented 16 dB lower than younger adult (in their 20s) – a similar finding as Baldwin (2002). As audio is a vital channel for IVNS, the speech rate is essential as time-compressed speech may pose additional speech processing problems for older adults (Baldwin, 2002). There is limited research on the most appropriate presentation rate for IVNS.

Llaneras *et al*. (2000) conducted an on-road trial of auditory format and speech rate of in-vehicle information system on drivers from a range of age groups. Twenty-four participants (age range 18-65) completed a two-hour drive. The authors found that accelerated speech displays improved driving performance, as measured by lane discipline and headway variability. Llaneras *et al*. (2000) tested the normal words per minute (wpm) of 125 and an increased version of

225wpm. Additionally, the auditory format was tested between prose (e.g. the Ramada has a vacancy and is 48 miles away) and list-form (Ramada, vacancy, 48 miles). The findings showed that the list- form resulted in greater driver performance, measured by lane discipline and headway variability. However, the participants' relative navigational performance was not assessed in this study. Therefore, further research is required into the most effective speech rate for delivering route guidance information.

2.4 The Presentation of Route Guidance Information

Simply knowing what information drivers require is not going to be sufficient to provide effective route guidance information for older drivers. How the information is presented and processed by a driver is of equal importance. How the information is delivered has provided interest from a wide range of academic disciplines and will be reviewed under four headings: the choice of modality, format of navigation information, alternative ways to present information and scheduling of route guidance information.

2.4.1 *The Choice of Modality*

Traditionally there are three ways to present information through an IVNS: visual only, auditory only and visual and auditory combined (Burnett, 1998; Srinivasan, 1999). This has resulted in researchers comparing:

1) Visual only vs. auditory only;
2) Visual only vs. visual and auditory combined;
3) Auditory only vs. visual and auditory combined; and
4) Visual only vs. auditory only vs. visual and auditory combined.

Visual Only VS. Auditory Only

It is generally accepted that the vast majority of information required for driving is visual (Burnett *et al.,* 2001). Consequently, to provide information that is not visual is thought to be beneficial, i.e. through the auditory modality. This has led to numerous studies comparing the two forms of information delivery.

Most recently, Dalton *et al*. (2013) conducted a simulator study with 20 participants aged between 18 and 34 which aimed at examining people's preference and performance of auditory information. The research concluded that spoken instructions are vital to safe and effective IVNS. The authors suggested that simple auditory route guidance information could be processed and followed without obvious interference to a simulated driving task. This supported earlier work which found an advantage of auditory over a visual display for the amount of cognitive demand placed on the driver (Moldenhauer and McCrickard, 2003; Jensen *et al.,* 2010). Yet, Hölscher *et al*. (2011) also found that when the complexity of the audio information increased it led to significant performance declines.

Although Verwey (1993) study was conducted over 20 years ago, it has perhaps provided the most controlled investigation of the relative merits of the comparison of visual and auditory information delivery. In two lab-based studies with 16 participants, 8 male and 8 female, Verwey compared the verbal and spatial format of route guidance information by asking participants, whilst under severe perceptual motor load, to interpret route guidance instructions against slides depicting real world junctions. The route instructions comprised either verbal, visual, or as symbols on the screen. The results showed that the participants responded quicker to verbal instructions than any other method. Therefore, Verwey concluded that verbal route guidance instructions are more appropriate than symbolic or spatial instructions. In addition, Verwey (1993) further concluded that oral information is system-paced so the driver may miss information, and verbal instructions for complex junctions or roundabouts may not be sufficient. In these cases, a visual display for confirmation is beneficial to the driver.

Additional research has reviewed the use of auditory and visual modalities with older drivers. For example, Green *et al*. (1993) conducted a road-based trial with 43 drivers, young and old, in which they drove a route through a city using route guidance information provided by either: a first generation head-up display, an in-vehicle display, or voice instructions. The study concluded that participants preferred voice instructions. Yet more navigational errors were made when participants only used voice instructions. Alm (1993) and Dicks *et al*. (1995) also highlighted that providing voice instructions only can lead to navigational errors, especially at complex junctions. However, it should be noted that no recent studies have investigated these findings with more recent technological advancements.

The use of auditory guidance messages is thought to be critical for safe and effective vehicle navigation systems (Burnett, 2000) as the auditory message does not require the driver to remove their eyes from the road (Burnett, 2000). Yet current systems use digitised messages that require considerable system memory. Thus, the number and length of messages they can currently provide is limited. Further research is required into whether the current IVNS audio messages can effectively navigate older drivers.

Visual Only vs. Visual and Auditory combined

As highlighted by Verwey (1993) providing only single information from visual or auditory information can cause navigational errors for drivers. The comparisons of this type of information delivery therefore have been prominent in the literature and studies have shown advantages in this mixed method delivery.

For example, Burnett and Parkes (1993) showed the advantages of a combined interface in a road-based study. Eight participants drove a route using simple visual route guidance symbols with graphical distance-to-turn information and another 8 participants drove with the same visual information plus an additional simple voice instruction. The study showed that when the information was combined, fewer glances were made and less time glancing towards the route guidance display when provided with audio information. Additionally, Burnett and Parkes (1993) found that the workload values were reduced and the participants self-rated the combined approach to be easier and less stressful through a workload questionnaire.

Auditory Only vs. Visual and Auditory Combined

Fastenmeier *et al*. (1994) conducted a road-based trial in Munich, Germany, with 16 participants who were not familiar with the area. This is one of the only studies of its type so is relevant despite its age. The participants were split by gender and drove an unfamiliar route using two different modes of route guidance: auditory only or visual display with verbal instructions. In addition, two control factors of using a paper map and instructions from a passenger were trialled. Two researchers would sit in the car and score the navigational errors they made and provide a safety rating.

The results from the study showed that the road map performed the worst and the co-pilot the best. There was little difference between the two methods of the navigation although as highlighted before the use of audio only resulted in confusion and navigation errors at complex junctions. The combined visual and auditory information did lead to significantly more safety errors that were thought to be caused by being distracted by the screen. However, no further research was undertaken to fully address how the visual display caused a distraction.

Visual Only vs. Auditory Only vs. Visual and Auditory Combined

The literature on comparing all three possible information delivery methods is limited. Liu (2001) conducted a simulator study which compared 16 younger and 16 older drivers' ratings of workload and performance of navigation and button-pushing tasks with information presented visually, auditory or multimodal (visual and auditory). The author found that all the participants using auditory and multimodal displays produced better performance in terms of response times, total number of correct turns and subjective workload ratings than those using visual only. In addition, older drivers using an audio and visual display significantly improve their navigation performance.

Lansdown (1997) conducted a simulator study with 21 participants in which they drove three different routes using visual information only, auditory information only, and visual and auditory combined. The author found that the visual only interface was associated with the highest number of navigational errors, and the highest subjective workload - assessed by researcher observation and NASA-RTLX. The combined visual-auditory display was the most preferred option.

2.4.2 *Alternative Ways to Present Information*

Research suggests that drivers possess six modalities that could potentially receive navigation information. These are visual, auditory, h, kinaesthetic (muscle sense), olfactory (smell) and gustatory (taste) (Alm, 1993). The research considering the three less well-known modalities (kinaesthetic, olfactory and gustatory) is limited which is understandable given their appropriateness within car navigation. Yet research on the haptic modality has been undertaken.

Van Erp and Van Veen (2004) conducted a simulator study with 16 drivers who were provided navigational instructions through a vibrating chair. Small vibrating boxes were mounted on the seat, four in a row under each thigh. Each box would then vibrate according to distance to the next turn under the left or right thigh dependent on the direction of the manoeuvre. This delivery of information was compared to a moving map-based screen. Van Erp and Van Veen (2004) found that when navigating with a haptic chair in combination with a visual display it resulted in faster reactions to the navigation messages, lower mental effort ratings and no performance decline when workload increased. The authors concluded that the use of tactile information should be employed in navigation and other automotive issues as the tactile channel has an unlimited field-regard. The findings have been supported by other research employing tactile information in navigation - although not car navigation. Pielot *et al*. (2009) found that pedestrian way-finding was significantly more effective (measured by route length time, walking time and completion time) when provided with a tactile belt which indicated on their person the direction to travel, compared to navigating with a paper map.

Moreover, the visual presentation of the information in future applications of in-vehicle technology may incorporate the use of HUDs. The aim of this system is to allow the driver to continue attending to the road ahead and driving tasks whilst taking in information projected onto the windscreen. It is, therefore, of particular interest in driving as the visual modality is highly loaded in the driving context and HUDs have the potential to reduce this. Burns (1999) suggested that HUDs may be of a particular advantage for older drivers as they experience difficulties in rapidly changing their vision between near and far object. No research has yet been undertaken that specifically investigate HUD for older drivers.

2.4.3 *Scheduling of Route Guidance Information*

There are two key issues whilst examining when information should be appropriately delivered to the driver:

1) The timing of the delivery of the final instruction before a manoeuvre; and
2) The amount of information you can deliver when manoeuvres occur straight after each other.

The first issue is critical to the system safety and acceptability, especially on the final approach to a manoeuvre. If a message is given too early, then memory demands and increased mental workload may be affected (Alm, 1993). On the other hand, if timing is late then this may result in sudden braking and an unsafe manoeuvre being performed. It has been argued that the exact timing of this message is complex and one that includes a number of variables: speed, gender, age and prevailing situation (Burnett and Joyner, 1996). Currently no exact timings of when the system should provide the information before an upcoming manoeuvre are known (Wu *et al.,* 2009). Kimura *et al.* (1997) suggested that the timings are highly dependent on vehicle speed and the drivers' capabilities. For instance, younger drivers can receive navigational commands 300m before a simple turn and lane changes and 700m in advance of sharp turns. However, this and other recommendations are based on subjective ratings for middle to young drivers (Ross *et al.,* 2008). What is clear is that older drivers need more time to prepare for navigational manoeuvres than their younger counterparts (Baldwin, 2002). Yet no scientific evidence currently exists as to the exact timings older drivers require information before a turning.

The second issue concerns combining more than one instruction into a single message. Alm and Berlin (1991) investigated this with 24 participants in a road-based trial in Sweden. They examined three levels of providing information: 1) one instruction for the upcoming manoeuvre, 2) two instructions for the next two upcoming manoeuvres and 3) three instructions for the next three manoeuvres. The authors found that participants would request repeats of the information at level three and this was found to be the most difficult due to age-related declines in short term memory. After analysis, it was concluded that if the driving time between intersections is less than ten seconds then information should be presented at level 2. Otherwise, level one should always be used.

2.4.4 *The Format of Navigation Information*

Information from an IVNS is generally presented in two key formats: a visual display and audible turn-by-turn instruction. The situation however is not as black and white as that - as the visual screen may present information in two distinct ways (Burnett and Joyner, 1996; Burnett, 2000a; Burnett, 2000c):

1) Moving map-based displays which present guidance information as a highlighted route on a map; in most cases, the map will move around a static vehicle symbol; and
2) Symbol-based displays that present the driver with step-by-step instructions via a graphical representation of the next manoeuvre, plus supplementary information, for example distance to the next manoeuvre and road names.

These two forms of presentation allows for two different methods of delivering visual route guidance information. In addition, auditory messages can provide supplementary information beyond the step-by-step instructions. Each individual manufacturer and system will provide different levels of detail and emphasis on visual and auditory information. The use of a simple display that does not include a moving map display or turn-by-turn instructions was found to be the most beneficial to older drivers (Dingus *et al.,* 1997; Pauzié, 2003). In comparison, the use of a moving map display with route guidance instructions has been found beneficial to drivers (Antin *et al.,* 2009). However, these findings did not examine older adults, only drivers up to the age of 55.

When considering the moving map display, then Obata *et al*. (1993) analysis of 44 student's sketch maps produced some alarmingly inaccuracies. For instance, the sketch maps would show curves as straight roads and distances grossly misjudged. The research concluded that future IVNS should not present information as an accurate map but rather focus on the roads that are the most relevant. This would affect the scale of the map but provide the driver with the most salient information.

Further research has been undertaken to examine the effectiveness of turn-by-turn instructions. Burnett (1997) conducted a road-based trial with 24 participants (aged 40-60) in which they drove three routes using two different sets of turn-by-turn instructions, or instructions by the passenger. The author found that using the two turn-by-turn instructions led to increased visual demand and negative effects on driving behaviour compared to travelling with a co-pilot. The reasons for these errors were proposed to be primarily due to one of, or combination of three reasons:

- Difficulties encountered in using distance countdown bars;
- The presentation of limited or inaccurate environmental cues; and

- Poor message timing on the approach to manoeuvres.

The literature review, however, does not provide definitive evidence on the most effective way to present information to older drivers; indicating a clear gap in current knowledge. Further research is required to first understand older drivers' preferences and then test these in a simulated driving environment.

2.4.5 *Design of IVNS*

How IVNS displays its information is of particular interest to transport authorities, as there is a concern that they may cause a distraction to the driver. Stevens *et al*. (2002) produced a report for the Transport Research Laboratory (TRL) which outlined the design guidelines for the safe use of in-vehicle information systems. The report outlines numerous areas that need to be considered for a safe IVNS which include colours, layouts and location of the display. The report outlines the guidelines for a general navigation system but does concede that certain aspects should be considered for the intended user groups. In the case of older drivers, Stevens *et al*. (2002) suggested that controls on the visual display should particularly be considered. Interestingly, the report proposes that, where possible, the information should be delivered with auditory and visually information in combination. The relative merits of this combination have been outlined above but no evidence exist as to whether this is the most appropriate method for older drivers.

2.5 Conclusions

The literature review presented in this chapter has shown that older adults rely on the car for their travel needs but navigation becomes more difficult as people age. Older drivers have been found to have difficulties in planning and way-finding routes. The effect of age-related declines impairs older adults' ability to navigate journeys efficiently and safely. These difficulties can result in older drivers limiting the amount they drive, particularly on unfamiliar routes. This has an impact on their mobility and thus their well-being.

In addition, there is a difference in how the genders navigate. The literature review suggests that older women have greater difficulty with navigation than men. They are more likely to reduce their driving activity to unfamiliar locations and many reported feeling anxious when navigating. Additionally, women are more likely to learn the route by relying on significant features to indicate turnings, for example landmarks; whereas men are more likely to navigate in relation to geographical reference points. This provides an indication of the potential gender differences when using the traditional methods of planning journeys, the road atlas. This may result in older women’s driving mobility being negatively influenced by navigational difficulties.

However, the literature did not provide a clear understanding of how older adults currently plan and navigate a journey. Without this information then older drivers’ route guidance requirements are unknown and potentially future IVNS will be unable to provide the required level of support. Moreover, the research in this area has predominantly been explored through large-scale questionnaire surveys. This method provided no contextual information as to the situations in which difficulties occurred. Further understanding is required to explore this in a contextual sense. As journeys and route guidance preferences can differ according to variety of different variables that questionnaires are not able to cover. The adoption of qualitative research methods can complement the quantitative findings highlighted in the literature review.

The development of IVNS has progressed dramatically since its inception in the 1980s. They provided pre-trip planning and way-finding support to drivers. They should provide adequate support to all drivers. Yet the review of the literature found that for a significant proportion of older drivers IVNS are deemed difficult to use and result in increased workload and navigational errors. The literature seems to suggest that the design of IVNS do not take into account the age-related declines or older drivers specific route guidance requirements. However, the majority of the research on IVNS was conducted on first generation or turn of the century IVNS. The current IVNS have progressed significantly since this earlier research was undertaken. There is a requirement to review current IVNS for older drivers. Identifying the usability of current IVNS may provide greater clarity of the route guidance requirements of older adults. Providing required route guidance information in a usable system should increase acceptance of this technology and potential to provide the required support in navigating in later life.

The literature review has highlighted the potential benefit of providing landmarks within the route guidance information. Landmarks are a key part of everybody's cognitive maps. In comparison distance-to-turn information, the current delivery of route guidance information on IVNS, has been found too difficult to interpret by all drivers. Thus, landmark information can be argued to be a more natural form of navigational information. However, only a limited number of studies have assessed the use of landmarks with route guidance information for older drivers. Moreover, those studies have mainly identified the properties of a 'good' or 'bad' landmark. In addition, the literature review did not clearly identify the most effective method to deliver route guidance information to older adults. This was a combination of older driver's rarely being considered in the route guidance literature and the largely quantitative nature of the methods used to date. Given that individual's navigate themselves differently, future IVNS need to consider specific characteristics and not view older adults as one homogeneous group.

A clear finding from the literature is that older drivers are not a homogeneous group. For all IVS, which includes IVNS, there is no one solution that fits all the requirements. Moreover, a proportion of older drivers are satisfied with current generation IVNS. However, the previous research presented in this chapter indicates there is a need to research this area further for the large proportion of older drivers who have indicated that they do have problems with such systems.

Finally, a wide range of both quantitative and qualitative methodologies have been used to investigate route guidance information requirements. The approach of adopting a number of different methods seems to provide the potential for a clearer understating of the navigation issue at hand. The following chapter will detail the methods used in the study and their links to the research aims.

Chapter 3. Methodology

3.1 Introduction

Following the literature review, it is clear that there are numerous methodological issues associated with investigating route guidance information (both pre-trip planning and way-finding) and IVNS to support the navigation task. As discussed in Section 1.10, the research has two aims:

- To identify older drivers' route guidance requirements; and
- To study older drivers' specific route guidance requirements, by investigating their navigational performance within a simulated driving environment.

In order to achieve this, data is required to assess older drivers' route guidance requirements, in both stages of the navigation task. Then from these findings, specific requirements can be highlighted and tested in a simulated driving environment to address the second aim. The following sections will review the potential methods available in this study under two key headings: route guidance requirements (Aim 1) and testing of route guidance information (Aim 2). After these two sections, the methodology for this thesis will be outlined.

3.2 Aim 1 – Route Guidance Requirements

3.2.1 *Focus Groups*

Focus groups and other qualitative methods are increasingly being used to complement quantitative analysis of travel behaviour (Rosenbloom, 2010). The use of this method has even been replacing the traditional quantitative approach of questionnaire surveys, for example in understanding driver behaviour (Kostyniuk *et al.,* 1997; Huang and Wang, 2008; Diana and Pronello, 2010). Focus groups have examined a wide range of older driver research areas (Oxley *et al.*, 2010; Shaw *et al.*, 2010; Siren and Kjær, 2011; Zhan *et al.*, 2013). This includes the information people require while driving and current opinions of IVS and IVNS (Kostyniuk *et al.,* 1997; Gardezi *et al.,* 2006; Musselwhite and Haddad, 2010).

The strength of focus groups lies in collecting rich qualitative data from a range of different people. Therefore, focus groups allow for older adults' feelings and attitudes towards driving, planning a journey, and information requirements to be captured and explored in depth (Vrkljan and Polgar, 2007; Rosenbloom, 2010; Zhan *et al.*, 2013). Additionally, as the participants of focus groups are chosen in some way, there is the opportunity to target groups according to age, gender, experiences and IVNS use. Moreover, focus groups allow for interaction between the participants which results in open discussions and comparing opinions and experience with each other as would naturally occur in real life (Krueger and Casey, 2009). This provides a greater understanding of the topic under investigation. Focus groups have a long and respected history in examining older adults mobility (Kostyniuk *et al.*, 2009; Rosenbloom, 2010; Zhan *et al.*, 2013).

Undertaking focus groups is a delicate balancing act between data gathering and moderating. Therefore, careful consideration has to be given to the questions and structure to allow the researcher to fully understand the chosen topic (Morgan, 1993; Morgan, 1996; Krueger and Casey, 2009). The focus groups have to be structured and moderated so that conversations are of interest to the researcher and crucially no single participant dominates the group, nor the discussions/questions are leading.

A key element when designing focus groups is the number of people within the group. Krueger and Casey (2009) argue that within large groups there is a tendency for the group to fragment whereas smaller groups allow a greater opportunity to share experiences and opinions. Taking into account previous literature, focus groups of five people were found to be optimal (Rosenbloom, 2007; Krueger and Casey, 2009; Zhan *et al.*, 2013). However, smaller groups do limit the number of ideas that can be expressed and discussed and are not appropriate for generalising findings (Morgan, 1993). Instead, the findings from all focus group research should be seen as a reflection of opinions within the chosen community (Rosenbloom, 2010). Yet, the results can complement quantitative findings from other studies and provide a basis for additional quantitative research to be undertaken.

3.2.2 *Questionnaires*

Questionnaires are a method of producing rich and substantial sets of quantitative data. Questionnaires can generally be used in two ways. Firstly, they can be used as a preliminary data collection tool in investigations with a relatively low number of participants (Musselwhite and Haddad, 2010; Dalton *et al.,* 2013). For example, Dalton *et al*. (2013) used a preliminary questionnaire to extract information about 16 participants' navigation preferences and use of in-car navigation systems, before the intended investigation was undertaken. Secondly, large-scale questionnaire surveys can be undertaken to address similar information as gathered in the preliminary stage but with a greater range of respondents. This allows advanced statistical techniques to be undertaken as the sample sizes are larger. The advantage of a questionnaire is that the participants' responses can produce quantifiable information through rating or rankings.

Questionnaire surveys have been used to address a number of areas associated with older drivers and navigation. This has ranged from understanding the process of driving cessation (Parker *et al.,* 2000; Siren *et al.,* 2004; Edwards *et al.,* 2008; Edwards *et al.,* 2010), to research more focused on navigation (Burns, 1998; May *et al.,* 2003; Kim and Son, 2011; Lo *et al.,* 2011; Roger *et al.,* 2011; Zhang *et al.,* 2012). However, questionnaires are rigid in nature and can only elicit information that is asked. Thus, when investigating route guidance requirements they predominantly use closed questions to identify requirements. This would require the list of potential answers to be pre-populated under assumptions devised by the researcher. For example, Bryden *et al*. (2013) assumed there were six possible way-finding strategies used by older drivers. This did not include travelling with a passenger, which this study's literature review found to be a significant method of way-finding for older drivers. The literature review highlighted that the most successful use of the questionnaire surveys has been to identify mobility trends in an ageing population rather than an attempt to request what information people require for, or use within, navigation.

Developing questionnaires can be considered an art form in itself (Cairns and Cox, 2008). The type of question and potential scale of responses needs careful consideration. The two fundamentals of the scale are the response categories and the labelling of these. Commonly there are two scales: Likert and Semantic. Likert scales have labels at each point whereas Semantic scales are just at each end (Bruner *et al.,* 2005). The number of points on the scale has received significant attention from a range of academic disciplines. Research to-date seems to suggest that the size of the scale directly impacts on reliability (Tourangeau *et al*., 2000; Weathers *et al.,* 2005; Lozano *et al.,* 2008). A scale with a width of between four and seven points generally is found to be the most beneficial. A larger or smaller scale and the respondents may struggle to adequately distinguish between each point (Bruner *et al.,* 2005). Furthermore, whether to fully label each scale point has resulted in a range of discussions (Krosnick, 1991). Research suggests that fully labelled scales result in more reliable responses (Weng, 2004).

3.2.3 ***Sketch Maps***

Sketch maps are a tool to understand the characteristics of route choice and route guidance requirements. Lynch (1960) first reported the use of sketch maps where a participant was required to draw a map of a specific area on a sheet of paper, based on memory. The method is frequently used in research on cognitive maps (Kitchin, 1994; Daimon *et al.,* 2000). This allows the researcher to consider the cognitive map elements the driver chooses to use for a familiar journey.

The analysis of the elements can provide a clear indication of the types of information used by drivers for route guidance requirements. This method has been used to develop a clear understanding of route choice by drivers (Obata *et al.,* 1993; Daimon *et al.,* 2000; Ishikawa *et al.,* 2008) and the possible variables that affect this, for example geographical location and age (Daimon *et al.,* 2000).

Other researchers have adopted a similar method but removed the element of the drivers' cognitive map. Most notably May *et al*. (2003), who gathered the information drivers require by requesting participants to identify the information they require on a videotaped unfamiliar journey. Thus, they were building up their cognitive map of the route and identifying the information they themselves need for an unfamiliar journey. Additionally, the results were categorised against Lynch's elements of a cognitive map.

This method can produce results that may be difficult to achieve through other methods; the process requires the participant to detail their actual behaviour. For example, if a participant is asked to outline the information they use to navigate themselves in a questionnaire, they might suggest what they think they should use, i.e. road names whereas this method forces the participant to identify the information they actually use.

3.2.4 *Driver Diaries*

Surveys and questionnaires have the ability to identify common trends in large samples. Yet the responses provide no additional information on the volunteers themselves, or the context into which the answers have been provided. Driver diaries can be designed to collect day-to-day or even hour-to-hour information over a specified period of time, and in so doing can provide a detailed level of information to the investigation. Diary studies have been used to investigate a wide range of topics (Silvis and Niemeier, 2009; Krishnasamy *et al.,* 2011). For example, Hutcherson (1989) developed a 47-item driving diary so that older drivers could self-monitor their behaviour. This allowed the research to capture information on times of travel, places driven and difficulties faced over four one-week periods. Other studies have investigated the behavioural adaption when drivers use IVNS while driving thereby addressing the safety aspects of interacting with IVS whilst driving (Blanchard *et al.,* 2010).

However, travel diaries can be seen to be burdensome which can lead to significant participant dropout (Wolf *et al.,* 2001). Generally participants become less compliant the longer the study goes on. Consequently, driver diary studies needs to be carefully planned to reduce the risk of incomplete results. The literature suggests that a two-week period is the maximum participants are willing to complete diaries (Marshall *et al.*, 2007; Hanson and Hildebrand, 2011).

3.2.5 *Interviews*

Interviews have been undertaken to investigate driver cessation (Vrkljan and Polgar, 2007; Burnett and Lucas, 2010; Shaw *et al.,* 2010), and what information people require for route guidance (May *et al.,* 2005; Gardezi *et al.,* 2006; Dalton *et al.,* 2013). As with all the methods highlighted, interviewing takes a level of skill to undertake successfully. Interviewing requires a high level of interpersonal skill as it is important to listen and respond accordingly. Interviews have the ability to be less rigid than questionnaires as they allow responses to be probed and investigated further.

Within route guidance research, interviews provide the ability to understand the attitude participants have towards different forms of navigation information as well as to understand their behaviour after an investigation has been undertaken. The questions need to be formulated beforehand but must be adaptable to the interview process. This is a semi-structured approach, which allows the participant to take the interview to themes they feel are relevant. This means the researcher is not directing the interview according to their assumptions of the topic under investigation (Creswell and Clark, 2007).

The process of interviews is similar in many respects to focus groups as generally they can never match the sample size of a questionnaire survey. Yet they allow for a more thorough examination of experiences, feelings or opinions that a closed questionnaire approach is not able to achieve.

3.3 Aim 2 – Testing Route Guidance Information

3.3.1 *Usability*

When considering IVNS for a user, usability of that system has been highlighted as extremely important (Harvey *et al.*, 2011c; Harvey *et al.*, 2011b; Harvey *et al.*, 2011a; Barnard *et al.*, 2013). There have been a number of different definitions of usability in the literature. Within route guidance research, Burnett (2000) suggests that usability is the quality interaction between the user and the system. Usability evaluations of IVNS are important to assess the extent to which the system allows for quality interaction. A number of authors have proposed that usability is one of the most important aspects of IVNS design (Baldwin, 2002; Vrkljan and Polgar, 2007). There are two keys reason for this belief – as outlined by Burnett (2000):

1. IVNS are arguably the most sophisticated systems with which drivers have to interact whilst driving; and
2. The system largely requires attention while the vehicle is in motion but still allowing the driver to be able to drive safely.

To review the usability of IVNS five functions are generally used: effectiveness, efficiency, satisfaction, ease of learning and novelty effect. These will be discussed below.

Effectiveness is when the driver is able to reach his/her required destination with no navigational errors and in a safe manner (Burnett, 2000). Additionally, for the majority of journeys the driver will aim to reach the required destination within a specific time frame.

Researchers, therefore, measure the effectiveness of IVNS by recording navigational errors (Schraggen, 1990; Goodman *et al.,* 2004; May and Ross, 2006). For instance, May and Ross (2006) in their on-the-road trials recorded actual and near navigational errors through observation. An actual navigation error was recorded when a wrong turn was made at a navigational decision point. A near navigation error were those in which a participant showed a clear indication that they were going to take an incorrect turn through the use of indicators or turning of the wheel only to correct themselves (May and Ross, 2006). Additionally, the user can report how successful they have been in reaching the required destination through questionnaires and interviews (May et al., 2005).

Efficiency is examined by assessing how demanding the IVS is on the driver (Burnett, 2000). The literature focuses on four key elements of efficiency; namely workload, attention, driver errors and ease of use.

When a driver relies on an IVNS it places certain demands or **workload**. The concern with the majority of IVS is that this will cause ‘overload’ (Wickens, 2008) whereby the driver will become overwhelmed with the IVS and this will affect his/her safe operation of the vehicle. Therefore, measuring mental workload can provide an indication of the cognitive demands placed on the driver (Cantin *et al.,* 2009). The literature highlighted numerous approaches to measuring workload such as subjective opinions, physiological measures and task performance. However, one particular subjective workload measure has been frequently used in IVNS research across a number of academic disciplines: The National Aeronautic and Space Administration Task Load Index (NASA-TLX). It is considered one of the most representative methods used to assess driver workload (Wickens and Hollands 2002). The scale was developed by Hart and Staveland (1988) and allows for a single measure of workload. However, this method requires a two-pass process with paired comparisons. It was often thought to be time consuming which led to Byers *et al*. (1989) proposing a Raw Task Load Index (RTLX) which does not require task paired comparison weights. The RTLX is a simple average of the six Tax Load Index scales. The research found that TLX and RTLX had comparable means, standard deviations and correlated above r=0.95. The method was considered to be far less time consuming and cumbersome than the TLX (Byers *et al.,* 1989; Fairclough, 1991). Park and Cha (1998) actually found that the RTLX scale was more sensitive to mental demand and difficulty in driving than the TLX. Therefore, the use of the NASA-RTLX is regarded as the most effective paper-based measure of workload.

Whilst drivers have always had the option to operate devices in the car, for example radios or air conditioning (Chiang *et al.,* 2004), more modern IVS require greater **attention**, cognitive load and operation form the driver. Whilst these systems can be of benefit to the driver they have been found to cause a distraction (Birrell and Young, 2011).

The literature review suggested that an in-vehicle display can result in drivers' attention being drawn away from the driving task (Davidse, 2006; Kim *et al.,* 2011). Rockwell (1988) proposed that drivers should not take their eyes off the road for longer than two-seconds. This clearly limits the amount of information a driver can obtain from a visual display. This can be quantified in terms of the number and duration of glances the driver needs to obtain the information from the screen. Moreover, including the glance allocation of the driver results in a clear review of the visual scene (Green, 1993). Recording the glance duration and frequency allows the researcher to indicate the percentage of journey time spent glancing towards the visual display.

Recording visual glance behaviour has become more achievable with the development of eye-tracking technology. Eye-trackers have reduced in cost and are now offering great potential as a research tool (Cairns and Cox, 2008). Modern eye-tracking can be used in a wide variety of academic fields and provide data on glance frequency, duration and allocation (Jacob and Karn, 2003). Using eye-tracking has been found to be particularly beneficial when designing and testing IVS, especially when considering the effect on older adults (Kim *et al.,* 2011).

The most common method to obtain **driving errors** is to assess the lateral position of the car within the lane. Measurements have recorded the actual deviation of a vehicle's position from the centre of the lane, to the steering wheel movements (Davidse, 2006; Shechtman *et al.,* 2009). Each method is used to provide an indication of the ability to stay in their lane whilst using an IVS.

The average speed has also been used to assess driving errors under the premise that when drivers are faced with an IVNS, driving becomes more erratic. Often drivers may slow down to provide themselves with a greater safety margin (Green and George, 1995). Caution should be noted, especially for on- the-road trials, that traffic conditions will be different and there is always a speed limit to which the driver must adhere.

Another measure used to address driving errors, albeit rarely used due to the financial cost, is using an expert to assess driving (Zhang *et al.,* 2012). The best example is by May and Ross (2006) in their road-based trial which assessed their participants with a qualified driving instructor. The errors were recorded as minor, serious or dangerous using the checklist that was developed in conjunction with the driving instructor. However, there are issues regarding the reliability of the judgment of the expert. Moreover, the participant is on a research trial and having their driving performance assessed may not result in a fair reflection of the participants' driving. Additionally, assessing a participant's driving performance in a driving simulator has been found to not be a fair reflection of actual driving performance (Kaptein *et al.,* 1996; Lee, 2003; de Winter *et al.,* 2009; de Winter *et al.,* 2012).

Ease of use is an important element when assessing usability. The ease to which the user can interact with the device has a significant bearing on the eventual acceptance and sustained usage of the system (Venkatesh, 2000; Barnard *et al.*, 2013). If experiences in use are negative this will lead to the rejection of the system (Barnard *et al.*, 2013). Ease of use of investigations in the literature have focused on design characteristics or training. These have been achieved by in-depth interviews and questionnaires (Fred D, 1993; Chown *et al.*, 1995; Leshed *et al.*, 2008).

The satisfaction of the IVNS affects the users' opinions of the device and naturally influences the confidence of navigation information (Burnett, 2000). The most common measures of satisfaction are questionnaires and interviews. These methods allow researchers to develop an understanding of drivers' experiences with IVNS. Currently there does not seem to be a set questionnaire used for assessing satisfaction of IVNS across all the studies undertaken.

In addition to the measurements highlighted above, the literature review suggested the importance of 'ease of learning'. Nielson (1993) was the first to use the phrase when studying IVNS. He proposes that there are two aspects of ease of learning: learnability (the length of time it takes to reach an 'expert' level of performance) and memorability (how quickly a user can return to an 'expert' level after time away from the system).

A handful of studies have included information on the level of training they have provided participants on IVNS or prototype products (Burnett, 1997; May and Ross, 2006). Generally, however, the learnability and training needs of IVNS have largely been overlooked. In fact, a number of trials seem to overlook the training completely or provide only a few minutes of training (Obata *et al.*, 1993; Dingus *et al.*, 1997; Dalton *et al.*, 2013). Noel *et al*., (2005) conducted a study which evaluated first-time use of IVNS. He proposed the high importance of learnability and memorability when assessing usability, additionally, highlighting how these areas are frequently overlooked in current usability studies. The author further suggests that when a device is already on the market then research based usability studies should be driven by user testing. Pre-trip planning and way-finding tasks drove their user testing. The former focuses on the inputting of information and the latter is following the route guidance information. The data is then collected through observations and semi-structured interviews. However, further investigation is required on how easy it is to learn new systems.

A number of studies have trialled IVNS on users with no prior experience (Kostyniuk *et al.,* 1997; Vrkljan and Polgar, 2007) or have trialled new route guidance information on participants (May and Ross, 2006). This can lead to the results being subject to the **'novelty effect'**. This is where the results may be influenced as the participants have an interest in the technology rather than the technology actually being of benefit to them. The novelty effect should be taken into account in IVNS investigations as it is not evident when it will appear, only that it will become reduced after a familiarisation period (Saad, 2004).

Therefore it is suggested that users should be allowed to experience IVNS over a period of time before to carry a more in-depth evaluation.

3.3.2 *Research Environment*

When investigating user-based IVNS themes researchers have highlighted the importance the research environment has on the results. Figure 3.1 outlines the main environments in which route guidance data can be collected (Parkes, 1991). The terms macro and micro simply refer to the number of the cars used. Micro level is a test of single car whereas macro refers to fleets.

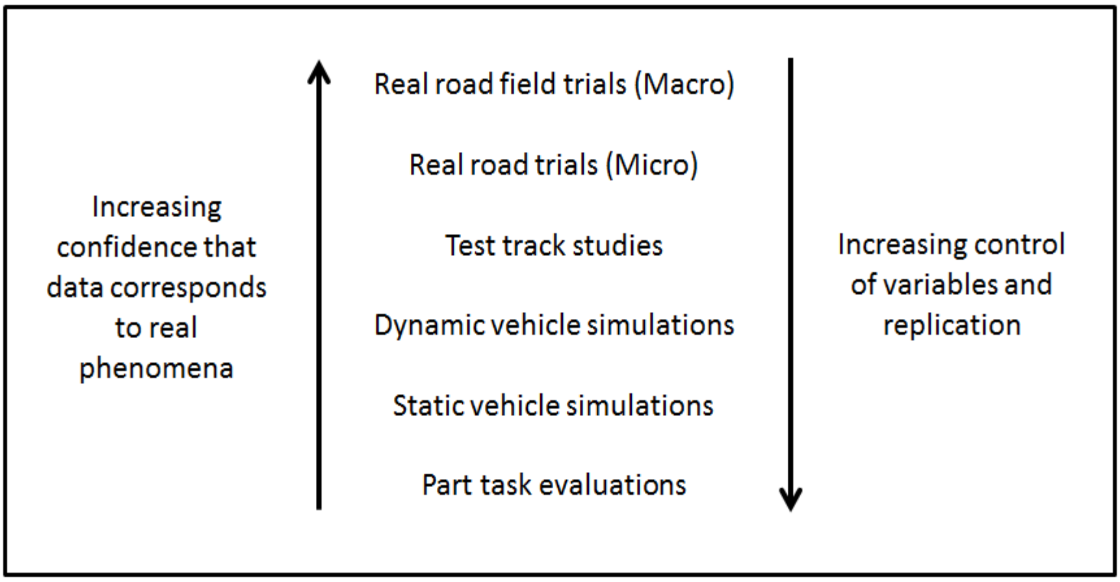


Figure 3.1 Options for research environments for route guidance studies (Parkes 1991)

Figure 3.1 shows vehicle simulators provide the middle ground of controlling the experiment and confidence in the data. Moreover, they provide a more cost effective option than test track studies. When testing the design or a new form of delivering route guidance information to drivers, Santos *et al*., (2005) suggests that a simulator is the most effective research environment for testing in-vehicle systems in the design stage. The advantages can be broadly grouped into four themes (Wassink *et al.*, 2006):

1) Controllability: All elements of the simulator are created, controlled and reproduced to address specific research aims (Wassink *et al.,* 2006). Therefore, all participants drive under exactly the same conditions. The use of on-the-road trials would mean the environment is largely random, changing from day-to-day and hour-by-hour (Santos *et al.,* 2005).

2) Data collection: A driving simulator can measure a wide range of performances accurately and efficiently. Numerous studies have found that recording even basic data during a road trial is extremely difficult when compared to a simulator (Green *et al.,* 1993b; Godley *et al.,* 2002; Shechtman *et al.,* 2009; Underwood *et al.,* 2011). For example, Santos *et al*. (2005) conducted a comparison between a laboratory, simulator and real-world studies when using IVS. The authors concluded that on-the-road trials would have significant problems in collecting driving data suggesting the use of a simulator can provide detailed analysis of the influence of IVS on driving.
3) Safety: The use of a driving simulator provides a safe environment for participants and researchers to conduct a study (Kaptein *et al.,* 1996). In addition, driving simulators allow investigation of potentially ethically challenging issues in a safe environment, for example hazard anticipation (Underwood *et al.,* 2011).
4) Design flexibility: The use of a driving simulator allows for the designs of IVS to be more flexible then in a real car. For route guidance information it allows for instructions to be delivered in other modalities besides audio, for instance an experimental visual display (de Winter *et al.,* 2012). In addition, the driving simulator allows for repeatable investigations in conditions designed specifically for the study.

However, as with the majority of research methods there are disadvantages to this approach. These can be grouped into two themes:

1) Simulator discomfort: Using a driving simulator can result in participants suffering from simulator sickness. The symptoms are similar to motion sickness but are not as severe (Domeyer *et al.,* 2013). Further research has found that older adults are especially prone to this (Brooks *et al.,* 2010; Domeyer *et al.,* 2013). Simulator sickness symptoms can undermine the research in question and result in a high number of participants failing to complete the study (de Winter *et al.,* 2012). However, there are measures that can reduce the feeling of simulator sickness. For instance, restricting the number of sharp curves in the road layout and limiting driving sessions to less than 10 minutes. Used in conjunction with sufficient rest breaks this

can reduce the effects or eliminate simulator discomfort (de Winter *et al.,* 2012).

2) Low-fidelity and validity: If the driving simulator in use is considered to have low-fidelity by its users then this may result in unrealistic driving behaviour and thus produce invalid research outcomes (de Winter *et al.,* 2012). Driving actions in low-fidelity simulators do not result in the same consequences that would occur in real driving (Kaptein *et al.,* 1996). Moreover, only a number of studies have concluded that driving-simulator measures are predictive for on-the-road driving performance (Lee, 2003; de Winter *et al.,* 2009).

3.3.3 *Test Routes*

When testing route guidance information, the route choice can be of fundamental importance (Gstalter and Fastenmeier, 1991). Yet the relevant literature is somewhat sparse on the subject. The literature search has only revealed one study, by Gstalter and Fastenmeier (1991), in which they examined how test routes should be chosen. They argue that routes need to be difficult to drive and navigate. This results in participants driving under conditions close to their limits. This will lead to an increase in mental demand that will result in true performance related measures. To achieve this, a route must be chosen that includes urban driving with a high degree of complexity for instance, a route that includes signalled junctions, turnings across traffic and lane changes. The need for the routes to be plausible and appropriate for IVNS to be used is also important (Gstalter and Fastenmeier, 1991). Within the context of this research, Gstalter and Fastenmeier (1991) suggest that when researching older drivers a route needs only to be of medium complexity.

3.3.4 *Base Line Conditions*

When testing new route guidance information the literature highlighted the role of collecting a base line. This base line data allows for a controlled comparison to the experimental conditions. It is apparent in the literature that the most common method of providing a baseline within route guidance research is to provide participants with a map. This approach, however, has varied across a wide range of studies. For example, Schraggen (1990) provided the research participants with either a conventional paper map or a customised map that they had to memorise. The number of navigational errors and safety of the driver are then measured against that of the experimental research.

3.4 Methodology of this Thesis

This section explains which of the methods discussed in Sections 3.2 and 3.3 were selected to address the aims of this research and why. In each of the following investigation chapters four, five and six, the experimental design will be presented.

During the literature and methodology review, it became clear that several methods would need to be used to address the study's aims. Firstly, the literature review found that only a limited number of studies collected data through only one method. In fact, the literature review leads to the conclusion that the use of qualitative and quantitative methods in combination are much more effective in increasing the understanding of navigation behaviour, route guidance requirements and the testing of those requirements. The literature review found that adopting several different research methods could provide a wider perspective and clarity of results than only using a single research method (May *et al.*, 2005; Baldock *et al.*, 2006; Creswell and Clark, 2007; Martin *et al.*, 2009; Dalton *et al.*, 2013). In addition, the methodology review detailed above has highlighted several methods that can be utilised to produce findings that combine to provide new insight and knowledge in this field. Consequently, as the aims are attempting to address two different, but related, themes there can be a range of methods undertaken, both qualitative and quantitative. Moreover, the second aim is solely reliant on the findings provided from the methods adopted for the first aim. This provides the opportunity to address both aims with a mixed method approach. Three methodological approaches have been selected to meet the two aims of this research: focus groups, a usability investigation and a driving simulator investigation. Figure 3.2 provides an overview of the methodology structure for this thesis along with the specific objectives of the three investigations used to address the aims outlined in Section 1.10. More specificity, the first two investigations provide insights into the first aim and the final driving simulator investigation will seek to bring understanding to the second aim.

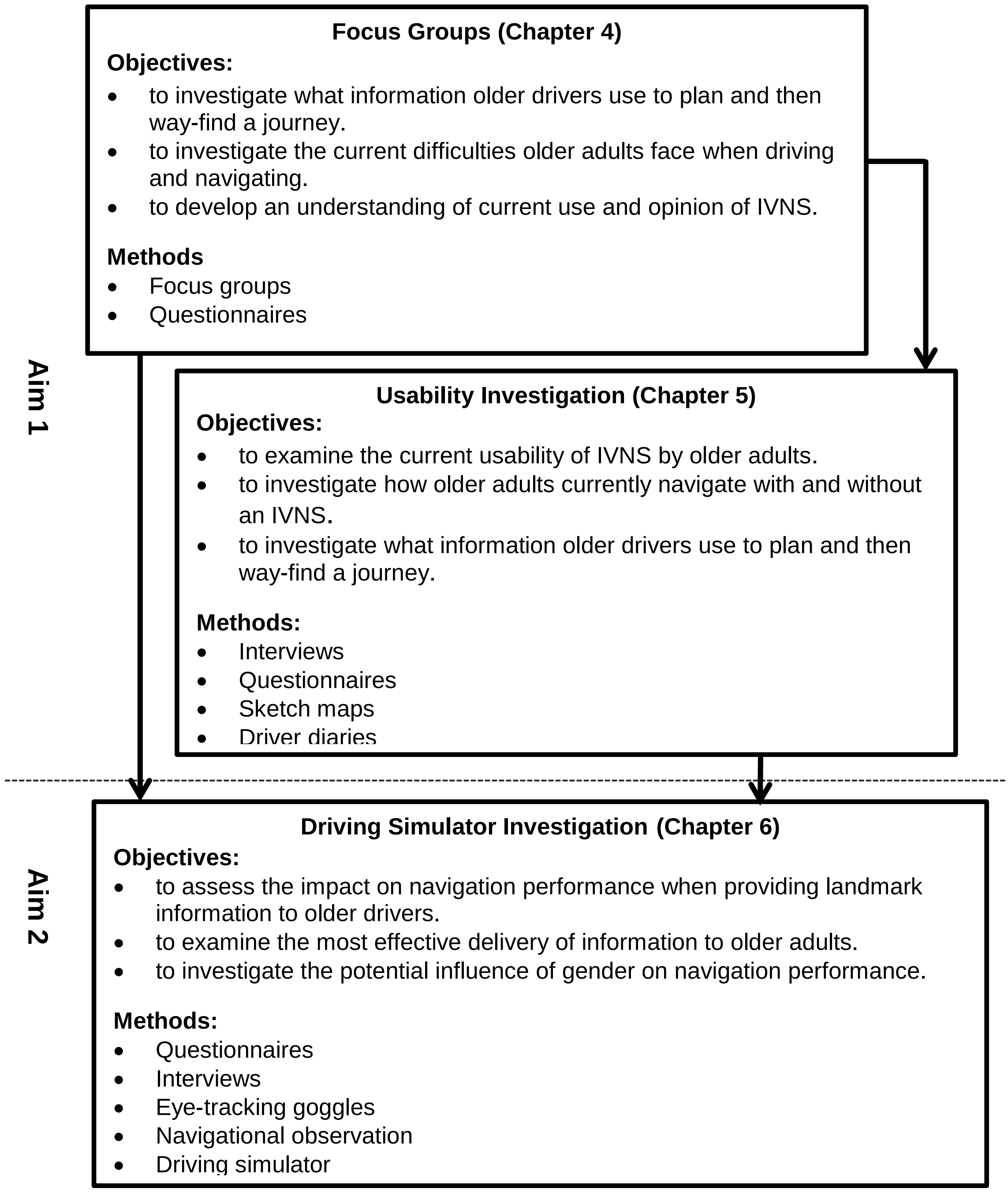


Figure 3.2 Overview of the methodology

At this stage it is worth highlighting that each of the three investigations will undergo the same procedure. Firstly, the method is defined and the investigation designed. Secondly, the investigation will go through Newcastle University's ethical committee (see appendix A for an example of the consent forms the participants signed for each investigation). Once this was granted a risk assessment is undertaken, taking into account Newcastle University advice on lone working policy. Finally, the participants are recruited through the Social Inclusion through the Digital Economy (SiDE) user group and the data collection began.

The SiDE project developed a participant user pool managed by professional research recruiters and managers, to which this study had access. This meant that this research was able to draw from a representative sample of the Tyne and Wear driving population. Also, a third party externally managed participant recruitment for this study identifying participants to specific requirements and making the initial approach. Access to this professionalism improved the rigour of this research by reducing sample bias and of course saved valuable time. In addition, access to the user group allowed greater flexibility in the design of the methodology; allowing three distinct but related investigations to address the over-arching aims. As part of the arrangement, the participants were given shopping vouchers for any participation in the investigations.

For all of the investigations undertaken there was a focus on navigation. Section 2.1 highlighted the elements of pre-trip planning and way-finding in the navigation process. The research focused on these elements and considered their role in familiar and unfamiliar journeys. Burnett proposed a key definition of what can be considered an unfamiliar journey (1998, 210): ‘these are journeys in which you need some information before setting off on the journey and/or during the journey’. This definition provided clarity on what can be considered an unfamiliar journey and was used for this study. As the study required older adults to self-report their driving behaviour throughout the three investigations, the definition was consistently used.

A clear definition was important as older drivers can have significant experience of driving throughout the UK. The Burnett definition provided clarity that the unfamiliar nature of journey was not just at the start of the journey but included the route guidance information whilst driving – i.e. way-finding. As large-scale questionnaires have found, older drivers can over-estimate their driving and navigation behaviour (Burns, 1999; Bryden *et al.*, 2013). As a consequence, there may have been a variation between what each participant considered an unfamiliar journey. However, the percentage of participants self-reporting annual unfamiliar journeys was found to be statistically significantly similar throughout the three investigations (81 participants in total), ranging from 22% to 27%, with an average of 25%. Given that the participants in the three investigations were sampled against the same criteria from the population it is reasonable to suggest that there is a degree of consistency in assignment of unfamiliar/familiar by the participant. However, if this had not been the case then the comparative analysis of journey type and potential use of an IVNS for older drivers would have been influenced by the inconsistency in the criteria used by each participant to self-report a familiar/unfamiliar journey. This is a limitation of this study against which the results should be interpreted. The following section will outline the methods used in the investigations undertaken in this study.

3.4.1 *Focus Group Investigation*

When considering the first aim, there is currently an understanding of the range of information that can be provided to the driver (see Section 2.3). However, a number of the key references are several years out of date. In addition, route guidance information is very rarely considered for just older adults, taking into account their driving experience and age-related declines. Moreover, the literature review identified that further understanding of navigation behaviour was required between those older adults who use IVNS and those who do not. Examining the potential gender differences that occur within navigation should be considered also.

The literature review highlighted that the majority of the research in this area is quantitative in nature. It was therefore decided that a qualitative approach would be most suitable to compare to the pre-existing findings. Therefore, the first investigation of this study will be a focus group investigation. Focus groups have been highlighted as a method to use at the start of a mixed method study (Creswell and Clark, 2007), and the review of focus groups in Section 3.2.1 found significant benefits to their use with older drivers.

The design of the focus group (see Section 4.1.1) investigation considered the research areas identified in the literature review and planned six focus groups. Three groups were undertaken with older adults who currently use IVNS and three groups who do not. Within each of the three groups one group would be for all males, one for all females and one mixed. This design would allow for the exploration of potential navigational differences between the genders. As groups would be exclusively for each gender, the participants are provided with a safe and controlled environment to express themselves freely (Krueger and Casey, 2009). Additionally, the mixed gender group will provide a more representative discussion based on navigation behaviour for all older drivers. Each of the six focus groups comprised five members and undertaking six focus groups would compromise for the limitations on the range of total ideas that can result when using a small number of people in each group. The design of the focus groups was as follows:

IVNS Users (5 participants in each group)

- 1 all-male
- 1 all-female
- 1 mixed gender group

Not IVNS Users (5 participants in each group)

- 1 all-male
- 1 all-female
- 1 mixed gender group

3.4.1.1 *Participant Recruitment*

The participants in this investigation were recruited under the criteria that they were a current driver and drove at least four times a week. During the recruitment stage the participants were required to specify their gender and whether they owned an IVNS. This was required as the focus groups would be structured as indicated above. Thus, of those 30 participants required half of them owned an IVNS and the other 15 had never used one.

Also a preliminary questionnaire was administered (see appendix B). This aimed at providing details on the participants' demographic information, and their driving behaviour. The design followed the advice outlined in Section 3.2.2 but was influenced by the driving ability and confidence scales (Parker et al., 2001), which is concerned with self-rated driving ability and confidence in various traffic situations.

3.4.2 *Usability Investigation*

The second investigation assesses the current usability of IVNS for older drivers, and provides additional findings for route guidance requirements from older drivers. As highlighted earlier, research in the area of route guidance requirements benefited from using a number of methods due to the complex nature of the topic under investigation. This stage of the research, therefore, adopted a similar approach to address the aims of the investigation and the study overall.

To assess the usability of current IVNS, data is required on the key areas highlighted in Section 3.3.1. A key finding from the literature and methodology review was that research projects assessing usability have incorporated the use of user-lead observations (Noel *et al.*, 2005; Harvey *et al.*, 2011c; Harvey *et al.*, 2011b; Barnard *et al.*, 2013), especially systems that are in market. User-lead interaction involves participants interacting with a chosen system. They are provided with no instructions or guidance and the researcher observes the interaction. To assess the usability of both stages of navigation then observations are required for the pre-trip planning and way-finding stages of navigation. The benefit of direct observation is that the researcher gets a first-hand account of how the user behaves when using the technology in question which can provide real insight into any potential barriers to their effective use (Hannukainen and Hölttä-Otto, 2006).

To assess the pre-trip planning stage of IVNS, a desk-based observation investigation was undertaken to assess the key usability features reviewed in Section 3.3.1. The participants completed two input-oriented tasks. These were based on research conducted by Noel *et al*. (2005), who outlined the requirements of evaluating first time and infrequent users of IVNS (see Section 3.3.1.4 for further details). The tasks were:

- Address entry: participants were given an address and requested to plan the journey with the IVNS; and
- Service location: participants were requested to plan a journey to nearest petrol station.

Participants were not given any prior instruction with the device or provided with the manual. The participants were given reasonable time to complete the tasks and no assistance was offered. Once they had completed the tasks or asked to stop, questions were asked on their experience. After this they were provided with training on the IVNS and given time to ask questions.

It may have been possible to review the way-finding ability with a similar observation task. However, interacting with an IVNS over a period of time was important as it reduced the potential of the novelty effect (see Section 3.3.1.5) that would have occurred if users had only interacted once with the device. Therefore, this investigation provided the participants an IVNS and investigated their experiences. To assist the collection of data, the participants were required to record their experience in a driver diary. Driver diaries were reviewed and the results are discussed in Section 3.2.4. They provide rich qualitative data over a period of time. Previous literature suggested that two weeks is the optimum length of time participants are willing to complete diaries (Marshall *et al.,* 2007). After this point there is significant participant drop out. Therefore, participants were limited to using the IVNS for two weeks. The diary (see appendix C) had three main sections to complete. The first section was used to gather factual data on the type of journey undertaken and their pre-trip planning behaviour. The data gathered in this section was nominal and under the categorical variable. This approach allowed the participants to answer this section with relative ease. As the participants had to complete a number of these diaries, it was important not to make them too complex or time-consuming (Hutcherson, 1989; Huebner *et al.,* 2006). The second section of the diary contained responses to seven attitudinal statements on a 7-point Likert scale. These were based on the usability issues highlighted in the literature focusing on effectiveness, efficiency and satisfaction of the IVNS and delivery of the route guidance information. The first and fourth questions examined the effectiveness of the IVNS. The second question focused on the efficiency of the IVNS on that particular journey. The fifth and sixth questions examined the audio and visual information delivered. The final question examined the participant's satisfaction with the IVNS. The data collected was ordinal and under the categorical variable. The final section of the diary was an open section where each participant was invited to provide their experience and thoughts on the system in their own words. To assist them in this section participants were provided with an information pack (appendix D).

Upon completion of the two-week survey period, the IVNS was returned and an in-depth post-investigation interview was conducted. The post-investigation interview focused on their experiences with the use of IVNS, and the questions were allowing the participants to detail their opinions (Heath and Cowley, 2004).Thus the interviews were driven by the participants rather than from any pre-conceived ideas from the researcher (see appendix E for an overview). The use of driver diaries allowed for real world examples to be discussed by the researcher and participant during the post-investigation interview.

The second aim of this investigation was to route guidance requirements for older drivers compared to those available in current IVNS. An understanding of older drivers' route guidance requirements was highlighted during the focus groups (see Chapter 4). This investigation allowed additional methods to be undertaken with the aim to provide further evidence to the previous findings in the literature and results from this study overall. To understand route guidance requirements then data needed to be collected before giving the IVNS to the participant. Section 3.2 highlighted the range of different methods that can be undertaken. This phase of the research used in-depth interviews, questionnaire and a sketch map exercise. An in-depth pre-investigation interview allowed the participants to discuss areas of driving and navigation, through open-ended questions (see appendix F). The questionnaire aimed to gather data on elements of their demographic information and navigation behaviour (see appendix G). To provide additional information on route guidance requirements sketch maps were adopted. These provided an insight into older drivers' cognitive map. Each participant was instructed to draw a route from a main street in Newcastle City Centre to their home which could be used to guide others who are completely unfamiliar with the area. Subsequently, the participants were asked to provide step-by-step written instructions to accompany the route once the map was completed. The information provided by the map and the written instructions were classified against Lynch's (1960) elements of a cognitive map.

3.4.2.1 ***Participant Recruitment***

Twenty-two participants, eleven male and eleven female, were recruited through the SiDE user pool. An even gender spilt was desired to explore any differences in the way males and females navigate (see Section 2.3.5). Participants were recruited using the following criteria: they were over the age of 60; drove at least four times a week; had never used an IVNS before and had not taken part in the focus group investigation. The length of time and resources available to this investigation determined the sample size. This investigation had two Garmin IVNS at its disposal (see Section 5.2.5) and each participant required two interviews and a two-week use of the IVNS. Thus, 22 participants would take 23 weeks to complete the data collection (an additional week for the post- investigation interview to occur). As this was the second investigation of three, no more time to recruit a larger sample size could be justified, or resources available to acquire additional IVNS.

3.4.3 *Driving Simulator Investigation*

The results of the focus groups, usability study and literature review provided a clearer understanding of the information required by older drivers and how that information should be presented. Therefore, the final investigation addressed the second aim. Section 3.3.2 highlighted the benefits of using a driving simulator in the design process of IVS. Newcastle University's fixed based simulator was used to test specific route guidance requirements highlighted by the first aim of this research. Participants operated the simulator from a cabin with all the usual controls found in a car, i.e. steering wheel, pedals and gears. The driving scene was displayed onto five plasma screens. The screens provided a fully simulated dashboard behind the wheel with rear view and side mirrors. Figure 3.3 shows the driving simulator used in this investigation.

Figure 3.3 Fixed-based ST Software Jentig50 driving simulator

Section 3.3.1 highlighted the importance of collecting data on visual behaviour, navigation performance, workloads and attitudes. Visual glance behaviour was be measured through the Tobii™ eye-tracking glasses. The data collected from the eye-tracking glasses are ratio classed under the continuous variables. The glasses collected data on:

- Glance frequency – the number of glances made towards the route guidance display, map or roadside landmark;

- Glance duration – the duration of single glances made towards the route guidance display, map or roadside landmark; and
- Glance allocation – the percentage of time in motion spent glancing towards the route guidance display, map or roadside landmark.

The participant's navigational errors were recorded during the investigation as advised by May and Ross (2006). A navigational error was recorded if the participant made an error through steering wheel movement or use of indicator, and if they actually made a navigational error. The data collected from the observations were ratios and were continuous variables.

Driver workload was assessed after each scenario by the NASA-RTLX questionnaire (see Section 3.3.1.3). The data was ratio and under the continuous variables.

Three types of questionnaires and an interview were used to assess driver attitudes. One questionnaire was administered pre-investigation, one after each driving scenario and one post-investigation. In addition, a short face-to-face semi-structured interview was conducted post-investigation. All three questionnaires were based on 7-point Likert scales, and therefore provided ordinal and under the categorical variable data. The pre-investigation questionnaire extracted information on the participant's navigation behaviour and demographic data. The questionnaire after each scenario addressed the participant's attitudes towards the method of information delivery. Finally, the post-investigation questionnaire and interview aimed to identify attitudes towards the specific route guidance requirement tested and future navigation behaviour (all questionnaires and interview plan can be found in appendix G to L).

In the debrief interview the participants were engaged in semi-structured questioning as given in Appendix K. The nature of semi-structured questioning allowed the researcher to react to the participant's responses with further questions such as 'how did the audio landmarks allow you navigate more successfully?' or 'do you usually use landmarks when planning a journey or whilst on route?' The questioning was designed to provide a richer understanding of each participant's experience in the context of the investigation. This was important as the interpretation of the responses needed to be grounded in each individual's own experience. This background information also meant that the results obtained from the analysis of the questionnaire were complemented by the specific experiences.

3.4.3.1 *Participant Recruitment*

After reviewing the use of driving simulators within research (see Section 3.3.2) it is clear that not every participant willing to take part would successfully complete the investigation. Therefore, the recruitment ran concurrently with the investigation, until 30 participants had completed the investigation. Thirty participants were required for this investigation for three reasons. Firstly, the driving simulator was only available for one month for this investigation. This placed a limitation on the number of participants that could take part in the investigation. This limitation was in part due to the number of participants who may suffer from simulator discomfort was unknown. Attempts were made to control for this during the screening of participants however anecdotal evidence suggested that volunteers might suffer simulator discomfort without any previous issue with motion sickness. This placed a practical limitation on the number of people who would complete the investigation in the given period. Secondly, a review of previous studies that used a driving simulator found that the number of participants ranged from 20 to 41(Mourant *et al.,* 2001; Gelau *et al.,* 2011; Zhang *et al.,* 2012; Dalton *et al.,* 2013). Therefore, 30 participants would fit within the range of previous studies. Finally, Field (2009) suggested that investigations with 30 participants or more have been found to yield results with normal distributions; thereby allowing for parametric tests to be undertaken rather than their nonparametric equivalents.

The participants were recruited if they satisfied all of the following criteria: aged 60 years and over; have a full driving licence; regular driver for at least the recent three years; have normal or correct vision and hearing; and that they do not suffer from motion sickness (a key indicator of simulator sickness Kennedy *et al.,* 1993). In addition to this, their gender, experience with IVNS and self-reported navigational ability were recorded.

3.5 Statistical Tests to be Undertaken in this Study

Table 3.1 provides an overview of the statistical tests undertaken in this study. The aim of the statistical tests was to allow the comparison of two or more groups, both independent and paired. For all numerical data collected during this study it was assessed for normality and outliers. Testing for normal distribution in the data determined which statistical tests were undertaken. If the data was found to be normally distributed then parametric tests were conducted. Similarly, if the data was found to be not normally distributed then non-parametric tests were undertaken. Normality tests were not conducted on any 7-point Likert scale questionnaire data, as these responses were ordinal and therefore restricted to reporting medians and subjected to non-parametric tests (McCrum-Gardner, 2008).

Normality was assessed through the Shapiro-Wilk test. Using this test removes any potential objectivity that may result through using graphical methods (Normal Q-Q plots and histograms). In addition, the sample sizes in this study were no greater than 30. Shapiro-Wilk test was found to be advantageous when samples sizes are low compared to graphical representation of normality (McCrum-Gardner, 2008; Field, 2009). Outliers were assessed through an inspection of a boxplot and reported if found. For the Repeated Measures, Analysis of Variance sphericity was assessed through Mauchly's Test of Sphericity. If sphericity was violated (the variances of the difference between all combinations of related groups are not equal) a correction was applied and reported in the results (McCrum-Gardner, 2008; Field, 2009). The correction would change the degrees freedom of the *F*-distribution.

Table 3.1 details the aim of each test used in this study; how the test works; the equivalent parametric and nonparametric statistical tests for each aim; and in which chapters they are used. All statistical testing was carried out in SPSS version 19 software, to 95% confidence (McCrum-Gardner, 2008; Field, 2009).

Aim of the test	How the test works	Statistical test		Use within this study
		Parametric	Non-parametric	
To assess normality	Shapiro-Wilk test is a dedicated test for normality. This tests the null hypothesis that the data's distribution is equal to a normal distribution. If the test returns significance of 0.05 or above then the data is deemed normally distributed.	Shapiro-Wilk test	Shapiro-Wilk test	Chapters 5 and 6
Comparison of two independent groups	Comparison between one independent variable that is categorical with two groups (i.e. gender) and one dependent variable that is continuous (or ordinal for the nonparametric test).	Independent -sample T-Test	Man-Whitney U test	Chapters 5 and 6
Comparison of two paired groups	The same comparison as the Independent-samples t-test and Mann-Whitney U test above. However, these participants are either the same individuals tested on two or more occasions or under two or more conditions but on the same dependent variable.	Paired-sample T-Test	Wilcoxon Signed-Rank Test	Chapters 5 and 6
Comparison of more than two paired groups	Comparison between one independent variable that is categorical with three or more related groups and one dependent variable that is continuous (or ordinal for the nonparametric test). These participants are either the same individuals tested on two occasions or under two conditions but on the same dependent variable.	Repeated Measures Analysis of Variance (ANOVA)	Friedman Test	Chapter 6

Table 3.1 Critical overview of statistical methods used in this study (May *et al.,* 2005; May and Ross, 2006; McCrum-Gardner, 2008; Field, 2009)

3.6 Conclusions

This chapter has highlighted the methods used in this study and their relevance in addressing the two aims. This study has chosen to use a mixed method approach that will hold the end-user, older adults, at the core of the research. This was achieved by initially adopting a qualitative approach before undertaking a quantitative investigation. The investigations undertaken in this study were:

- To use focus groups to provide user context to navigation behaviour and preference to findings highlighted in the literature review.
- To undertake a usability study of current IVNS employing a number of different route guidance methods. This will provide further clarity on the required route guidance information in addition to the current usability of IVNS for older drivers which the literature review highlighted as a significant gap in current knowledge.
- To test specific older drivers' route guidance requirements within a simulated driving environment. This aims to provide a greater statistical robustness to the qualitative findings used to address the first aim.
- All of the data collected for further analysis will be tested for normality. The statistical tests presented in this study were dependent on whether the data was normally distributed or not.

Chapter 4. Navigation and Older Drivers

The first phase of the study would be a focus group investigation. The aims of the focus groups were four-fold: first to investigate what information older drivers use to plan and then way-find a journey; second, to investigate the current difficulties older adults face when driving and navigating; thirdly, to develop an understanding of current use and opinion of IVNS; and finally, to identify any potential gender differences in navigation behaviour.

The chapter begins by detailing the experimental design and then provides an overview of the participants followed by the analysis. A more detailed overview of the method was provided in Section 3.4.1. The results are presented in Section 4.2 followed by discussion in Section 4.3 before concluding the chapter in 4.4.

4.1 Experimental Design

The focus groups were undertaken across a week, during the day in a small meeting room on the Newcastle University's campus. On average, they lasted around an hour (length determined by focus group advice in the literature (Kostyniuk *et al.*, 2009; Krueger and Casey, 2009)) and were recorded using a digital dictaphone. Before the session began, the participants were provided with a full overview of the project and the aims of the focus groups. At this point or at any point during the focus group sessions, the participants were free to leave. The preliminary questionnaire was then administered to the participants. See Figure 4.1 for images of the conducted focus groups.

Figure 4.1 Focus group participants

The focus groups were semi-structured and the plan varied according to whether the group were IVNS users or not. Nonetheless, they followed this semi-structured format:

- Common journeys made with the car;
- The information required when planning and navigating journeys, both familiar and unfamiliar;
- The difficulties encountered when driving on an unknown route;
- Reason for use, current usage and opinions of IVNS (IVNS groups only);
- Information and design changes they would make to their IVNS (IVNS groups only); and
- Reason for not using IVNS (none IVNS group only) and current use of technology.

4.1.1 *Participants*

The average age of the participants was 71 years and ranged from 60-86. Table 4.1 provides an overview of the main respondent's characteristics. Generally, the participants felt they were experienced drivers and in turn proficient at navigation. When asked, in the questionnaire, to estimate what percentage of their annual millage was spent on unfamiliar roads, an average of 27% was reported. Additionally, when asked 'when driving on your own in an unfamiliar area, how good are you at finding your way', on a 7-point scale (where 7='very good' and 1= 'very poor'), 17 of the 30 participants responded with a rating of 5 or more.

	Gender		Age			Frequency of driving on an unfamiliar journey (per month)			
	Male	Female	61-70	71-80	80+	0	1 to 3	4 to 6	6+
Number of participants	15	15	16	8	6	1	19	7	3

Table 4.1 Characteristics of the participants (N=30**)**

4.1.2 *Analysis*

It is important that the investigation had a sound theoretical basis before undertaking the research, as the framework chosen can influence the entire procedure of the focus groups. Moreover, the framework chosen should be complementary to the research aims so that the qualitative research matches what the researcher wants to know (Braun and Clarke, 2006). With this in mind, thematic analysis was found to be the most suitable to this investigation. Thematic analysis is one of the lesser-known analytical methods in the social sciences, despite researchers often using this approach without realising it (Braun and Clarke, 2006). Thematic analysis is a process for encoding qualitative data and is particularly useful at the start of a study (Boyatzis, 1998). Thematic analysis aims to identify meaning across a dataset to answer the specific research questions (Braun and Clarke, 2006; Clarke and Braun, 2013).

Within thematic analysis there are two main approaches to identifying themes; inductive and deductive (Braun and Clarke, 2006; Guest *et al.*, 2011; Clarke and Braun, 2013). An inductive approach codes and develops themes based on the content of the data. In contrast, a deductive approach codes and develops themes based on the researchers pre-existing concepts and ideas.

Given the exploratory nature of this first investigation, an inductive approach to analysing the data was adopted. This approach is independent of theory and allows the data gathered to drive the analysis (Frith and Gleeson, 2004). The thematic analysis undertaken was guided by Braun and Clarke (2006; 2013).

What to classify as a 'theme' is one of fundamental tasks of thematic analysis. It is possible to count the number of participants mentioning an issue or by count the frequency of each mention of an issue. These counts can then be used to create and identify the themes. Yet, as Musselwhite and Haddad (2010, p. 184) state 'it is not about how often the theme is discussed but the qualitative depth and importance the issue received during the discussions'. This is supported by additional literature that suggests that simply counting the responses misses the point of undertaking qualitative research (Pyett, 2003). Thus, the researcher is the one to guide the development of the themes and this determines the quality of the outcomes (Smith, 2004). Therefore, the use of frequency counts was rejected on the basis that quantifying the study was not the aim; rather it was to explore qualitatively the issues concerning older drivers and navigation. Moreover, this form of research is currently not available in the literature.

As advised by Braun and Clarke (2006; 2013), the data analysis ran concurrently with data collection to aid the iterative process. The analysis followed a four-step process of thematic theme development: first, each transcript was read independently and initial codes created for each one; second, the codes were then examined together to identity initial common themes; thirdly, the themes were reviewed to assess them against the original data; and finally, the themes were defined and named. From this process, three themes were produced; navigation behaviour; route guidance requirements, and IVNS and older drivers. These themes will now be explored in the results section below.

4.2 Results

This section explores the data collected through the six focus groups. The results are presented in the three themes highlighted from the thematic analysis. The first theme is navigation behaviour and explores the current driving and navigating behaviour of older adults. The second theme is the route guidance requirements and will detail the navigational information needed before and during a journey. The final theme examines the opinions and potential use of IVNS by older drivers.

4.2.1 *Navigation Behaviour*

When discussing driving and navigating an overwhelming response, from all the participants, was the need to be able to read a road map. This was developed further into a criticism of current navigation behaviour that the participants have observed from other drivers. In particular, the participants suggested that the younger generations were not able to read maps and were over reliant on technology. Being able to navigate with a road map was seen as a fundamental requirement as a driver.

'You should have to take a map reading test with your driving test' (Male, no IVNS)

'My grandchildren can't read a map and I fear if they ever get lost they will stay lost. Phones don't always work.'(Female, no IVNS)

The participants detailed their typical navigation behaviour. For local journeys, the participants reported relying on their own knowledge of the road network to navigate. They suggested that they have built up, over time, an extensive map of their familiar journeys in their area. The participants were then asked to consider the navigation of longer and more unfamiliar journeys. The majority of unfamiliar journeys were planned with a published map and online route planners. For example, participants reported comparing the routes outlined by websites such as Google Maps with their own printed road atlas. The online map would provide turn-by-turn instructions in addition to an overall route on a digital map. It would seem this approach provided them flexibility with planning but also familiarity with their own more traditional techniques, i.e. the printed road atlas. The participants were able to plan a journey online and print out a full list of the way-finding instructions. Although, participants did admit to finding it difficult to replicate the route they personally had planned with the online route planner. Furthermore, this method allowed participants to plan their journeys according to their self-regulation behaviour for example, avoiding motorways or complex junctions.

'I like to use Google maps. You can play with [way-finding] line for hours planning a route via a nice pub you know or not taking the motorway or a road that I know will be busy' (Female, not an IVNS user)

They were aware of the limitations of using the internet to plan journeys and the consequences of printed out instructions. Participants stated they always have a map in the car and use them to overcome the limitations of online route planners.

'I use a combination of things. I always have a map in the car but I use the internet. Google is the one I tend to use for a route which is good for urban environments but not for in the country. As you can't really tell what roads are driveable as they are all the same colour' (Male, not an IVNS user)

'Google Maps is fine for major roads and routes but when you zoom in on a housing estate then the colours are hard to see' (Female, not an IVNS user)

However, participants who did not use an IVNS explained how they take this planning a step further. By printing out the directions provided from the online route planners and then travelling with them, the majority of the time in potentially unsafe ways. For instance, participants would write these instructions in large letters on several pieces of paper and place them on the passenger seat, their lap or even in some cases tape them to the steering wheel. This clearly highlights unsafe driving behaviour and an unmet navigation need.

'If I am going to some place I don't know of say the south or Wales … what I will do is work out my route from a map and then on the computer and print the

instructions out in large bold letters and put it next to me in the car. Then I can read them while driving and see how I am doing' (Female, not an IVNS user)

'I like to use Google map before a long journey and I usually make a list of roads for long journeys. I also I have to say that I have at times printed the instructions out and stuck them to the wheel of my car. This makes them easier to read as you go along' (Female, not an IVNS user)

The three groups of participants that were familiar with IVNS were asked about the most common journeys for which they use their system. The majority used them for unfamiliar and all for longer journeys, especially relying on the IVNS to reach the required destination. Reaching the final destination can be considered to be the most difficult stage of the journey so you would expect that this is where the IVNS would provide the most support. This part of the journey was largely considered the most demanding part of a trip by all the groups. Interestingly, several of the participants who currently use IVNS stated that they use them for every single trip they undertake, whether for familiar, unfamiliar or long distance journeys.

'I know you are supposed to prepare for a journey but the sat-nav only needs a postcode and without even looking at a map it takes you there. It removes any stress out of navigating. I can just focus on driving' (Male, IVNS user)

'*It is part of my routine now. I get into my car and get settled. Get the sat-nav up and programme it and this gets my mind focused on driving'* (Male, IVNS user)

The participants were asked to detail the difficulties they face with navigation. A common trend across all of the focus groups was the amount of traffic on the road. This made the task of driving more difficult which limited their ability to focus on navigating.

'As you age, driving takes a little bit more thought than it did when you were younger. Every time you step into the car you have to be focused' (Male, IVNS user)

'It is not so much that my driving is terrible. It is the other people on the road that you have to look out for. A lot of other drivers are driving too fast' (Female, not an IVNS user)

This focus on driving resulted in the participants admitting that navigating becomes more difficult as you age. The demands of driving were thought to become more acute as they aged. Many of the participants sole focus while driving was to be safe and be aware of what other drivers were doing. The focus on the driving task would reduce their ability to observe the navigational information on the roadside, for example road markings and road signs.

Consequently, the participants would undertake more wrong turnings and occasionally became lost.

As suggested earlier the participant's pre-trip planning, for unfamiliar journeys, would often rely on online route planners to detail the route. The participants would then check off the instructions whilst driving. This approach additionally resulted in an increase in navigational errors. The driver was focusing on driving and reading the information on the printed sheet. Therefore, the participants were unable to relate the instructions to the real-world environment.

'I do miss a lot of turns which have resulted in a bit of trouble. Through missing signs or focusing on driving I have just sailed past where I was meant to turn' (Male, IVNS user)

'To be fair to myself, I do think that I get lost more often than I did in the past. It is a little disconcerting. I try to read the information on the sheets I use. I'm so focused on driving that I often can't see the turning I'm looking for' (Female, not an IVNS user)

All the participants were asked whether they had changed the way they navigate on the roads over time. Some suggested that it was more difficult due to the increase in traffic and complex road layouts. Others highlighted the change in driving behaviour of other road users as a problem to modern driving. A significant majority discussed the increase in street furniture that has occurred since they started driving. This was especially evident to them in the number of different speed limits in use. Several admitting to being unaware of speed limits on familiar stretches of road while others had been caught speeding because of this. This was of great concern to the participants, as they want to be law-abiding drivers. Yet the road network left them, at times, confused about the speed limits due to the number of speed limit changes and number of street signs.

4.2.2 *Route Guidance Requirements*

The participants were asked to detail what navigational information they require for a journey. The responses were wide ranging depending on what journey they were undertaking. When the participants navigated around the local area, they relied on their local knowledge, using street names and landmarks to guide them. The use of landmarks was a tool used not only to identify which turning to take, but also to provide confirmation that they were on the correct road.

'I know that I'm on the right road to my sister's house when I pass a little church' (Female, IVNS).

'I see the road name high up on the side of the building and I know that's my turning. I don't read the sign because I turn down that street so often' (Male, not an IVNS user).

'When I travel on journeys I know well I can pick out certain things that let me know I am on the correct course. I use bridges or noticeable houses. When I travel on unfamiliar journeys I do try to pick things out from maps that I should look out for. Things like national trust properties or villages names' (Male, not an IVNS user)

'I plan my journeys with landmarks more than roads names. I do this when giving direction for people walking and driving. When I give directions to my wife I often say turn right at the second set of traffic lights or after we pass B&Q we will turn right' (Male, IVNS user)

'*My father used to plan all journeys by pubs. He had encyclopaedic knowledge of them. I don't do it that way but I do plan with other landmarks like churches or monuments'* (Female, not an IVNS user)

The participants discussed the information they require on longer and more unfamiliar journeys. The older drivers highlighted the use of place names, junction numbers and landmarks. Females, in particular, outlined the use of landmarks as a navigational requirement. They would use road maps to plan the route and identifying any potential landmarks on the journey to assist in the way-finding task. The participants highlighted the use of street view on online route planners as a tool that can identify landmarks on route. They would plan the route on an online route planner and then observe the route by virtually driving part of the route through 'street-view'. Thereby allowing them to gain experience of the route and remove any potential anxiety from travelling on an unfamiliar route. Participants additionally suggested knowing the complexity of the journey or particular junction layouts is useful. The participants would often note down the type and difficulty of turnings. For example, right turns across traffic or roundabouts with two or more lanes. This would allow them to prepare for the complex junction ahead or for them to avoid that route and plan another one.

The older drivers in the relevant groups also discussed what information they would like to receive from their IVNS (if they owned one). A common improvement for IVNS users was to make the pre-trip planning more like the online route planners. Allowing them the opportunity to have more control of the chosen route and therefore avoid situations with which they would not be comfortable. They felt that the IVNS takes complete control of the pre-trip planning stage. Instead they prefer to plan the journey ahead and have clear idea of the route. This allows them to be aware of the roads and the route they will be travelling. Similar comments were echoed by the non-users who felt they did not want to move away from the printed map. Rather something should be incorporated into this process so the control of the route choice is with the driver and not a machine.

'It is hard to find out which route you are going to be taking on my system, especially on longer journeys. You have to place a lot of trust in the system and at times go the way you wanted to go in the first place and just hope the sat-nav catches up with your thinking. Which is not ideal' (Male IVNS user)

'I like to spend time planning journeys and make decisions to go this way or that. For some electronic thing to take all that away from me is just crazy' (Male, not an IVNS user)

Moreover, participants suggest that more control on the level of information provided at the start of a journey would be beneficial; proposing that any system should be personalised to the individual user and the needs for that particular journey. This could range from highlighting points of interest on route, to the inclusion of weather conditions ahead. They particularly felt that their driving was noticeably different to when they were not retired. The participants highlighted how the majority of their driving is not constrained by time. The majority of IVNS plan a journey according to time. Future IVNS should take into account the differences in how journeys should be planned.

'I think if I were to go out for a leisurely drive then to have something to tell me what is around the roads whilst I am driving would be great' (Female, not an IVNS user)

'A system that would plan a journey the way I would, with my preferences for the time of day or purpose of the journey would be amazing' (Male, IVNS user)

The participants were, however, cautious about information overload. Outlining the need for the IVNS not to be over complicated but deliver adequate information in the way they wanted.

'What I don't need is an all singing all dancing system that is too complicated to use and has a hundred and one features on it ' (Male, not an IVNS user)

‘*The more complicated, it is the less likely I am to use it. That does not mean I want some old persons tech. It has to be cool and sexy but usable. That's the key. Usability*.’ (Male, IVNS user)

The participants reported a decline in their vision and found difficultly, at times, reading road signs, road markings and judging distances (headways). This was further compounded by what the respondents felt was a cluttered roadside. Since the majority of the participants had passed their driving tests, they felt the number of road signs and street furniture in general had increased dramatically. This has resulted in a greater difficultly in reading the required road signs. This was especially true for built up areas where road signs are numerous and speed limits uncertain. In fact participants admitted to only travelling with a co-pilot on longer journeys so they can act as the eyes and ears of the driver. Meaning they can provide the driver with the relevant information so they can focus on the control of the vehicle. Therefore, they felt an IVNS that displayed road signs relevant to their journey would be useful.

‘*I’m getting old … my vision is not as good as it used to be. There is no getting away from that. One of the hardest parts of driving for me is to read the road signs. Especially when travelling at higher speeds. Trying to not only read the road signs but reading the right road sign can be a challenge’* (Male, IVNS user)

‘*On longer journeys I read all the road signs for my husband and feed them back to him. That way he can focus on the road ahead*’ (Female, not an IVNS user)

4.2.3 *IVNS and Older Drivers*

The majority of participants who currently use IVNS admitted to a ‘get in and go’ attitude towards driving. Suggesting that all they needed was a postcode and they were able to go anywhere. They felt that using the IVNS means that they would never become lost. However, they did admit to never travelling anywhere without a published map.

‘You can just jump in the car, put the sat-nav on and away you go. It’s quite invigorating’ (Female, IVNS user)

Those without an IVNS took more care over their route choice. Moreover, male participants who do not use IVNS believed that if you do not know where you are or where you are going then you should not be driving.

‘Quite frankly if you are unsure where you are on a road, should you be driving?’ (Male, not an IVNS user)

'It is normally women that don't know where they are going. I'm sure they would find some use for using one [IVNS]' (Male, not an IVNS user)

Those who currently use IVNS were asked to explain why they started to use one. Their answers varied but a common response was to assist them navigating in an ever-increasing complex road network.

Many of the current IVNS users describe their system as a companion, referring to their systems not as an object but rather as 'he' or 'she' depending on the gender of the voice used. Participants admitted to arguing with them, sometimes even driving a different route to see what the 'voice' would say to them. It was evident that those who drove the majority of the time alone or who have a high mileage seemed to view their IVNS as more of a companion, rather than an inanimate object.

'I feel the NAV is a second person with me in the car' (Female, IVNS user)

'It is nice to know that you are not the only person in the car. It sounds stupid but having something to interact with makes me feel more assured when driving' (Female, IVNS user)

Furthermore, participants discussed a level of pleasure and freedom that they receive from using their IVNS. They seemed to indicate increased confidence in driving on unfamiliar routes, long and short, as the anxiety with reaching the required destination was reduced.

The changes in driving habits resulting from using an IVNS were also discussed. The majority felt no change had occurred in their driving habits. Yet they suggested earlier a 'get in and go' attitude. The participants reported driving on more unfamiliar routes without the need to plan every detail of the journey.

'For unknown journeys around the local area I tend to rely solely on my sat-nav, it saves a lot of hassle that I just don't need at my age' (Female, IVNS user)

For those participants who had no experience of any navigation system they were asked if they would ever consider using one. Some felt they would have a use for an IVNS in their lives, whilst others felt they would never need a device to assist them with navigation, feeling that current generations were too reliant on these systems. These participants were especially critical of other older adults who currently use IVNS. The all-male group, in particular, were definitely proud of their map reading skills and knowledge of UK roads. The all-female participants identified that any longer unfamiliar journeys were undertaken by their partners which meant that most of their journeys were only in known local areas.

‘If we go anywhere that's new to me then more often than not my husband will drive’ (Female, not an IVNS user)

With the majority of the women admitting that this had reduced their confidence in driving. Meaning they are not likely to drive to unknown locations they want to go without their partners.

‘*If I wanted to go somewhere new, something silly like a garden centre, then my husband has to drive me. It is a shame as he will do nothing but moan and this does restrict where I drive’* (Female, not an IVNS user)

‘Since I retired I definitely don’t drive as much to unfamiliar locations as I did. I don't drive as much on unfamiliar roads and I definitely don't keep my skills up as my husband always drives. I have noticed I drive less at night and to places I have never been to. I know he is not going to be around forever and I know I have to do something about it’ (Female, not an IVNS user)

Participants highlighted the importance of training with an IVNS. The participants suggested that training on the IVNS should not assume they have used technology of this type before. They just need someone to take their time to explain it to them on their terms, allowing them to learn at their own pace. The majority of participants had sought training on using an IVNS but admitted to only being aware of the basic functionality of the system. This training either was from the point of sale or requested from a family member.

‘I bought one, a decent one, from Halfords. They showed me how it worked and fitted it in for me. I can't remember what they showed me now but I know how to put in a postcode which I guess is all you need. It’s funny though, I don't know how to turn it on or off. I just leave it on all the time in my car’ (Male, IVNS)

‘I asked my son to show me how to use mine. He has one you see but he just explained it so quickly I had no real idea what he was really doing’ (Female, IVNS)

All the groups discussed an unwillingness to press buttons and essentially ‘play’ on electronic devices, as they were unsure if they could go back to where they started. This was highlighted as an obstacle to using any technology to its full potential. Several current users were unsure how to turn their IVNS off and as such simply left it on in the car at all times. A particular area of frustration from current users was the terminology used by IVNS. They felt if they had information that they understood it would make it easier to use. For example, one respondent re-counted her first few journeys with her IVNS:

‘When I first went out with it I had problems as I’m a terrible judge of distances. So when it said turn right in 300 yards I used to just turn right as soon as I could. Then when it says ‘keep left ahead’, I would take an immediate left and then just end up going round and round in circles. I had to learn what the information meant over time’ (Female, IVNS user)

‘*I re-call driving with my sat-nav for the first time. It would say bear right or left. I’d be frantically looking for where to turn. To be honest I took my eye off other cars and the road and just focused on finding where to turn. In the end it was just a bend in the road that you have to follow. The first few times it really confused me. Even now on some country roads and there is a turning off the bend in the road I’m in two minds which one to take as you only have a few seconds to decide what to do’* (Male, IVNS user)

The participants therefore identified that the current route guidance information does cause significant problems to them. This provides an opportunity to focus on what older drivers do currently use to navigate. Therefore, the goal should be to incorporate their requirements within the route guidance information.

The need for training was not confined to IVNS but rather to a raft of electronic devices. The important factor highlighted by the participants was the need to understand the usefulness of using such as system.

‘*A sat-nav might work perfectly well and get you from here to there but I don't think I need one so I am not going to use one’* (Male, not an IVNS user)

‘I never thought I needed one until I borrowed one from a friend for my first long journey alone and I could not believe how useful it was. I ended up getting one straight away’ (Female, IVNS user)

All of the IVNS users highlighted how they rely almost solely on the audio information. Participants indicated only using the screen for complementary information and often not glancing at the display at all. As the driver was focused on driving, the time it takes to examine the screen was felt to be too much for many people; similar to the issues around the road signs.

‘The screen takes my eye away from the road which is not good. I can’t be having my attention taken away from looking at the road for any longer than necessary’ (Male, IVNS user)

‘I never look at the screen. Just listen to the nice lady. I never put the screen on the windscreen in actual fact’ (Female, IVNS user)

Yet, despite the audio information being preferred, this was considered to be confusing and too ‘dry’ and not how they would navigate someone; this was evident for female IVNS users. The language used by the IVNS was thought to be ‘strange’ and miss leading. Particular reference was made to phrases such as ‘bear left’ and the distance-to-turn information. Older women considered the distance-to-turn information particularly troublesome. They found that judging distance extremely difficult when there were multiple options ahead for the same instructions. These difficulties would often result in the older female participants making wrong turns and losing confidence in using an IVNS on their own. Generally, this would then result in relying on partners to drive them to unfamiliar locations.

4.3 Discussion

This investigation aimed to provide additional understanding of older driver’s navigational behaviour and outlined their route guidance requirements. The participants detailed the difficulties they face on the road and in turn how this affects their navigation. The difficulties can be categorised into two main areas. Firstly, the changes they have experienced in the road network; predominately-increased complexity and growth in volume of traffic. This has resulted in the participants having to focus on the control of the vehicle and consequently their effective navigational performance had decreased. Alternatively, when the participants focused on navigation then the safe control of the vehicle was affected. Previous research found that strength and dexterity declined with age making the control of the vehicle more difficult compared to younger drivers (Mynatt and Rogers, 2001); and age-related decline in vision made the reading of road signs problematic. Coupled with the perceived increase in street furniture has resulted in the increase of navigational errors. Owsley and McGwin (2010) identified the decline in certain aspects of vision can affect road sign recognition. The inability to effectively read road signs and other visual features whilst driving resulted in significant difficulties with navigating a journey.

When compared to previous research the results from the focus groups produced some new findings on the navigation behaviour of older drivers. The use of the published map was the primary tool used for planning journeys. This was perhaps to be expected given that paper maps are the traditional source of navigation (Petchenik, 1989). In addition to printed road maps, drivers in this investigation and other studies have been found to make notes to assist them in the way-finding task (Streeter and Vitello, 1986; Parkes and Martell, 1990; Bryden *et al.*, 2013). The results from these focus groups found that online route planners were a tool that older drivers will use in conjunction with published maps. Older drivers will use online route planners to digitally plan their route, and to produce printable navigational notes to take with them on a journey. This suggested that older drivers were willing to use technology to overcome the challenges they face with route planning. This is important when considering the potential benefits IVNS can provide older drivers. Furthermore, the use of online route planners further highlights the increased assistance with navigation that older drivers require. As older drivers detailed how they would spend time planning journeys to their specific requirements; either through self-regulation preferences or the type of journey being undertaken. Examples given included planning a trip where total journey time was not a critical factor. The use of online route planners were found to be a tool that also reduced the anxiety associated with travelling on unfamiliar roads. Older drivers would virtually drive the route and select the route options that best suited their needs. By virtually driving the journey, the participants would reduce the fear of the unknown and gain confidence and knowledge for the journey ahead. Preparing themselves for any potential complex junctions or re-planning a journey if the route was perceived to be too demanding. However, currently there is no way to transfer the route planned online, on the PC, onto a personal IVNS. As highlighted, older drivers spent significant time planning journeys only for the IVNS to potentially guide them along a different route. This is a significant falling of current IVNS. This would often result in older drivers creating written notes from the guidance given by the online route planner. The manner in which the participants used the printed notes from online route planners was a significant finding. A number of participants, particularly those without an IVNS, openly admitted to printing out the instructions and reading them while driving. This clearly highlights a potentially dangerous method used by some to way-find a journey. Particularly considering the age-related declines experienced by older driver. For example, divided task attention (Salthouse and Siedlecki, 2007), and the high levels of distraction older drivers face when undertaking a demanding secondary task (Fofanova and Vollrath, 2011). Moreover, this research highlighted a clear need for route guidance information for older drivers whilst driving. The results from these focus groups therefore suggested that older drivers are willing to use technology to help them navigate, but for the majority only at the pre-trip planning stage. Currently only 6% of over 65s (see Section 1.6) own an IVNS in the UK. Yet this investigation has found that older adults are open to using an IVNS to help them navigate. Consequently, there seems to be a barrier that stops the vast majority of older drivers from using technology for the way-finding task. A clearer understanding is needed on what are the barriers and how to overcome these if older drivers are going to receive navigational support while driving.

When considering older drivers' route guidance requirements, the participants highlighted the importance of junction numbers and place names. These are both included in the majority of IVNS and online route planners. Another form of route guidance information suggested was landmarks. Landmarks form a fundamental component of a person's cognitive map (see Section 2.1.1). For journeys within the local area the use of landmarks were highlighted as a key feature to assist them. Landmarks have been shown to form an integral part of how humans assess their surroundings and thus navigate that environment (Lynch, 1960; Kitchin, 1994; Chown *et al.,* 1995; Hölscher *et al.,* 2011). Additionally, for longer and more unfamiliar journeys the participants attempted to identify landmarks within printed maps and online route planners as checkpoints. This was especially prevalent amongst the female participants. This result is consistent with earlier work which showed that females navigate a journey by focusing on learning the route in particular, key features of a route – landmarks (Lawton, 1994; Cutmore *et al.,* 2000). The use of landmarks within the route guidance information supports previous research within this area (May *et al.,* 2003; Goodman *et al.,* 2004; Goodman *et al.,* 2005; May *et al.,* 2005; May and Ross, 2006). It is important to consider what landmarks can be considered for car-navigation. Landmarks can change at the roadside, in either colour or type (bank into a pub). Given that current IVNS and route planners do not include navigational information based on landmarks there is a requirement for further investigations in this area. Additionally, in comparison to current IVNS then no participants suggested distance to next turning as an important requirement. This may be in part to judging distances not being an everyday task (Burnett, 2000).

With respect to the route guidance requirements, participants stated that they did not want to be overwhelmed with information. This complements findings of Pauzie (2003) and Eisses (2011), which highlighted that the design of all IVS for older drivers has to be optimised for the true benefits to be achieved. For those participants that currently own an IVNS, they suggested a level of pleasure or, perhaps, even freedom of travelling with an IVNS. A postcode was all that was needed for them to jump into a car and drive to a new destination. This level of freedom was not evident in the non-user groups who had to plan the journey and create paper notes to help them navigate. This is not to suggest that the IVNS were perfect for all those older drivers who currently use one.

The focus groups highlighted a number of significant problems with IVNS. Firstly, this investigation found that within the cohort of older drivers there is a wide range of abilities with technology. The result is not surprising but is worth highlighting given the importance this has on older adults' ability to benefit from the services an IVNS can offer. For those with an IVNS, the ability to alter settings and the understanding of their use, again, ranged dramatically. These findings relate to research that has highlighted how older adults use ITS differently (Caird, 2004). These groups showed that many older adults have limited understanding of their IVNS beyond the default setup. Previous research has found that older drivers are more likely to have technology difficulties with IVS than younger adults (Mynatt and Rogers, 2001; Pak *et al.,* 2008; Barnard *et al.,* 2013). Moreover, the findings from the focus groups highlighted the lack of understanding of the usability of current IVNS for older adults. The research on usability for IVNS was conducted over ten years ago when IVNS were very different from today's generation of devices. For instance, the findings from these focus groups highlighted gender differences in preferences for information delivery. The female participants found the distance-to-turn information particular difficult to understand. This resulted in a number of wrong turnings and navigational errors. The usability of IVNS is a key factor in providing adequate support to older drivers in the navigation task (Burnett, 2000; Baldwin, 2002).

With respect to the non-users, IVNS were generally not seen to be useful or necessary to their lives. These responses came from only travelling in the local area, making a fundamental stance that all the navigation information they needed was in a printed road atlas; believing that IVNS are too complex to use and would only cause a distraction. Hence, IVNS are currently at a fork in the road. Many older drivers do not perceive any benefit from them as they only drive in the familiar area. Yet they have reduced the amount they drive on an unfamiliar journey as they no longer have the confidence navigating. It would therefore seem that the IVNS has an image problem. A proportion of older adults do not want to rely on technology for assistance in this particular instance. A limitation of these focus groups was that the key features of usability were not covered due to time constraints. Further investigation into the usability of current IVNS for older driver may provide a clearer understating of route guidance requirements, and any potential barriers that may discourage an older adult from using one.

Finally, older drivers received more than just turn-by-turn instructions from their systems. Participants, who admittedly drive the majority of the time alone, found an element of companionship with their IVNS. They identified the benefit to receiving a second voice in the car. Kostyniuk *et al.* (1997) highlighted that companionship whilst driving was important for older drivers – although this was primarily from an additional person in the car. Forlizzi *et al*. (2010) suggested future IVNS should be context-aware and allow people to interact with it depending on the journey undertaken. These focus groups provided an additional element to this research area in that older drivers can build up important bonds with IVNS and this should be nurtured within the future design of IVNS. This is an area for further investigation as the ability to connect with 'someone' in the car seemed to ease the navigation burden, even if the 'someone' is a 'something'.

4.4 Conclusions

This investigation provided a solid foundation to understanding older adults' navigation behaviour when driving, and their route guidance requirements. The key findings were:

- The majority of older drivers are reliant on using a printed map to plan and then way-find a journey. They are critical of other drivers not taking care with the pre-trip planning stage of navigation.
- The majority of older drivers like planning journeys and will use a number of different forms of information to help them plan. For longer and unfamiliar journeys, they will often plan a journey that takes into account their self-regulation behaviour. This will include an avoidance of motorways or large, complex junctions.
- The use of online route planners was found to be a tool that provided them with accurate information that is sufficiently flexible to enable their self-regulation preferences. Older adults find the way-finding instructions provided by online route planners to be useful.
- Older drivers produce detailed notes of their planned journey and use these to way-find their trip. However, these notes have the potential to cause a distraction to the driver and they are unable to react to changes on the road network (heavy congestion) or if the driver misinterprets the notes and makes a navigational error.
- A proportion of older drivers, who do not use IVNS, were found to have reduced their driving on unfamiliar journeys. The older adults identified changes to their travel behaviour through an increased anxiety in navigating (planning and way-finding) unfamiliar journeys and age-related declines. A way to overcome the difficulties was to travel in pairs. However, this approach does limit the spontaneity that driving should provide.
- Older drivers identified several benefits to using IVNS. Older drivers identified a sense of freedom and companionship with using an IVNS. This allowed them to travel on unfamiliar journeys with increased confidence. However, usability issues with current IVNS were highlighted. The difficulties in effectively and efficiently using an IVNS influenced their use of IVNS.
- The older adults in this investigation identified and proposed several forms of navigational information that they currently use. Both in the pre-trip and way-finding stage of navigation. This included landmarks, speed limit changes, road names and road junctions.
- The focus group investigation found a difference between the genders. Females were more open regarding their declining abilities and need for

navigational assistance. In addition, females identified a greater change in their travel behaviour as they aged.

- This investigation supports the hypothesis that older drivers have specific needs that should be considered within the design of IVNS.

The findings from the focus group investigation have identified two areas that require a deeper understanding. Firstly, neither this phase of research nor the literature clearly indicates the usability of current IVNS for older drivers. The older drivers who currently use IVNS highlighted the benefits of using the system but also usability issues with using it effectively. A further investigation of the usability of current IVNS for both stages of navigation can provide understanding of what are the barriers to effective use and how route guidance information should be delivered to older drivers. This is a key area as usability is an important element of all forms of IVS. IVNS need to be usable for older drivers so that they are able to receive the benefits of bespoke designed route guidance information. Secondly, the focus groups identified several route guidance requirements. An in-depth focus on route guidance requirements with older drivers should clearly identify the most pertinent to subsequently test in a simulated driving environment. The study is limited by time so it is vital that the route guidance information chosen for testing has the greatest potential to positively affect navigational performance.

The next chapter will detail an in-depth investigation with 22 older adults using an IVNS for the first time over a two-week period. The results will aim to validate and expand upon the findings from the focus groups and literature review, and identify the route guidance requirement to be tested in a simulated driving environment.

Chapter 5: Older Drivers Using an IVNS for the First Time

5.1 Introduction

The findings in Chapter 4 highlighted the understanding that navigating and driving are complex tasks for older adults. The chapter also suggested potential route guidance requirements and current difficulties older drivers have with using IVNS. However, reflecting on the current literature and the findings from the focus groups there is still no conclusive evidence as to whether current IVNS are 'usable' by older adults. This is particularly important as usability has been highlighted as a key feature for IVNS and older drivers (see Section 3.3.1). Usability for IVNS encompasses the pre-trip planning and way-finding tasks of navigation.

Therefore, this chapter details an investigation that is aimed at two of the study's objectives. Firstly, what is, and how do we quantify the current usability of IVNS for older drivers; and secondly, what are older drivers' route guidance requirements in comparison to what is generally available with current generation IVNS. The design of the investigation is detailed below in Section 5.2. The results, discussion and conclusions start from Section 5.3.

5.2 Method

This section will review the design of the investigation; the methods used were outlined in Section 3.4.2.

5.2.1 *Experimental Design*

Before outlining the experimental design in detail, it is important to propose the theoretical framework for this stage of the research. This investigation was designed under the framework of *modified grounded theory*. Musselwhite and Haddad (2010) first used this approach in their study of older drivers' perceptions of driving. In this approach, older drivers participate across a range of data collection methods and actively influence the research process. Musselwhite and Haddad (2010, p. 182) suggest that this allows for 'the generation of knowledge and meaning from a wide variety of opinions and attitudes, without doing an injustice to their diversity and depth'. One of the key aims of grounded theory is to explain the knowledge from whence it came (Glaser, 1965; Glaser, 1999; Glaser, 2002). This is achieved by examining the origins of attitudes and behaviour from each participant and then the relationship between each of the them. The word ‘modified’ was attached by Musselwhite and Haddad (2010) to show that their use of grounded theory was not the method outlined by its founders, Glaser and Strauss (1965, 1967). Grounded theory was one of the first qualitative methods to be developed during their (re)emergence in the late sixties (Krueger and Casey, 2009). Since then a range of different varieties and versions of grounded theory have been developed (Birks and Mills, 2011). One of the main deviations from the original method of grounded theory has been the inclusion of a literature review before undertaking the research. The original grounded theory proposed that researchers should not engage with the relevant literature so that they are not influenced by previous research. Thus the resulting findings are grounded solely in the data (Urquhart *et al.,* 2010). In addition, the grounded theory literature highlights that the expertise of the researcher should not influence the data analysis and that a hypotheses should not be tested (Vrkljan and Polgar, 2007; Shaw *et al.*, 2010; Urquhart *et al.*, 2010; Jones and Alony, 2011). However, the literature should be compared with the formulation of ideas through the process of grounded theory (Glaser, 1965). Since an extensive literature review and a focus group investigation have already been undertaken, the use of grounded theory for this phase of research therefore could not be considered a purist’s version. Rather this approach is ‘modified’ to the needs of the research. This uses the techniques of grounded theory for the development of categories and their relationships to each other (Pidgeon and Henwood, 1997; Glaser and Holton, 2004).

Modified grounded theory has been particularly successful with in-depth interviews, allowing participants to discuss the key concepts that they find important within the scope of the research objectives (Urquhart *et al.,* 2010).The literature highlights that other methods often drive the data based on their methodical framework (Pidgeon and Henwood, 1997; Jones and Alony, 2011). The researchers roll is to become a moderator and maintain focus on the key area of interest allowing freedom to explore areas without allowing deviations to take control. This approach allows the findings to be grounded in the knowledge of the individuals themselves (Musselwhite and Haddad, 2010).

As detailed in Section 3.4.2, this investigation undertook a number of different methods. Table 5.1 provides an overview of the data recruitment method (see Section 3.4.2 for further detail).

Phase of investigation	Method	Aim
Pre-investigation	In-depth interview	To explore their current navigational behaviour and requirements.
	Sketch map	To assess the participants cognitive map on a familiar journey.
	Questionnaire	To provide demographic data of the participants.
	Desk based test	To assess the usability of current IVNS for older drivers.
Investigation	Driver diary	To provide contextual information to their experiences with the IVNS.
Post-investigation	In-depth interview	To explore their experiences and attitudes towards an IVNS.

Table 5.1 Overview of methods used in this investigation

5.2.2 *Participants*

Twenty-one older adults completed the investigation; one participant dropped out due to personal reasons. The age of the participants ranged from 61 to 86, with an average age of 70. During the recruitment process, significantly more women were willing to participate. This resulted in a slight bias in gender as 57% were female (N=12). Just over half were aged between 60 and 70 (52%), indicating a good spread across the older age bracket. Participants had held a full driving license for an average of 51.5 years (SD=8.6), with 58% driving between 5001-10,000 miles a year. Just under half considered themselves to be confident with technology (N=9, 43%). On average the participants spend half of all their journeys travelling with no passengers and 22% of their journeys travelling on unfamiliar roads. Just over half (N=12, 57%) of the participants considered themselves to be at least slightly ‘good’ at finding their way on an unfamiliar journey, on a 7-point scale. Again just over half (N=12, 57%) had actively avoided driving on an unfamiliar journey within the last six months.

5.2.3 *Experimental Procedure*

The overall process for each participant is provided below:

1. Before the participant arrived the IVNS was checked to ensure it was working and is resorted to factory settings;

2. When the participant arrived their driving licence was checked. They then completed the consent form and disclaimer. At this stage the investigation was explained to them in full;
3. The in-depth pre-investigation interview was conducted;
4. At the end of the interview the questionnaire was administered;
5. Upon completion of the questionnaire the sketch map exercise was carried out;
6. The desk based usability study was then undertaken;
7. The participants were then provided with training on the IVNS;
8. The two-week deployment of the IVNS took place;
9. After two weeks the participant returned the IVNS along with completed diaries; and
10. Within a week of returning the completed diaries the in-depth post-investigation interview was conducted.

Both the ‘before’ and ‘after’ interviews were conducted in a small meeting room within Newcastle University’s campus and were digitally audio recorded.

5.2.4 *Analysis*

The study was designed to provide both qualitative and quantitative data. The use of numerous methods resulted in adopting a number of different analytical methods to analyse the data and address the aims of this investigation. The analysis was divided between the desk based usability task, the sketch map, interviews with elements of the diaries, and the preliminary questionnaire with data collected from the diary.

The data analysis of both interviews ran concurrently with the data collection to aid the iterative process, as advised by (Musselwhite and Haddad, 2010). The interviews and open diary entries were transcribed at the same time, to provide a rich source of material and for findings not to be repeated. The method of grounded theory involved constant comparative analysis using three stages of coding: open, selective and theoretical coding (Glaser, 1965; Heath and Cowley, 2004; Charmaz, 2006). Open coding was employed when the data was in a raw state, generally in the form of transcripts. The aim of open coding is to split the data into similar areas, without the limitations of the research objectives or grand theory (Jones and Alony, 2011). The researcher was essentially looking for patterns within the data. The disaggregated data fell into different categories. When a particular category becomes dense with populated data they become known as core categories (Glaser, 2001). During this stage the key features of constant comparative analysis was undertaken. As the core categories gained depth the researcher is encouraged to reflect on the data, through notes (they are often called memos) (Glaser, 1999; Heath and Cowley, 2004). The second stage was selective coding; this occurred when the core categories become apparent. This stage allowed the researcher to filter and code the data according to emerging themes. The final stage of coding emerged when the core categories became exhausted. This meant that no new evidence could be collected from data delivers a new result. The final coding stage was theoretical coding which examined the saturated categories and provided the researcher with the opportunity to analyse the relationship between the core categories and the literature.

The desk based usability study was analysed under the guidance of Noel *et al*. (2005). During the task the researcher made observations on the participant's performance. After the tasks had finished the researcher asked questions to supplement the observations. Thereby exploring interesting issues that came up during the observation stage (Noel *et al.,* 2005). The results of the participant's performance were then compared across the entire sample and themes highlighted through the process of grounded theory.

The sketch map exercise undertaken by the participants followed the structure advised by Daimon *et al*. (2000), who has undertaken extensive research with sketch maps. The information provided in the sketch map and written notes were coded against the five elements of Lynch's cognitive map: nodes, landmarks, paths, edges and districts (see Section 2.1.1). To understand the information provided in greater detail the frequency of each element was recorded just after making a turn at a junction until just after a turning at the next junction (i.e. per right/ left turn). This provided a clear overview of Lynch's elements for route guidance information.

The pre-investigation questionnaire and parts of the driver diary (see Section 3.4.2 for overview) provided quantitative data. The results from these were presented as descriptive statistics and statistical testing was carried out. The statistical methods used in this investigation were outlined in detail in Section 3.4.

5.2.5 *Equipment*

This investigation used two Garmin Nuvi 2440 IVNS. These devices have 5" screens and retail for over £100. This system is in the mid-price bracket for IVNS, has a large screen and a junction preview. Figure 5.1 shows images of the system used.

Figure 5.1 Garmin Nuvi 2440

The investigation could have used two different IVNS but it was important that every participant received the same experience when examining the perceived value of a navigation aid. There are two main limitations with using the Garmin system: only considers one user interface for the delivery and presentation of information, and no real time traffic information. Some systems can give up-to-date traffic information providing way-finding information to avoid potential delays. This feature is often perceived to be valuable to drivers but was not available in this mid-priced system. The participants may have changed their perception of the value of the system with additional features found on more advanced systems or on a similar system from a different manufacture. However, the investigation here, aimed to assess how an IVNS is used within current navigation behaviour of older drivers and the results are therefore presented in the context of the Garmin system chosen for the study. Furthermore, the additional features of advanced systems focus on way-finding information. The results will outline the importance of the pre-trip planning element of navigation to older adults.

5.3 Results

The results from the investigation presented in this section are separated by headings: driving behaviour, route guidance requirements and usability. Following the results section a discussion will be presented and salient conclusions drawn.

5.3.1 *Driving Behaviour*

When generally discussing planning journeys in the pre-investigation interview, participants felt that in their local area, they had built up enough experience to navigate to most locations without needing assistance. In local areas where the destination was perhaps unknown to them, they were most likely to use a printed road atlas or a local A to Z to assist them. They felt they were proficient in using these navigation tools. All participants stated that they would not travel without having a printed road map in the car. This was primarily due to them requiring a ‘safety net’ whereby if they became lost they would always have a navigational tool to hand. For longer and unfamiliar journeys, the participants used online route planners in conjunction with their printed road atlas to assist them. For example, participants reported comparing the routes outlined by websites such as Google Maps with their own published maps. The pre-trip planning of a journey is a key element of navigation and they openly admitted to enjoying this stage; perhaps even spending longer than necessary planning journeys – see Figure 5.2.

‘It might seem sad but I enjoy planning journeys. I have always liked maps and now with online maps it makes it easier to double check things … making sure that I know what to expect on journeys’ (Male, aged in sixties)

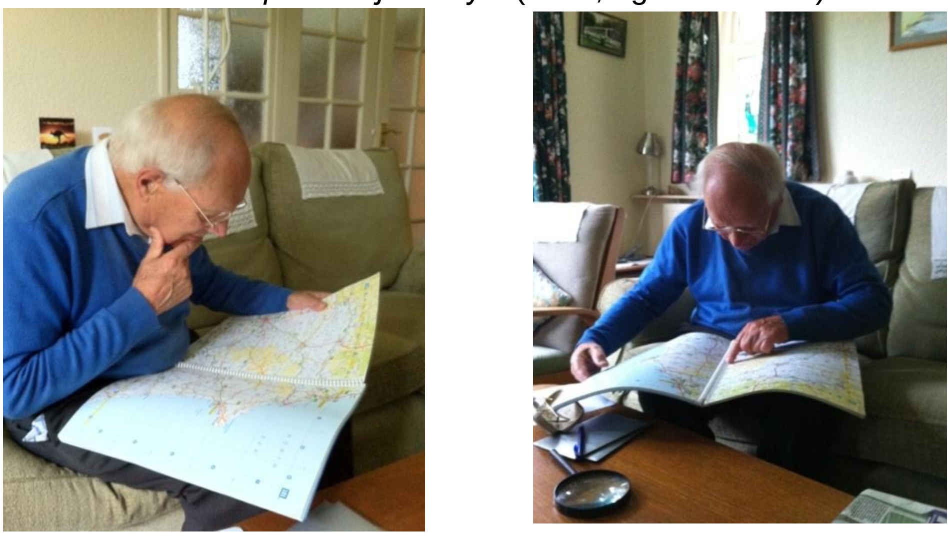


Figure 5.2 Participant planning a journey with a printed road map

However, participants would often copy the instructions provided by the online route planners and take this information with them on a journey. If the journey resulted in several pages of way-finding notes then the participants explained how they could lose track of which turning was next. They also confessed that they try to read their notes whilst driving often resulting in them becoming distracted whilst driving as they were keen not to make a navigational mistake. They admitted to not focusing on the safe control of the vehicle and although no one had been in an accident, several near misses were reported. One of the main factors was the amount of information the older drivers would include in their notes. This often made it difficult to read in time-critical situations. In fact, for some journeys participants reported that they would only travel with a passenger who would act as co-pilot. This clearly limits the spontaneity that having access to a car should provide.

Moreover, the participants did admit to driving less on unfamiliar routes due to losing confidence whilst on these roads. Many participants felt since retirement they have taken the easier option and found alternatives to driving on unfamiliar routes for example, asking more confident drivers to take them. This makes them more cautious about travelling on an unfamiliar journey. If they did not feel confident from the outset of the journey, they would then be unlikely to make complete journeys. The female participants in particular seemed to be more cautious about travelling unfamiliar journeys when there were no alternatives to them driving. To overcome the anxiety, many would use online route planners. Those who used them would often use the Street View option to virtually drive the journey. This therefore reduced the unfamiliarity of the journey to them.

'I have recently found Google Maps has this Street View feature. I love to use this to drive a journey that I am going on if I do not know the way. Not all of it but enough to make me feel comfortable with where I will be driving for real' (Females, aged in sixties)

'I like to prepare for all my car rides on roads I am not sure of. I use my road atlas and now the computer. You can print out the instructions but now you can all see the roads you will be driving on which can be of real benefit. Allows me to get my head around where I am travelling' (Females, aged in sixties)

During the interview the participants discussed their common journeys. The participants highlighted that since retiring their driving behaviour has changed. This ranged from reducing the number of days they drive to the reasons for travelling. The majority of journeys were based on more leisure driven activities. The driver diary was able to collect data on the participants' driving behaviour. In total 230 journeys were undertaken by the 21 participants. Table 5.2 provides the breakdown of the journey purpose for all journeys, familiar and unfamiliar journeys. The figures in bold refer to the three most popular journeys. Table 5.2 clearly shows that the three most popular journeys were for shopping, banking or errand; to see family or friends; and for a leisurely activity. In addition the driver diaries provided information on the familiarly of the journey. As expected the majority were familiar trips. Although, the overall percentage of all the trips travelled that were unfamiliar (33%) was higher than their annual estimated behaviour (22%). This provides an indication that the participants tested the IVNS beyond their normal travel behaviour within the two week period.

When comparing the participant's unfamiliar journeys to the overall picture, then the participants seem to undertake a greater number of journeys for shopping, banking or for an errand. This would suggest that they were accessing amenities that were previously not deemed accessible. The post-investigation interview found that the participants were keen to test the system by travelling to unfamiliar locations. In addition, participants felt that they were able to travel a little further than normal with the use of the loaned IVNS. This was a result of the older drivers believing that the IVNS would always know where they are. They felt that the IVNS could always get them to a location they would recognise, within their cognitive maps.

Journey purposes	Percentage		
	All journeys	Familiar	Unfamiliar
Shopping, banking or errand	**31**	**27**	**40**
See family/ friends	**28**	**28**	**29**
Get to an appointment	12	14	8
Leisurely drive	5	3	8
Leisurely activity	**22**	**26**	**16**
Other	1	2	0
Total No. of Journeys	230	154	76

Table 5.2 Breakdown of journey purpose (%)

5.3.2 *Route Guidance Requirements*

During the two-week investigation the participants were requested to detail their navigation planning methods and the information they needed to know before setting off on a journey. Of the 230 journeys, pre-trip planning was undertaken 143 times (62.2%). Table 5.3 details the tools used to plan the 143 journeys. In addition, the pre-trip planning methods for all familiar and unfamiliar journeys are shown. The figures in bold are the two most commonly used methods for each joinery type.

Method	Percentage		
	All journeys	Familiar	Unfamiliar
Paper map	22	12	**41**
IVNS	**32**	**29**	**38**
Online route planner	13	12	16
Visited websites	9	12	7
Planned route from memory	**24**	**25**	25
Total No. of journeys	143	85	58

Table 5.3 Pre-trip planning methods

Table 5.3 shows that for all the journeys and for familiar journeys where pre-trip planning occurred, the use of an IVNS and planned route from memory were the most frequently used. The planned route from memory was expected, as Chapter 2 highlighted the importance of people's own cognitive maps for navigation. The high percentage for the IVNS is perhaps a reflection of the pre-trip planning being a fundamental part of using an IVNS, and that the participants were asked to use the device for every journey. In comparison when compared to unfamiliar journeys the participants reverted to their traditional navigational behaviour. A paper map scored the highest followed by the IVNS. Therefore this can be seen as a true reflection of their pre-trip planning behaviour. These results seem to suggest that the participants deemed that the IVNS was not usable or that it did not provide them with adequate information at the pre-trip stage of navigation, to be the only method used.

These issues were discussed in greater depth in the post-investigation interview. The predominant view from the participants was that planning a journey on the device did not relate to their normal planning methods. When using the IVNS, they predominantly needed to know the postcode of the destination; which resulted in either going online or calling the destination to make data entry to the IVNS easier. They felt the use of the IVNS was time consuming and that it did not provide enough information at this stage of navigation. Moreover, the IVNS was only found to work outdoors - as GPS signal currently cannot be obtained without a clear path from device to the satellites. For those who prefer to plan their unfamiliar journeys and understand what roads they were going to drive on, they predominantly wanted to do this in the comfort of their own home. This could not be achieved as generally IVNS do not work indoors.

‘It takes too long for me to use and is over reliant on postcodes’ (Male, aged in sixties)

‘I like to plan my journeys in my study and I could not find a way to include the IVNS in the way I normally do things’ (Male, aged in sixties)

When considering the pre-trip planning stage it is important to know what navigational methods are used but also what route guidance information the participants require within this stage of navigation. For all the journeys where pre-trip planning occurred the most important information required was the type of roads and route on which they would be travelling (57%), followed by building up a mental map of the route (53%) and then how long the journey would take (21%). This seems to suggest that older drivers require a clear understanding of the types of roads ahead, which allows them to build up a mental map of the journey. Thus, this allows the participants to clearly understand the journey ahead, before they travel. From the interview, this became more evident when discussing self-regulation behaviour. The participants did identify some elements of this behaviour but also some coping strategies.

‘I don't like driving on motorways particularly but that does not mean I avoid them. If I plan in advance and know I am going to travel on them and when then I can prepare for it. Get ready for it. I would hate for someone or something to just tell me turn left and it is onto a motorway’ (Male, aged in eighties)

‘From here to there I like to have a clear idea of the journey. This way I am more confident setting out as I know roughly what to expect’ (Female, aged in sixties)

When considering the pre-trip planning for unfamiliar journeys a similar pattern emerges. The most popular information required was to know what type of roads and route on which would be travelling (71%), followed by building up a mental map of the route (66%) and then how long the journey would take (19%). The participants felt that the IVNS did not provide this type of information. They felt the IVNS planned the route too quickly and took too much control away from them. They prefer to take time to plan unfamiliar journeys so that they glean the information above, however the IVNS would only provide a bird's eye view of the entire route, overall distance and length of time for the journey. Information of this type was not found to influence the pre-trip planning of older drivers. One of the benefits of using online route planners was the detail it provided for each way-finding stage and the information provided for the entire route. With a few simple mouse clicks the participants were able to zoom in and out at any part the route which allowed them to review what type of roads they were driving on. This helped them to build up their cognitive map of the journey. As the IVNS did not allow them to do this to their required needs, it alienated them and reduced the benefits of using the system to plan journeys.

'I like to know before I set off on a journey exactly the routes I am going to be driving on' (Male, aged in eighties)

'I don't really like driving on motorways, I will do but I could not tell whether the sat-nav was going to make me or not' (Females, aged in seventies)

Knowing what roads they would be driving on and the overall route were key requirements by the majority of the participants. This is especially the case for unfamiliar journeys. The participants spend time planning a journey so that they are not surprised by complex junctions or by the road types they will face while driving. Moreover, the majority of all journeys undertaken by the participants were familiar in nature which means a large majority of the time the participants had at least some understanding of where they were going. This suggests, for this cohort at least, that the IVNS was not needed for the pre-planning stage as they had a clear understanding of which route they was going to take. This was certainly evident in the interviews as participants felt that some of journeys planned were strange.

'I have no idea which way it was planning on taking me but it was ludicrous. It was just going back on its self so I decided against it and went the way I wanted to go' (Male, aged in seventies)

'There is a trip I do every week to see my friend and have been doing for well over a year now. I don't need this machine on a journey like that' (Female, aged in seventies)

Yet at times, it was reported, that the IVNS proved to be more useful in the local area than first expected. Participants that followed the IVNS recommended route on well-known journeys found the system's journey would often take less time than their normal route.

'For as long as I can remember I have driven to the bottom of my street and turned right in order to get to the A19. This time the sat-nav told to turn left. I thought I would go with it and you know it took half the time, I could not believe it' (Female, aged in sixties)

'I once followed the route on a journey that I knew well and was having a go at the navigation thing until I realised that it actually took me on a route far better than the one I usually go on. That I was surprised at' (Male, aged in eighties)

Way-finding

The pre-investigation questionnaire asked the participants to rate perceived usefulness of different types of navigation information when travelling on an unfamiliar road. The figures refer to the median score, and in the brackets the percentage of participants who responded '7, 6 or 5' from a 7-point scale (where 7=very useful, and 1= very useless). The figures in bold refer to the top three information types for travelling on an unfamiliar journey. The table also shows the results split by gender.

Table 5.4 also indicates the top three rated forms of information provision on a journey (indicated) in bold. Overall, place names were the highest rated forms of information required for an unfamiliar journey. Landmarks and road numbers were both tied for second. Currently IVNS deliver information based on distance-to-turn information, both short and long. Long distances scored particularly poorly, only compass directions scored lower (compass direction can be provided as route guidance information on the majority of IVNS). Short distances scored level with junction numbers but both were outscored by landmarks. Landmark-based information is currently not provided by any form IVNS, either through audio instructions or a visual display. When examining the scores for each of the genders there were slight changes in the top three. Males scored short distances in their top three whereas females scored junction numbers higher. Further analysis with a Mann-Whitney test found no statistical difference between the genders for information requirements.

	Unfamiliar Journey		
	Total	Male	Female
Road numbers (e.g. follow A69)	**6 (91)**	**5 (89)**	**6 (92)**
Place names (e.g. follow signs for Manchester	**6 (95)**	**5 (100)**	**6.5 (100)**
Junction numbers (e.g. exit at Junction 12)	5 (86)	5 (78)	5.5 (92)
Street/ road names (e.g. turn left into Green Street)	5 (67)	5 (67)	5 (67)
Landmarks (e.g. turn left at the traffic lights)	**6 (91)**	**6 (89)**	**6 (100)**
Long distances (follow the road for 3 miles)	5 (57)	5 (67)	5 (75)
Short Distances (e.g. turn right in 300 yards)	5 (86)	**6 (89)**	5 (83)
Compass directions (e.g. head Northwards)	4 (43)	4 (33)	4 (33)
Total No of participants	21	9	12

Table 5.4 Preferences for different information types on an unfamiliar journey

During the first interview, the participants were asked to plan a familiar journey by drawing a map and providing step-by-step written instructions for a driver unfamiliar with that route. The information provided by the map and written instructions were classified against Lynch's (1960) elements of a cognitive map – see Section 2.2.1. Participants would only complete this task if they reported this route to be at least slightly 'familiar', on a 7-point scale, and all of them did. Figure 5.3 provides a breakdown of the results from the sketch map and the written instructions. The information was analysed as outlined in Section 5.2.4. When considering the information from the sketch map, Figure 5.3 illustrated that paths, nodes and then landmarks were the three most popular. Then sharp decrease in the frequency for edges and districts. A similar finding is evident for the written instructions. Nodes were considered the most frequently used followed by paths and then landmarks.

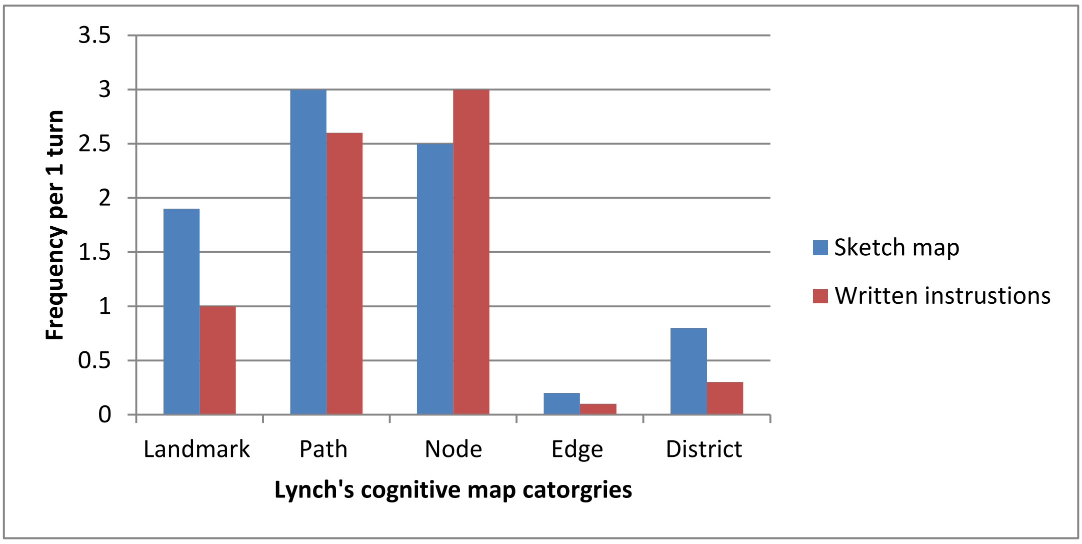


Figure 5.3 Frequency of elements in cognitive map per turn

The results displayed in Figure 5.3 illustrate the divide between paths, nodes and landmarks compared to edges and districts. This seems to suggest that edges and districts are not important forms of information for car navigation. However, landmarks are seen as an important form of route guidance information. This can be clearly seen within the sketch map exercise. This may provide an indication of the preference of how landmarks should be delivered to older drivers. From this exercise landmarks were highlighted to a greater degree in the visual sketch map compared to the written instructions. Figures 5.4 and 5.5 respectively, provide examples of sketch of maps and of written instructions by the participants.

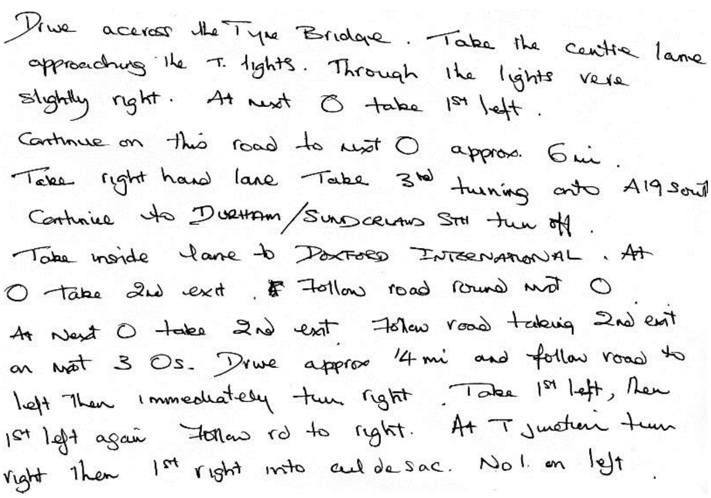


Figure 5.4 Example of the written instructions from the participants

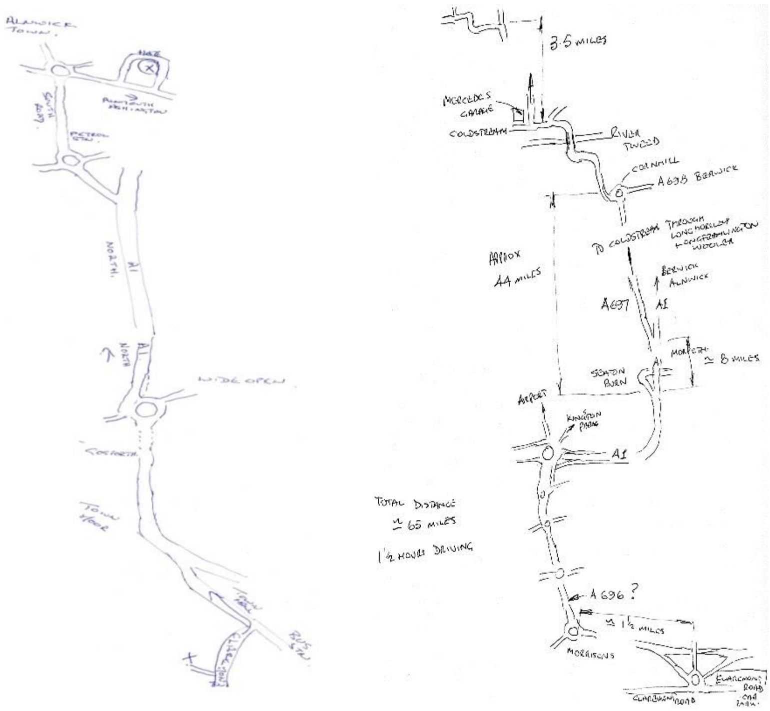


Figure 5.5 Examples of the sketch maps from the participants

When discussing what information they require on a journey in the pre-investigation interview, the use of landmarks was highlighted as a key feature. The drivers were keen to ‘place’ themselves on the route on which they were travelling. As indicated earlier the participants wanted to build up a cognitive map of the route. The sketch map method illustrated that this would be achieved with the combination of paths, nodes and also landmarks. The classification of what the participants considered a landmark varied. Some would use pubs while others shops as indications of where to turn or confirmation that they were on the correct route. The landmarks seem to serve two functions: firstly, to identify a landmark close to where a turning is required, and secondly to provide confirmation that they were on the correct route. These findings in addition to the sketch map exercise build a strong case for older drivers actively using landmarks to navigate.

‘When I am driving on a journey I do every week I know when I pass a church on my left hand side that I am nearly home. It is strange but I find it comforting to have little things like that’ (Female, aged in sixties)

‘I drive to see my daughter in Manchester and I know that I have to cross the Pennines so I have to climb them and pass bridges and farms in the middle of the two roads on the way … which gives me an indication that I am on the right road and how long is left’ (Male, aged in sixties)

As part of the driver diary, the participants responded to two questions based on their preferred method of the delivery of the route guidance information. Table 5.5 provides an overview of the results. The figures refer to the median score, and in the brackets the percentage of participants who responded ‘7, 6 or 5’ from a 7-point scale (where 7=very good, and 1= very poor).

	All journeys	Familiar	Unfamiliar
How did you rate the audio information provided	5 (55)	5 (55)	5 (62)
How did you rate the visual information provided	3 (25)	3 (25)	3.5 (29)
Total No. of Journeys	230	154	76

Table 5.5 Participant’s responses to the delivery of the navigational information

Table 5.5 illustrates that audio information outscored the visual information across all journey definitions. Further analysis with a Friedman tests found no statistical difference in the rating of the provision of audio and visual information across the three definitions of journeys.

Wilcoxon Signed-Ranks tests were run to determine if there were differences in the rating between each method for each journey type. There was statistical difference for each journey:

- All journeys: Audio (Mdn=5) compared to visual (Mdn=3), $z=7.454, p<0.05$
- Familiar journeys: Audio (Mdn=5) compared to visual (Mdn=3), $z=5.389, p=<0.05$
- Unfamiliar journeys: Audio (Mdn=5) compared to visual (Mdn=3), $z=5.184, p=<0.05$

The result provides statistical evidence that the participants’ rated the audio information higher than the visual display for all journey types.

The participant’s experience of how the route guidance information is delivered from the IVNS was discussed in the post-investigation interview. The participants felt the visual screen was a major distraction to their driving. As the map was consistently moving, it often drew their eye and caused them to take their eyes of the road. In addition, the participants suggested that the visual screen caused a significant distraction to them. They would often place the screen away from their field of vision.

'The screen was just too busy. I felt my eyes drawn to it and when you looking at that and not at the road then you have a problem' (Female, aged in eighties)

'I can't seem to focus when the voice is blurting orders to me and the screen is beeping and moving around. It was all too much' (Female, aged in sixties)

'I did not like having something else to look at. I like to focus on the road and especially other cars on the roads. Having something else to draw my eye away from these things was not for me' (Male, aged in seventies, diary entry)

When discussing the visual screen not all the information provided was deemed a distraction. In fact, the visual speed limits sign as well their current speed was thought to be useful. Many of the participants found knowing the correct speed limit was difficult and maintaining the correct speed limit as challenging, a similar finding was highlighted by Guo *et al*. (2013) and in the focus group investigation in this study. Although, the majority admitted that the speed limit signs (on the IVNS) were too small and they simply could not observe the screen while driving. The information was therefore not used unless travelling with a passenger as they could read the screen and relay the information to the driver. They thought that if the speed limits could be provided through audio instructions this could be beneficial to them.

When examining the results in Table 5.5 then it becomes clear that even though the audio information outscored the visual display, the audio was only rated 'good' 54% of the time. The audio and visual display did score slightly higher on unfamiliar journeys, as the participants were more reliant on the information. However, even on the unfamiliar journey the score was only 62%. The audio information was discussed during the in-depth post-investigation interview. The participants highlighted the unfamiliar nature of judging distances. A similar finding was proposed earlier in Chapter 4. As judging distances has not been found be an everyday task, it can be difficult to accurately achieve while controlling the vehicle and at speed. In particular, the female participants felt the information provided was difficult to follow; highlighting the distance-to-turn information as difficult to process correctly. Additionally, the language and terminology used often left the participants confused as to what action they were meant to undertake at junctions.

‘I found the voice instructions to be hard to follow. I don't know how far 300 yards is no matter how many times it tells me’ (Female, aged in sixties)

‘I was not too sure what bear left or right was, so I often put my indicator on expecting a turn. It was just telling me to follow the road. This left other drivers and people on the roads confused as to what I was doing’ (Female, aged in seventies)

‘I took so many wrong turn using it. I would just start turning left and right whenever it told me’ (Male, aged in sixties)

5.3.3 *Usability*

During the pre-investigation interview, the participants undertook a desk-based usability task - see Section 3.4.2 for further details. This uncovered a number of usability issues with current IVNS. One of the most obvious issues was that older adults were not aware of how to turn on the device. In some cases, this took a considerable amount of time and resulted in significant frustration. Once the system was on, the participants were asked to plan a journey to a street in Newcastle. The participants had difficulty with the touch screen technology and the slow response time from the device was often resulting in pressing several icons at once or not being able to press the screen firmly enough. When the device responded the menu would often jump several menu screens ahead. This resulted in a key difficulty being highlighted, the participants were unaware of how to return or go back to the previous screen. This particular IVNS model does have a ‘go back’ icon at the bottom left hand corner of nearly every screen. However, it took time before they realised what this button did.

A positive feature of these IVNS was the use of icons which indicated what that option would entail. For instance, when planning a journey an address entry button was complemented with an image of an envelope. In addition the systems icons and words are large and the participants could, overall, read the text clearly on the menus (the IVNS used were large screen versions).

When inputting the address into the system there were significant difficulties. The participants did not understand what the device required. When a user does not have a postcode then the Garmin system asks for information of an address in a strange order, i.e. city, then house number and finally the street. This order seemed alien to the participants and left them hesitant that they were doing something wrong. Moreover, inputting words on a touch screen keyboard took considerable effort. For the majority, this was their first experience with a touch screen device. They would often make a mistake and delete the whole word rather that up to the point that contained the error. The device would also pre-populate possible streets in the entry box, many of them failed to realise this and continued typing.

When the participants were asked to plan a second journey to the nearest petrol station, they were more confident with the system. They were more aware of the back button feature and touch screen display as they had now being using the system for a short time. However, the participants did struggle to find the menu that contained the nearest petrol station icon. This resulted in the participants accessing the more advanced features within the system. Those with more confidence simply used the ‘go back button’. However, those without this confidence became frustrated with the device.

However, the Garman IVNS overall performed well in this desk based task. The majority of participants were able to plan the two journeys. The large screen and icons in the menus were particularly well liked by the participants. Once they realised they had a ‘go back’ button they were more willing to explore the different menus. The touch screen and slow response to touching were the main draw-backs to the IVNS.

The desk based task aimed to assess the usability of the system during the pre-trip planning stage. The post-investigation interview and travel diaries identified the usability of the IVNS while on a journey, i.e. during way-finding.

Table 5.6 provides an overview of the results from five attitudinal questions in the driver diary. The figures refer to the median score, and in the brackets the percentage of participants who responded ‘7, 6 or 5’ from a 7-point scale (where 7= strongly agree, and 1= strongly disagree).

	All journeys	Familiar	Unfamiliar
I relied on the IVNS while on this journey	4 (44)	4 (38)	5 (57)
The IVNS positively affected my navigation performance	4 (34)	4 (33)	4 (36)
The IVNS was very easy to use on this journey	4 (35)	4 (32)	4 (42)
The IVNS was effective on this journey	4 (28)	4 (22)	3 (40)
The IVNS made me confident while navigating this journey	4 (30)	4 (27)	4 (34)
Total No. of journeys	230	154	76

Table 5.6 Participants responses to question in the diaries

Table 5.6 shows that the participants scored largely in the middle of the 7-point scale. The most noticeable differences in the scores are when they travelled on a familiar or unfamiliar journey. The scores in the '7, 6 and 5' end of the scale are higher for all the questions when travelling on an unfamiliar trip. The results will be presented under the headings of effectiveness, efficiency and satisfaction below. First, however, the participants scored how reliant they were on the IVNS. For over half of all the unfamiliar journeys the participants were reliant on the IVNS. However, the low scores may be a reflection of the loyalty to other methods. Table 5.6 showed that the participants still planned unfamiliar journeys with published maps. Moreover, the pre-investigation interview showed the participants loyalty to the published map. Therefore, this may be a result of not taking into account the numerous methods employed during navigation. A Friedman test was undertaken to examine if any statistical differences on how much they relied on the IVNS according to journey type. The tests found statistical differences according to journey type. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. The scores were significantly different relying on the IVNS, $X^2(2)=16.794, p=<0.05$. Post-hoc analysis revealed statistically significant difference between:

- All journeys (Mdn=4) compared to the familiar journeys (Mdn=4), p=<.05
- Unfamiliar journeys (Mdn=5) compared to familiar journeys (Mdn=4), p=0.015

The results show that the participants did not rely on the IVNS for familiar journeys. This result was perhaps to be expected. The post-investigation interview found older drivers ignoring the IVNS when travelling on familiar journeys. Moreover, the participants felt uneasy about being solely reliant on the IVNS. They rather used it to complement their usual methods rather than replace them.

Effectiveness

The participants scored the effectiveness of the IVNS relatively low overall and for familiar journeys – see Table 5.6. The score does increase on unfamiliar journeys. Friedman tests found a statistical difference and a Bonferroni correction for multiple comparisons was produced. The scores were significantly different for effectiveness, $X^2(2)=20.492, p=0.001$. Post-hoc analysis revealed statistically significant difference between:

- All journeys (Mdn=4) compared to the familiar journeys (Mdn=4), p=0.007
- Unfamiliar journeys (Mdn=4) compared to familiar journeys (Mdn=4), p=<.05

The scores from the 7-point scale produce similar results across all the questions. The scores are low overall but are slightly higher when travelling on an unfamiliar journey. This results in significant differences. The participants felt that the IVNS was effective at navigating but delivered information that was difficult to follow.

'It is good at what it does. It is not I would want from a system. There is too much going on' (Male, aged in seventies)

The participants highlighted that relying on the IVNS for their route guidance would lead them to taking the wrong turn. This was largely a result of failing to judge the distance to the next turning. The analysis from the post-investigation interview seemed to suggest this resulted in the participants feeling frustrated. They either had to turn around or wait for the IVNS to re-calculate the route. The participants would outline that if the system would re-calculate then they were moving away from the pre-trip planning they had conducted. This resulted in the participants feeling anxious when travelling on a journey that had deviated from their pre-trip planning.

Efficiency

The travel diaries asked the participants to detail the ease of use for the IVNS. The scores are low across all journey types. Friedman tests found a statistical difference and a pairwise comparison was performed with a Bonferroni correction for multiple comparisons. The scores were significantly different for ease of use, $X^2(2)=15.125, p=0.001$. Post-hoc analysis revealed statistically significant difference between:

- All journeys (Mdn=4) compared to the familiar journeys (Mdn=4), $p=<.05$
- Unfamiliar journeys (Mdn=4) compared to familiar journeys (Mdn=4), $p=0.022$

The participants rated the system easier to use for unfamiliar journeys compared to familiar. Again this is reflection of the participants perhaps seeing the IVNS as unnecessary for familiar journeys. The diary entries reflected the observations made from the desk-based task.

'…screen is too sensitive to the touch. I can't click on what I want to click on and it is very frustrating' (Male, diary entry, unfamiliar journey, aged in seventies)

'I may not be au fait with technology but this system just seems to do what it wants … I can't get my head around it' (Female, diary entry, unfamiliar journey, aged in seventies)

Satisfaction

The final question within the travel diary aimed at assessing their satisfaction with the device by asking about the confidence it provided them. The scores again were low for the participants. A Friedman test found a statistical difference and pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. The scores were significantly different for confidence, $X^2(2)=11.108, p=0.004$. Post-hoc analysis revealed statistically significant difference between:

- All journeys (Mdn=4) compared to the familiar journeys (Mdn=4), $p=<.05$
- Unfamiliar journeys (Mdn=4) compared to familiar journeys (Mdn=4), $p=<.05$

The participants outlined in the post-investigation interview that they have confidence in navigating the majority of their journeys. Therefore, the IVNS did not install any more confidence for them to undertake a journey they would not normally take. The participants however did outline that they enjoyed the 'company' that was provided with the IVNS.

'It is very nice to hear a second voice in the car' (Female, aged in eighties)

'I normally listen to the radio but with this I liked to hear what she had to say and I must say she was very good and entertaining. Especially the way she pronounced street names' (Female, aged in seventies)

5.4 Discussion

This section will review the findings under the headings of usability and route guidance requirements, before a conclusion is drawn in the final section of this chapter.

5.4.1 *Usability*

The usability findings will be divided between four of the five key elements highlighted in the literature: effectiveness, efficiency, satisfaction and ease of learning (see Section 3.3.4). Novelty effect was the fifth element in the literature; this was accounted for as the participants were provided with the IVNS over a period of time rather than a one-off use.

5.4.1.1 *Effectiveness*

Effectiveness of IVNS is defined as achieving the driver's goal of reaching the destination with no navigational errors. This investigation found that older adults thought the IVNS to be effective in principle. They could see how the system could navigate them from point A to B. However, over the course of the two-week loan the participants found that the system was not overly effective. In the travel diary, the participants rated the effectiveness very low. Only in 22% of all the familiar journeys was the IVNS considered effective in navigating them. The figure did increase (39%) for unfamiliar journeys. Yet the scores can be considered low across all types of journeys.

The difference in scores highlights the perceived difference in effectiveness when using the IVNS for a journey that is familiar compared to an unfamiliar trip. When travelling on familiar routes the older drivers would become frustrated with the journey the IVNS would take them on. They would often perceive the journey to be strange compared to their normal route. This resulted in the perceived effectiveness of the IVNS to be reduced. This was particularly the case for local journeys. The participants in the focus groups (Chapter 4) reported very similar findings.

As suggested above, the Likert scale value for effectiveness did increase when travelling on unfamiliar journeys. Yet for 61 % of all unfamiliar journeys the participants did not consider the IVNS effective. The findings from this investigation propose two reasons for this. Firstly, when travelling on an unfamiliar journey the participants would plan their route with a published map and the loaned IVNS (see Table 5.3). The results found that there is a natural divide between these two methods of pre-trip planning that currently has not been overcome within an IVNS. The published map allows for complete control over the route chosen and sufficient time for the planner to become familiar with the journey ahead. In contrast, the IVNS plans the route quickly and with minimal input from the user. In this instance, the participants were not provided with sufficient information of the planned route for them to undertake the journey with confidence. They were reluctant to allow the IVNS to completely plan the journey for them. They were keen to have clear understanding of the route ahead, which they can achieve with a published map. Moreover, the diary found that for the unfamiliar journeys the participants would only rely on the IVNS for just over half of those trips (57%). This again highlights how the IVNS did not support older drivers' navigational requirements. Secondly, the current route guidance information provided by the IVNS resulted in a number of navigation errors. This was found due to the IVNS use of distance-to-turn information. Judging distances also has been found to be a difficult task for drivers by Burnett (1997). A number of the participants found it difficult to know which turning to take when there were several options in the road layout ahead. In addition, the moving map-based display was found to be a distraction and difficult to follow. When the participants were unsure of which turning to take, the visual display was not able to provide additional clarity. Predominantly this was found to be a result of the current moving map-based displays, which has been found not to be the most suitable for older adults (Dingus *et al.,* 1997; Pauzié, 2003). The current format of information delivery was found to lead to navigation errors that reduce the overall effectiveness of the system.

5.4.1.2 *Efficiency*

The efficiency of the IVNS is determined by how demanding it is on the driver. During the two week IVNS survey period the participants rated the device to be easy to use on 35% of their journeys. The ease of use can be divided between the pre-trip planning and way-finding. The desk-based usability task found that the participants had significant difficulties in planning a route. The unfamiliarly with touch screen technology resulted in a number of problems. In addition, the process of inputting an address for the pre-trip planning to take place was thought to be confusing. Current IVNS predominantly require a postcode to plan a journey. Older adults were not aware or not able to obtain postcodes to where they wanted to travel. Full postcodes are rarely used to plan a journey with published maps and therefore have not formed a part of their pre-trip planning behaviour before. When planning a route in the local area they would locate the street name in an A to Z. For longer routes they attempt to find landmarks on the published maps close to their destination and use street names. The IVNS requirement for a postcode was especially difficulty for those without access to a computer, which is the majority of older adults (Barnard *et al.*, 2013).

When using the IVNS for way-finding information (i.e. while driving) it was considered to be demanding. As highlighted earlier, moving-map based displays have been found to not be the most appropriate display for older drivers. Previous studies have suggested that when navigating with a visual display older drivers average speed and lane position vary greatly (see Section 2.4.1). This investigation was not able to collect visual glance behaviour, yet the participants suggested they would ignore the visual screen to focus on the driving and rely solely on the audible information. The audible information does not require older drivers to remove their eyes from the road. Therefore, this reduces any safety concerns in which using just the visual display to navigate would result (Burnett, 2000). However, the earlier section highlighted how the current audible information from IVNS did result in navigation errors. Further investigation into the most efficient method of delivering route guidance information is required.

5.4.1.3 *Satisfaction*

Users of any form of IVS need to be satisfied with the device as this will affect their confidence in its use. The participants' satisfaction was assessed in the driver's diary. They recorded the level of confidence the IVNS provided while on a journey. The highest score was recorded when travelling on an unfamiliar journey. Yet, only on 34% of all unfamiliar journeys did the participants suggest that they were gaining confidence from using the system. The results from the data collection seem to suggest that the participants would still plan these journeys with a published map. Therefore, they had built up a clear idea of the route ahead and IVNS could not provide any additional route guidance information. In addition, the distance-to-turn information was found to be difficult to interpret and led to navigational errors (a finding echoed in the literature review – see Section 2.3.2). This reduced the confidence in the IVNS as they felt unsure on where to turn. Nevertheless, given the difficulties older drivers face with travelling on unfamiliar journeys it is encouraging that a current IVNS provided confidence on 34% of unfamiliar trips. For a proportion of older drivers, it is fair to suggest that a tailored older driver IVNS has the potential to provide significant confidence in the navigation task.

5.4.1.4 *Ease of learning*

This investigation examined the learnability of the IVNS for older adults. The desk-based study found that there are barriers to the use of IVNS for older drivers. The participants were eventually able to plan a journey but the process was not intuitive to them. The IVNS used was well received due to the large screen, icon-based images and back button. There were difficulties with the touch screen as this was often their first experience with the technology. After the desk-based study was trailed the participants were provided with training on the device (see Section 3.4.2 for details). On return of the system, the participants reported their experience in the use of IVNS as they did in training. They rarely had accessed the other options in the IVNS to plan journeys. This highlights that without additional support older adults will not realise the potential benefits of advanced features included in IVNS. In addition to whatever training older adults receive on technology it must be comprehensive as they are unlikely to develop abilities beyond the training provided.

5.4.2 *Route Guidance Requirements*

This investigation has found that older drivers currently plan their unfamiliar journeys with a published map. When deemed necessary they will complement this planning with the use of online route planners. This finding supports the results from this study's focus groups (Chapter 4). Older drivers seem to hold the published map in high regard as their main planning method. However, as found with the participants in the focus groups, there are limitations to the published map when way-finding a journey. The participants would use written notes to help guide them on their way. Generally made from the published map or copied from online route planners. Yet when the participants admitted to losing track of where they were or if they took a wrong turn then the written notes could not adapt. The quality of drivers' way-finding notes has also been found to vary greatly (Streeter and Vitello, 1986; Parkes and Martell, 1990). In addition, Dingus *et al*. (1997) found that when older drivers navigate with a map this would result in significant safety issues. Therefore, it would seem that paper maps can be used for the pre-trip planning stage but are not an effective tool to way-find a journey. However, older drivers in this study and in Bryden *et al*. (2013) survey found that that using maps for both stages of navigation is prevalent in older drivers. For instance, Bryden *et al*. (2013) found that 62% of older drivers would use a map to navigate while driving. This is a safety concern for older drivers and a clear navigational requirement that IVNS could overcome.

These findings, and those from this study's focus groups, also highlight a potential limitation of current route guidance research. A number of studies have tested potential route guidance information against the current design of IVNS. However, it is worth considering if this approach produces the most effective results. The majority of current older drivers do not use IVNS and the current IVNS have been found to have the same limitations in design as first generations models. Therefore, comparing new route guidance information to the current set-up of IVNS would only provide findings against something that has been found to be ineffective. To be able to inform the design of the next generation of IVNS then the testing of potential route guidance information should be investigated with older drivers preferred method of navigating, a published map with notes.

Cognitive maps have been found as the method humans use to make sense of their environment and then navigate it (see Section 2.1). Older drivers are no different and rely on key cues in the environment to assist them. Additionally there are environmental factors that assist car navigation, for example road signs and road markings. The use of the sketch map exercise is a method to remove environmental information and focus on the participant's own cognitive maps. The results found that landmarks featured in the top three forms of information with the sketch map as most important followed by written instructions. Furthermore, the pre- investigation questionnaire found that landmarks were required for navigating unfamiliar journeys. These results support the findings in the literature and focus groups. Landmarks are an effective tool used for day-to-day navigation on journeys that are familiar. Therefore, they are an appropriate form of information to navigate older drivers.

The results from this study so far, and the current literature, has now built-up a clear understanding of older drivers' route guidance requirements compared to current IVNS. This can be split between the two stages of navigation, pre-trip planning and way-finding. Older drivers have been found to enjoy the pre-trip planning stage of the navigation. With the creation of online route planners then older drivers are provided with a tool where they can create routes exactly to their requirements. This will include the planning of journeys according to their self-regulation behaviour. Generally, this stage of navigation is seen as enjoyable and important for older drivers in advance to be aware of the journey details for example, roads and junctions they will encounter. If this is compared to the IVNS, then pre-trip planning occurs very quickly with very little input from the user. IVNS will plan a journey from its current location to another and provide an estimated driving time. The route can be changed by altering a few variables, for instance planning the fastest route or avoiding motorways. However, this is far removed from the older drivers planning the entire journey themselves. In addition, older drivers will use the pre-trip planning stage of navigation to build-up a cognitive map of the journey. An IVNS does not provide sufficient information to allow them to achieve this. This does not allow IVNS to easily become part of their navigation behaviour. Moreover, they are unlikely to use IVNS to overcome the difficulties they face with way-finding unfamiliar journeys.

During way-finding then the use of road numbers and place names have been highlighted as useful information. Many of the current IVNS provide this form of information. The post-investigation questionnaire found that landmarks scored higher as a route guidance requirement than short distance-to-turn information. That is not to say that short distance-to-turn information did not score highly as useful information (86% compared to 91% for landmarks). Instead older drivers have a higher preference for landmarks compared to distance-to-turn information. The main way-finding information that IVNS provides is distance-to-turn information. Yet from the questionnaire there were three other forms of information that scored higher. The two week survey of the IVNS by older drivers and the participants in the focus groups who owned IVNS found distance-to-turn information difficult to follow; this was especially true for older females who reported more navigational errors when following this information than the male participants. The use of Lynch's elements of a cognitive map found that participants highlighted paths (road numbers), nodes (road junctions) and landmarks as a route guidance requirement. Currently landmarks are not provided in the route guidance information. The literature review highlighted the use of landmarks within route guidance information (see Section 2.3.2 and 2.3.3). The findings from this study so far have shown that landmarks should be included in the route guidance information for older drivers. Currently only a limited number of studies have reviewed the navigational performance of landmark-based route guidance information for older drivers. Moreover, there is only a limited understanding on the most effective method of landmark-based route guidance information to older drivers.

Also it is important to consider what information older drivers require to navigate but how that information should be presented. Generally IVNS deliver information through the combination of audible instructions and a visual display. This investigation found the audible instructions with statistically significant confidence was preferred to the visual display. This is despite audible instructions delivering distance-to-turn information that was not considered useful or easy to follow. This may reflect more on the delivery of information rather than the information provided. The visual screen with the moving-map based display was found to be a distraction as the display would consistently move and it was unhelpfully drawing the attention of the older driver.

Additionally, the visual screen displays information that may be beneficial to the driver for example, the speed limit of the road. However, the participants could not either read it or did not want to glance at the visual screen while driving. Further understanding is required on the potential for landmarks to navigate older drivers compared to their traditional navigational methods.

5.5 Conclusions

This investigation has validated and expanded upon the results of the focus groups and the literature review. The key findings for this investigation were:

- Older drivers have significant problems with using current IVNS. The current systems rely on touch screen technology. The touch screens were found not to be intuitive by older adults, who have limited experience with this form of technology (Barnard *et al.*, 2013). In addition, the systems used in this investigation were not deemed easy to use or learn. This limited the perceived benefit that IVNS can provide older drivers.
- The current pre-trip planning undertaken by IVNS is not appropriate for older drivers. IVNS plan the route and provide very little information to the driver. Older drivers require a full overview of the planned route, for both familiar and unfamiliar journeys. The lack of pre-trip information does not allow IVNS to be part of pre-trip planning of older drivers. This resulted in older drivers being anxious of the route planned or avoiding the advised route and subsequently the way-finding information provided.
- The way-finding information provided by IVNS is in the form of audio distance-to-turn information and a moving map-based visual display. The distance-to-turn information was found to be difficult to follow and the visual screen was considered a distraction. The visual display was not used to way-find; this placed an increased reliance on the audio information. Additionally, the visual display provided potentially useful information that may have been beneficial to the driver.
- Landmarks were found to be an integral part of the pre-trip planning and way-finding stages of navigation. Moreover, they are part of everyone’s cognitive maps and therefore are a very natural part of navigation and have the potential to be effective form of route guidance information.

The findings from this investigation have paved the way for the next stage of the study. Landmarks have been found to be the key route guidance requirement that could potentially provide significant benefits to older driver’s navigational performance. The current moving-map based display is not appropriate for older drivers and an alternative approach should be tested. Moreover, there is no clear evidence as to how landmark-based information should be delivered to older drivers.

The next chapter of this thesis will detail an investigation that significantly tests the findings from the two investigations already undertaken. A driving simulator investigation that was used to test the navigational performance of older drivers when they are provided with landmark-based information compared to road map will be presented. In addition, the most effective method of delivering navigational information will be examined, and the use of an icon-based visual display instead of a moving map-based display on an IVNS will be demonstrated.

Chapter 6. Driving Simulator Investigation

6.1 Introduction

As highlighted in Chapters 4 and 5 and in the literature review there is a clear requirement for the use of landmarks within route guidance information. There has been only been a limited number of studies that have investigated navigational performance related effects of using landmarks within route guidance information (see Section 2.3.3), and only a small number of those studies have focused research in the context of older adults.

In response to this knowledge gap, this chapter will detail a driving simulator investigation that was conducted to address three key areas. Firstly, to compare older drivers' navigational performance when provided with landmark-based route guidance information compared to a road map; secondly, the most appropriate method of delivering landmarks within the route guidance information; and finally, whether there were any potential gender differences with the provision of landmarks as navigational information.

In this investigation, drivers of different ages (although all above 60), genders and levels of IVNS experience were recruited to participate in a driving simulator investigation. The overview of the investigation is given in Section 6.2 below. The results, discussions and conclusions follow on from Section 6.3.

6.2 Method

The methods adopted and dependent variables collected for this investigation were highlighted in Section 3.4.3. This section will review the design of the driving simulator investigation.

6.2.1 Experimental Design Considerations

As suggested above, the investigation had three aims and a mixed design of within-subject and between-subject factors was used. The within-subject factors were:

- Method of information delivery – The investigation will examine delivering landmark information through a visual display and audio instructions. This allowed for the comparisons between the three methods of delivering information: audio only, visual only and a combination of audio and visual. Furthermore, the investigation adopted an icon-based visual display instead of the moving map format. This provided a comparison between previous research findings that have examined older adults and moving map-based displays.

- Navigational information provided - The current literature (see Section 2.3.3) highlighted the potential benefit drivers may receive when provided with landmark-based information. The research focused on pedestrian navigation or a comparison between distance-to-turn and landmark-based information. Current research has yet to examine the comparisons of navigational performance between landmark-based route guidance information and older drivers preferred method of navigating. As shown in chapter 5 this research found that older drivers primarily used a map with notes to navigate. Therefore, this investigation focused on a comparison of landmark-based route guidance information and the traditional road map.

The between-subject factor:

- Gender - The between-subject factor covers the navigational preference and performance that might occur through gender. In carrying out the investigation, an even split of gender was recruited. From the literature review (Chapter 2), it was expected that there would be a difference in navigation performance and preference between men and women. These findings could have significant impacts on the future design of IVNS for male and female drivers. Details of the participants recruited in the investigation are in Section 6.2.6.

The use of the within-subject factor for method of delivery and navigational information provided reduces the threat of error variance that can occur in between-subject studies. Moreover, as the investigation was testing four methods it would have been difficult to ensure homogenous of sample across four different groups. Instead, adopting within-subject factor allows each participant to be exposed to each method of information delivery. This increased statistical power as differences in performance can be detected and analysed.

The implication of adopting a within-subject factor approach for method of delivery was that each participant was required to drive four times. It was important that the order in which tasks were allocated was controlled so that any difference observed were the result of the nature of the task and not the order in which they were completed. The participants were divided into three groups, and to reduce the risk of the error variance the participants were screened – see Section 3.4.2. This meant a balance of gender; navigational ability; and exposure to IVNS was controlled for in each group. This allowed the comparison of the genders to be undertaken as the between-subjects factor without the results being affected by profile of the participants recruited. Table 6.1 outlines the order in which each group received the navigational information.

Group	Information Order			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
A	Map	Audio	Visual	Audio and visual
B	Map	Visual	Audio and visual	Audio
C	Map	Audio and visual	Audio	Visual

Table 6.1 Order of scenarios for groups A, B and C

Navigating by the paper map was held as the first scenario for each group. The reason for this approach was two-fold: firstly, the participants were provided with a paper map (see Section 6.2.5) and asked to plan a journey from point A to B. All of their driving scenarios would occur in the same driving simulator map and there was no guarantee that the participants would all navigate the same route or indeed reach the required destination. Therefore, by having the map driving scenario first this would allow them to travel across an entire unknown area and not be influenced by what they had seen on previous scenarios. It was important the participants considered this drive as an unfamiliar journey with no previous experience of driving in the environment. Secondly, the participants were asked to navigate the most direct journey from A to B and if this was placed in the later scenarios they may have been able to predict the route by following previously used landmarks (as the same landmarks were repeated for each driving scenario). Consequently, this would not provide a true reflection of their navigation ability.

6.2.2 Landmarks Chosen

This investigation required the participants to navigate an unfamiliar environment with the use of a map and then landmark-based route guidance information. The aim was to examine the impact of landmark-based information on navigation performance and method of delivery, rather than the quality of the landmarks used. Consequently, suitable landmarks needed to be highlighted and incorporated into the design of the route. Previous research has proposed the most effective landmarks to use in route guidance information (see Section 2.3.3). Using previous literature and reviewing the simulator software four landmarks were considered appropriate: traffic lights; pelican crossing; petrol station; and church. These four landmarks all held the five key characteristics of 'good' landmarks: permanence, visibility, usefulness, uniqueness and brevity. Moreover, the use of the driving simulator allowed these key characteristics to be positively manipulated in the design of the scenario. For example, the church was a large dominant shape, highly visible and in the immediate vicinity of the navigational decision point. The audio instruction also was unique and concise. Thus, each landmark across every scenario was maximised to fulfil the criteria of a 'good' landmark.

6.2.3 Test Route

Several criteria were used in the design of the driving scenarios. As each participant completed four scenarios and practice drives, it was important to establish that the test route was::

- considered a typical driving situation;
- an unfamiliar road network;
- an urban environment;
- conducted in stable, realistic and repeatable traffic conditions;
- complex to drivers so that they perform as they would in normal navigation situations; and
- incur real navigational decision points with the possibility of getting 'lost'.

As the investigation was conducted in the driving simulator a number of these criteria could be included in the design process. The study required the participants to complete four driving scenarios, each of which the participant would receive a different method of delivering navigational information. Therefore, the participants could have driven four independent test drives. However, for consistency and validity of the participants undertaking an unfamiliar journey an entire route was planned through an urban environment. This was then subsequently divided into four individual driving legs. Meaning that when the participant stopped one scenario the next scenario started at the end of the previous stopping point.

As this investigation was examining navigation performance the participants had to make navigational decisions whilst driving on route. Four turnings on average would take five minutes to complete, providing time between each manoeuvre to reduce the chance of simulator sickness (Brooks *et al.*, 2010). Time restrictions were placed on each scenario as a driving simulator was being used (see Section 3.3 for further details). This meant that during the entire investigation each participant would encounter 16 navigational decisions points with a specific landmark attached. Table 6.2 provides an overview of the four turnings that were included for each scenario. The manoeuvres were chosen as a direct result of the findings from Gstalter and Fastenmeier (1991) (see Section 3.3.3 for further details).

Once the landmarks and manoeuvres were chosen and the route designed, the route guidance information was developed. Table 6.2 displays the manoeuvres and landmarks along with the audio and visual information provided. Older adults have been found to have increased difficulties in processing speech (Baldwin, 2002). Therefore, the audio information had to have brevity as highlighted in the literature (Burnett, 2000; May and Ross, 2006). The direction of travel was indicated first, followed by the landmark information. This list-from delivery was found in the literature to be most effective for drivers (see Section 2.3.4). The landmarks chosen were concise and therefore did not involve long instructions that may have distracted or confused the driver.

The visual screen displayed an image of the landmark that was located at the navigational decision point and an arrow indicated which way to turn. This approach adopted the icon-based display that was part of the early IVNS conceptions (see Section 2.4.5). Figure 6.1 shows an example of the visual display with the navigational arrow used in this investigation.

Manoeuvre	Landmark	Information Provided		
		Audio	Visual	Combination
Right turn at a signalled T-junction	Traffic lights at turn	‘turn right at the traffic lights'	image of the junction with navigational arrow	both audio and visual display
Left turn from major to minor road	Petrol station	‘turn left after the petrol station'	image of the junction with the petrol station with navigational arrow	both audio and visual display
Right turn from major to minor road	Church at the side of road	‘turn right after church'	image of the junction with the church and the navigational arrow	both audio and visual display
Left turn at a signalled T-junction	Pedestrian crossing	‘turn left after the pedestrian crossing'	image of the manoeuvre with navigational arrow	both audio and visual display

Table 6.2 Overview of information provided for each manoeuvre

6.2.4 Equipment

Driving Simulator

This investigation was carried out in a fixed-based ST Software Jentig50 driving simulator (see Section 3.4.3 for further details). The risk of simulator discomfort to participants was reduced by providing rest breaks between each drive. In addition, participants were not required to undertake strenuous manoeuvres for instance, multiple turns in a short space of time.

Figure 6.1 Driving simulator with visual screen

Tobii™ Eye-Tracking Glasses

Tobii™ eye-tracking glasses are an unobtrusive and efficient mobile eye tracker. They can track the driver’s eye movement through the calibration of two cameras in the glasses. Each user requires an eye calibration so that the glasses track the participant’s pupil, which will be in a different location for each user. Once the glasses are calibrated they will record the eye movement for each participant. After the investigation was completed, the Tobii™ Studio 3.2 eye-tracking software can be used to analyse the data. This includes the analysis of the visual glance, duration and allocation. Figure 6.2 shows an image of the glasses used in this investigation.

Figure 6.2 Tobii™ eye-tracking glasses

6.2.5 Map Provided

The participants were provided with a map against which they planned and then navigated the journey with. This provided a comparison between navigating with a paper map and receiving landmark-based route guidance information. Ideally the map would be a replica of a standard road map, featuring road names and appropriate colours. However, as the route is based in a driving simulator the software would not allow for this standard of map to be created. Therefore, the map created was able to provide the basic principles without the high level of detail one would expect in a road atlas (see appendix M).

6.2.6 Participants

Forty participants began the simulator investigation with 10 failing to complete, primarily due to simulator discomfort. Table 6.3 provides a detailed breakdown of the participant profiles of each group. The table shows there is a consistency between each group for gender, average age, ownership of IVNS and experience of driving.

	Gender		Average age (years)		Presently own IVNS		Years held licence	
Group	Male	Female	Mean	SD	Yes	No	Mean	SD
A	5	5	69	7	5	5	47	12
B	5	5	69	7	5	5	46	12
C	5	5	71	6	5	5	51	4
Overall	15	15	69	7	15	15	48	10

Table 6.3 Overview of participants in each group

6.2.7 Experimental Procedure

The overall process for the investigation is as follows:

1. Before the participant arrived the equipment was checked;
2. When the participant arrived their driving licence was checked, completed the ethical form, the investigation explained verbally and the pre-investigation questionnaire was administered;
3. The equipment was demonstrated to the participants who were provided with time to practice in the simulator and become familiar with wearing eye-tracking goggles;
4. The Tobii™ eye-tracking goggles were calibrated for each participant – see Section 6.2.4. Training continued until participants confirmed verbally that they were comfortable with the eye-tracking googles and the driving simulator environment.
5. The participants planned a journey with a paper map. Once they were happy with the route they had planned (no time restrictions) they attempted to follow their planned journey on the simulator. For all the scenarios the participants were asked to adhere to the highway-code. Once they had reached the required end destination they verbally indicated this to the researcher;
6. The participants were provided with a rest break (5-10mins, to reduce the possibility of simulator sickness – see Section 3.3.2). In this time, they completed the NASA-RTLX and attitudinal questionnaire;
7. The participants drove three more scenarios in the simulator. In these scenarios, they were navigated by landmark-based information. The landmark information was delivered through audible instructions, a visual

display or a combination of them both. The order of which was determined based on the group they were in (see Table 6.1). After each scenario the participants were given a rest break (5-10 mins). In this time they completed the NASA-RTLX and the attitudinal questionnaire;

8. After the fourth scenario had been driven and the two questionnaires completed, an additional post-investigation questionnaire was administered (see Section 3.4.3 for details) and followed by a short semi-structured; and
9. After each investigation was complete the data from the eye-tracking goggles was downloaded for further analysis.

All the participants (n=30) completed all the data collection methods, this was a requirement for inclusion in the analysis. As highlighted earlier, ten participants failed to complete the investigation and their data was destroyed in compliance with the Data Protection Act 1998. When the eye-tracking data was reviewed, six participants' data was rejected as it was not of sufficient quality to analyse. The remaining 24 were of even gender split, and divided equally between the three groups. The data was analysed for normality and parametric tests conducted where possible. There was no other missing data in any other data collection method.

The remaining sections of this chapter will detail the results from the investigation and provide an in-depth discussion of the findings.

6.3 Results

The first section of the results will focus on the analysis of the responses from the pre-investigation questionnaire, before moving onto the findings collected during the driving simulator investigation. The final section will present the findings from the data collected post-investigation.

6.3.1 Questionnaire

The participants reported a quarter (25%) of their annual mileage on unfamiliar journeys. Similar findings were found between the genders. Only one participant had avoided travelling on an unfamiliar journey in the last six months. In addition, the questionnaires elicited information on their perceived navigation ability and map reading skills. Over a quarter of the participants (27%) suggested that they frequently became lost when travelling on an unfamiliar journey. Similarly, 20% of participants considered themselves at least ‘bad’ on a 7-point scale at finding their way in an unfamiliar area.

Of the 30 participants, 83% find published maps to be at least ‘good’ at helping them find their way. In comparison, just over half (53%) thought online maps were at least ‘good’ at helping them find their way. Males (Mdn=6) were more likely to find online maps helpful then females (Mdn=4) but no statistical significance was found, as determined by a Mann-Whitney test.

Four questions were asked concerning their ability to use a published map. Table 6.4 provides an overview of the results. The figures refer to the median score, and in the brackets the percentage of participants who responded ‘7, 6 or 5’ from a 7-point scale (where 7=very easy, and 1= very difficult). The table also shows the results split by gender.

	Overall (N=30)	Male (N=15)	Female (N=15)
How easy do you find it to locate a particular street name on a published map?	6 (80)	6 (93)	6 (67)
How easy do you find it to plan a route using a road atlas?	6 (83)	6 (100)	6 (67)
How easy do you find it to establish your current location using a published map?	6 (77)	6 (87)	6 (67)
How easy do you find it to follow a route from a map you have planned?	6 (83)	6 (100)	6 (67)

Table 6.4 Participants ability with a published map

The results show that the participants found the use of published maps to be relatively easy across these four questions as the medians were all 6, across both genders. The lowest scoring question was found on the ease to which they are able to establish their current location on a road map. Mann-Whitney tests found no statistical significance between the genders. Yet, the results do seem to suggest that the male participants may have a greater perceived ability of using a printed road atlas to navigate compared to females. The questionnaire provided an overview of the participants. The remaining sections of this chapter will detail findings from the driving simulator investigation.

6.3.2 Visual Glance Analysis of Landmark-based Route Guidance Information and Paper Map

This section of the results will report the visual glance behaviour for three of the four driving scenarios. The visual glance behaviour for the audio only scenario is excluded from this section.

6.3.2.1 Glance Frequency

Figure 6.3 shows the mean number of glances the participants made while driving with the map, the visual display, and the visual display with audio instructions. Figure 6.3 illustrates that the visual display incurred the highest average number of glances by all the participants. When the participants used the map, this resulted in the lowest number of glances. A repeated measure ANOVA was conducted to determine whether there were statistical significant differences in the number of glances made for the three forms of delivering navigational information. The assumption of sphericity was not violated, as assessed by Manuchly's Test of Sphericity $X^2(2) = 0.326$, $p=0.850$. The method of delivering information elicited statistically significant changes in the number of glances, $F(2,46)=34.645$, $p=0.001$, partial $n^2 =0.601$. Post-hoc analysis with a Bonferroni adjustment found that there was a decrease in the number of glances 45 (SD=17.7) when using the visual screen to 21 (SD=12.5) when relying on the audio and visual information, a statistical significant decrease of 24 (95% CI, 14.74 to 33.3), $p<.0005$. Additionally, there was a decrease in the number of glances from 45 (SD=17.7) when using the visual screen to navigating with the map 18.2 (SD=12.2), statistical significant decrease of 26.8 (95% CI, 36.3 to 17.3), $p<.05$.

Figure 6.4 shows that females glanced more often at the landmark-based information than did the male participants. Two repeated measure ANOVAs were conducted to determine whether there were statistically significant differences in the method of information delivery for the male and female participants. The assumption of sphericity was not violated for either gender, as assessed by Mauchly's Test of Sphericity (males, $X^2(2)=1.462$, $p=0.841$; females, $X^2(2)=0.167$, $p=0.920$).

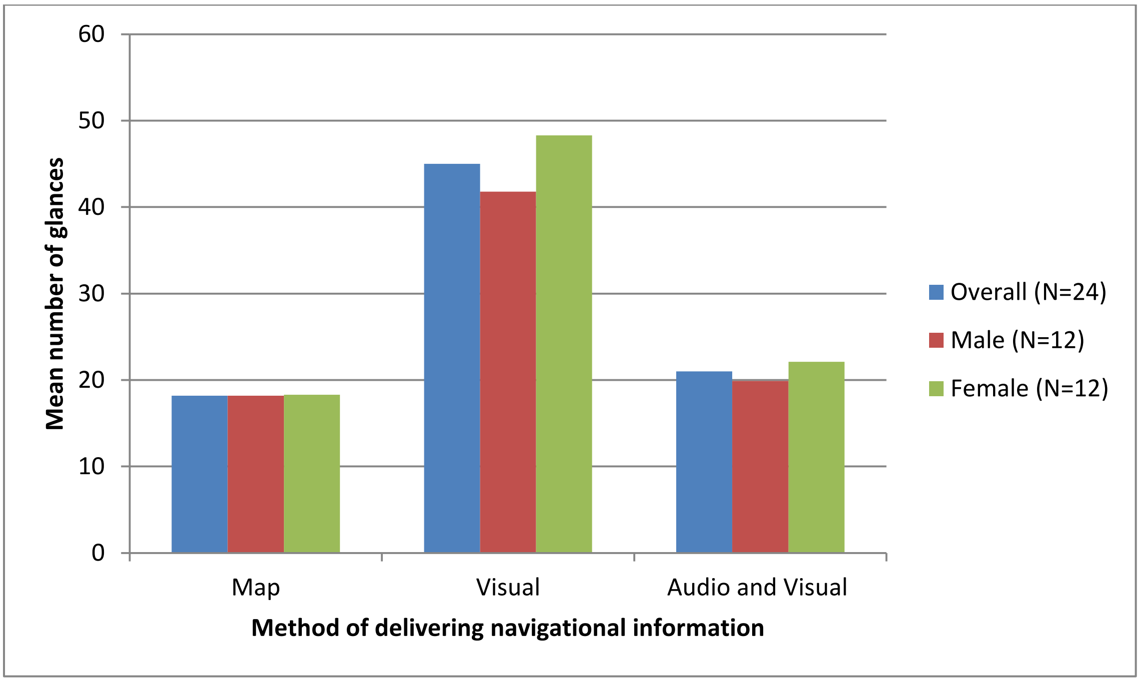


Figure 6.3 Mean number of glances towards three forms of information delivery

For the male participants the method of delivering navigational information resulted in statistical significant changes in number of glances, $F(2,22)=14.243$, $p<.05$, partial $n^2=0.564$. Number of glances was highest for the visual screen 41.8 (SD=19.5), followed by audio and visual 19.9 (SD=10.2). The males incurred the lowest number of glances when using the map 18.2 (SD=10.3) to navigate. Post-hoc analysis with a Bonferroni adjustment revealed that the number of glances was significantly reduced when the participants obtained information from the visual display to the audio and visual combination (21.83(CI 95%, 7.2 to 36.4),p=.004); and from the visual display to the map (23.58 (CI 95%, 39.1 to 8),p=.004).

The repeated measures ANOVA test for the female participants also resulted in significant changes in the number of glances, $F(2,22)=19.635$, $p<.05$, partial $n^2=0.641$. Number of glances was highest for the visual screen 48.3 (SD=15.9), followed by audio and visual 22 (SD=14.8). The participants incurred the lowest number of glances when navigating with the map 18.3 (SD=14.3). Post-hoc analysis with a Bonferroni adjustment revealed that the number of glances was significantly reduced when the female participants obtained information from the visual display to the audio and visual combination (26.16 (CI 95%, 11.75 to 40.57), p=.001). The numbers of glances were also statistically decreased from the visual display to the map (29.99 (CI 95%, 15.96 to 44.03), p<.05).

The results from the repeated measures ANOVA for each gender followed a similar pattern. Independent-samples t-test found no statistical difference between male and females for all three forms of information delivery.

Glance Frequency: Navigating with a Map Compared to Landmark-Based Information

Figure 6.4 shows that when the participants navigated with the landmark information it resulted in a higher number of glances compared to using the map. A paired-samples t-test found that participants glanced more at the visual display providing landmarks 33 (SD=12.5) compared to when using the map 18.2 (SD=12.2); a statistical significant decrease of 14.78 (95% CI 8.5 to 21), $t(23)=4.895, p<0.0005$, d=0.99.

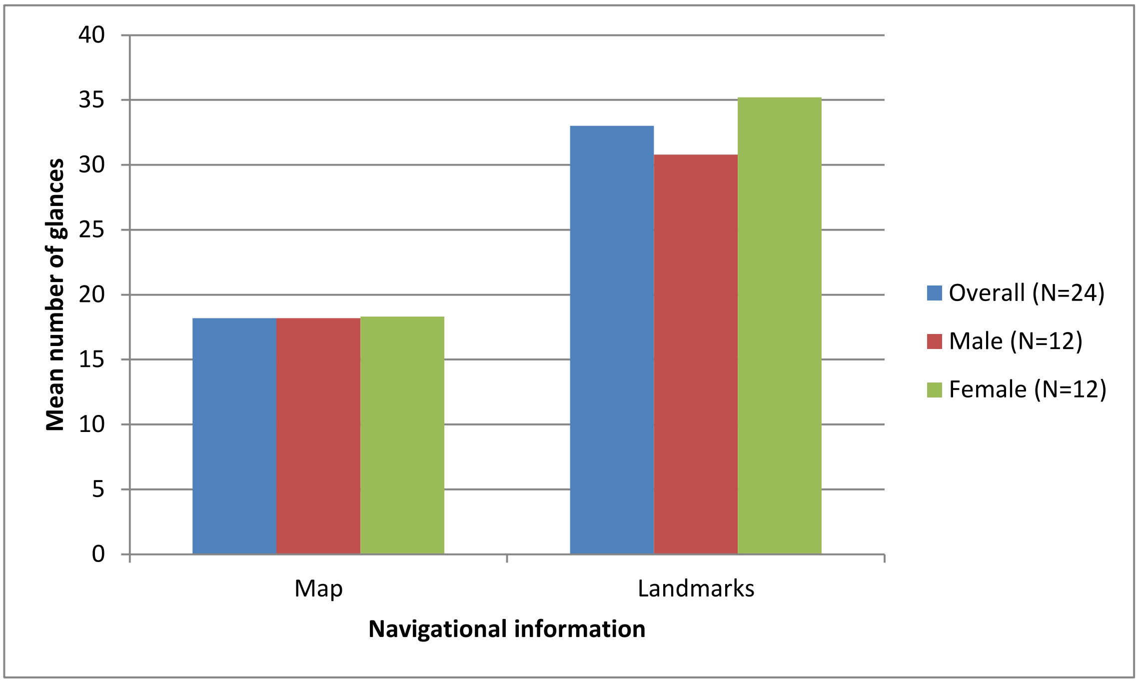


Figure 6.4 Mean glance duration for the map and landmarks

The mean number of glances for males and females when using a map or landmark-based information are also shown on Figure 6.4. A paired-samples t-test was run for males and females to determine if there are statistical differences in the number of glances. The male participants made more glances towards the visual landmark information 30.8 (SD=12.7) than the map 18.2 (SD=10.3); a statistical significant decrease of 12.6 (95% CI, 3.80 to 21.53), $t(11)=3.145$, p=.009, d=0.9. The same finding was found for the female participants. They made more glances towards the visual landmark information

35.2 (SD=12.6) than the map 18.3 (SD=14.3); a statistical significant decrease of 16.9 (95% CI, 27.02 to 6.79), $t(11)=3.67$, p=0.004, d=1.06.

An independent-sample t-test conducted earlier found no statistical significant difference between the genders when using the map. The same result was found when an additional independent-sample t-test was run to determine any difference between the genders when following the landmark-based information.

6.3.2.2 Glance Duration

Figure 6.5 shows the average glance duration (seconds) for the three forms of information delivery, and indicates that the participants would look at the map on average longer than either the visual display on its own and the combination of audio and visual. However, there was no statistical difference between the methods, as assessed by a Friedman test.

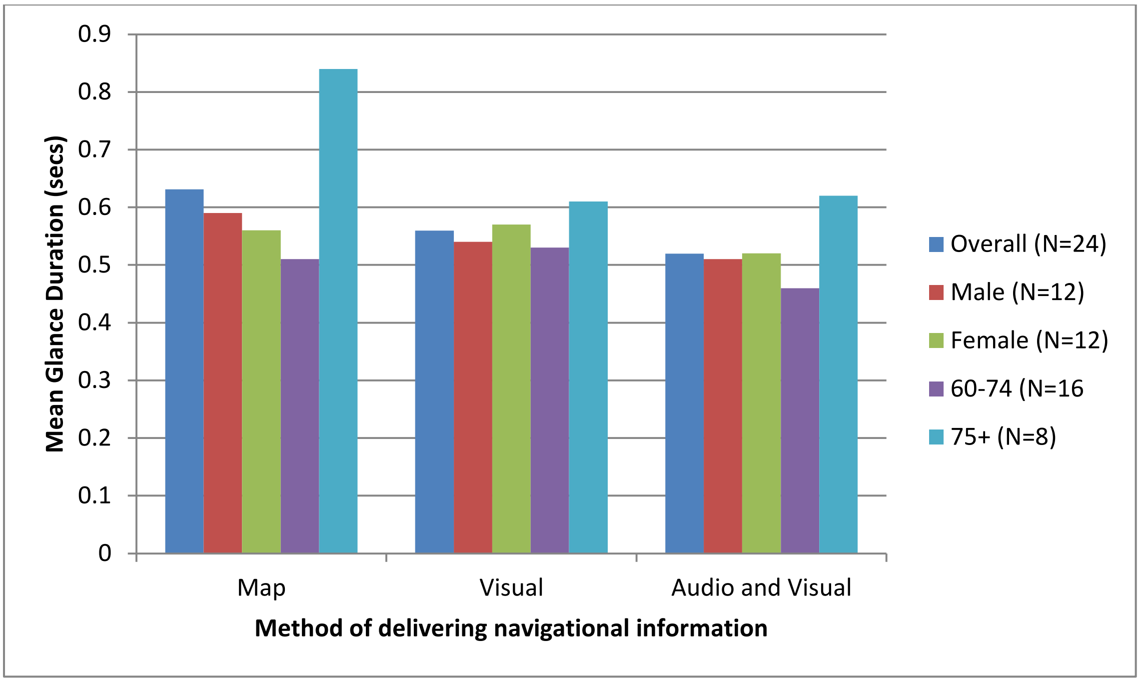


Figure 6.5 Mean glance duration across the three forms of information delivery

Figure 6.5 additionally shows the mean glance duration for males and females. Males had higher glance duration when using the map but lower glance duration for the visual landmark information. Paired-samples t-tests found no statistically significant difference for glance duration for male and female participants. In addition, there was no statistically significant difference between the genders, as assessed by independent-samples t-tests.

Figure 6.5 also displays the mean glance duration for two age categories, 60-74 and 75+. The older age group has a higher mean relative to the younger, 60-74yrs but with no statistical difference between the methods, as assessed by a Friedman test. However, an independent-samples t-test found that there were statistically significant differences in mean glance duration score between age when navigating with a map, with 75+ scoring higher than 60-74, 0.51 (95% CI, -0.05 to -0.02), t(22) =-4.3204, p=<.05

Glance Duration: Navigating with a Map Compared to Landmark-based Information

Figure 6.6 shows that the average glance duration was longer when the participants used the map compared to when landmarks were provided in the route guidance information. However, a paired-samples t-test found no statistically significant difference between the scores.

Figure 6.6 also indicates that males had higher glance duration when using the map but had lower glance duration for the visual landmark information, but no statistically significant difference was found as assessed by a paired-samples t-test. In addition, an independent-samples t-test found no statistically significant difference in the glance duration scores between the genders.

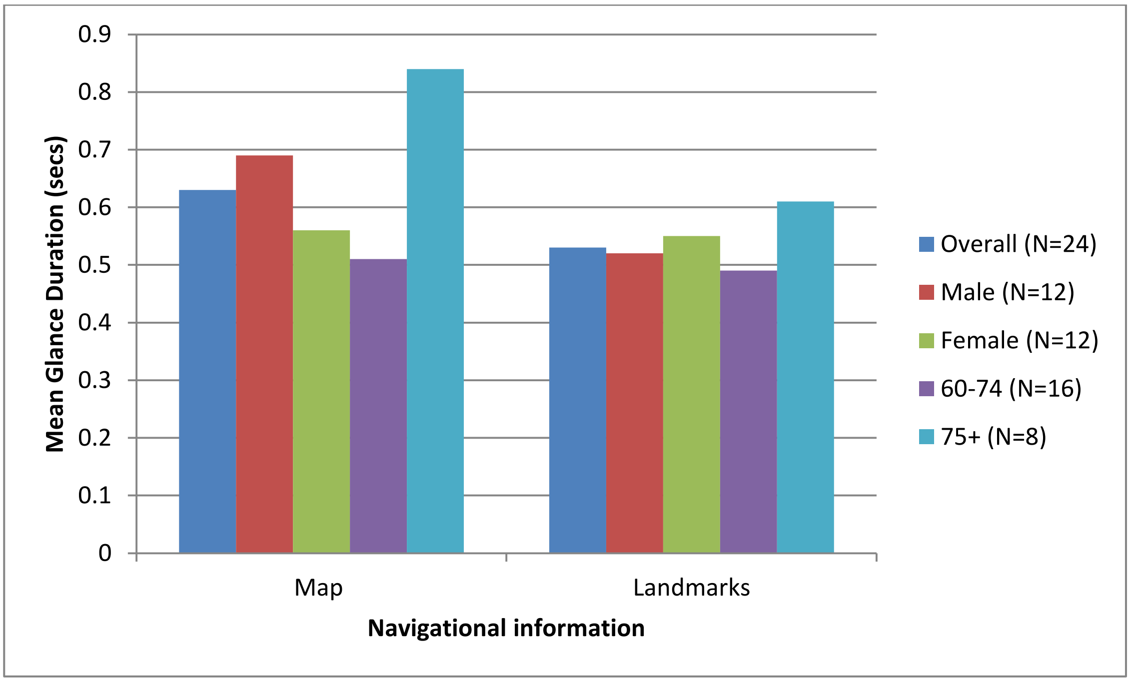


Figure 6.6 Mean glance duration (seconds) towards navigational information provided

Figure 6.6 shows the difference in scores between two different age groups. The participants aged 75 over shows higher mean glance duration for the map and landmark information, but no statistically significant difference was found for each age group as assessed by a paired-samples t-test. In addition, no statistical difference was found between the age groups, as assessed by independent-samples t-test.

6.3.2.3 Glance Allocation

The final glance analysis undertaken was glance allocation. Glance allocation is the percentage of time the driver glances at the map or visual display while the car is in motion. Figure 6.7 illustrates that glance allocation was at its highest when the participants relied on just the visual display. The use of audio with the visual display incurred the lowest percentage score. A Friedman test was conducted to determine whether there were statistical differences in glance allocation across the three forms of information delivery. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. Glance allocation was statistically significantly different for each delivery method, $X^2(2)=16.083$, $p<.005$. Post-hoc analysis revealed statistically significant differences in glance allocation from the map (Mdn =5.6) to the visual display (Mdn=8.9) (p=.001), and from audio and visual (Mdn=3.89) to the visual display (p=.001).

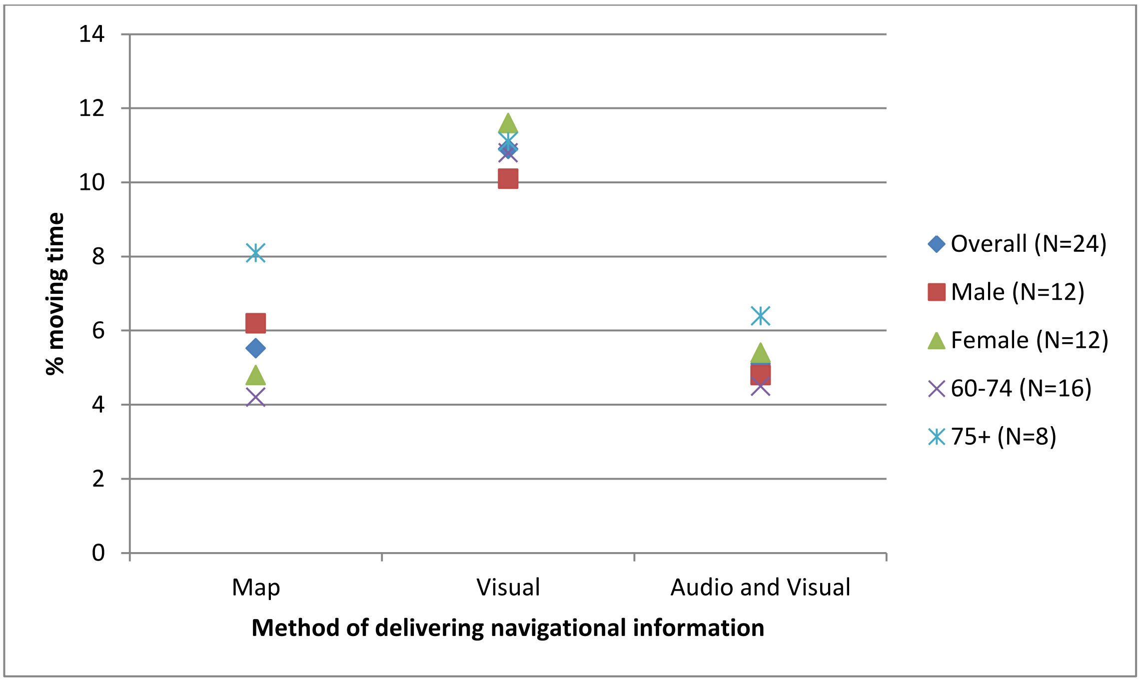


Figure 6.7 Percentage of time spent glancing to the map or visual displays while driving

Figure 6.7 shows the results for males and females. Friedman tests were conducted for each gender type to determine whether there were statistically significant differences in glance allocation across the three forms of information delivery. The findings when examining just the scores for males and then females followed the same pattern as the results overall. For the female participants, glance allocation was statistically significantly different for each delivery method, $X^2(2)=10.167$, $p=.006$. Post-hoc analysis revealed statistically significant differences in glance allocation from the map (Mdn=3.8) to the visual display (Mdn=10) (p=0.013), and from the audio and visual (Mdn=3.8) to visual display (p=0.024). For the male participants, glance allocation was significantly different for each delivery method, $X^2(2)=6.500$, $p=.039$. Post-hoc analysis revealed significant differences in glance allocation from audio and visual method (Mdn=3.7) to the visual display (Mdn=7.8) (p=.043). However, there was no statistically significant difference between male and females' scores, as determined by a Mann-Whitney test.

Figure 6.7 also displays the results for two different age groups, 60-74 and 75+. Friedman tests were conducted for each age group to determine whether there were statistically significant differences in glance allocation across the three forms of information delivery. The 60-74 age group were statistically different for each delivery method, $X^2(2)=15.875$, p=<.05. Post-hoc analysis revealed statistically significant differences in glance allocation from the map. Post-hoc analysis revealed statistically significant differences in glance allocation from the map (Mdn=3.5) to the visual display (Mdn=9.8) (p=.001), and from the audio and visual (Mdn=3.4) to visual display (p=.002). There were no statistically significant differences for the 75+ age group. Mann-Whitney test found statistically significant difference between the map for 60-74 (Mdn=3.5) and 75= (Mdn=7.8), U=100, z=2.205, p=0.27.

Glance Allocation: Navigating with a Map Compared to Landmark-Based Information

Figure 6.8 provides an overview of the glance allocation overall, gender and two age groups (60-74 and 74+) when glancing at the map of landmark-based information. A Wilcoxon Signed-Rank test was used to determine if there were statistically significant differences in glance allocation overall for the two forms of navigational information. The results showed that there was a statistically significant increase in glance allocation when the participants were provided with landmark information (Mdn=6.6) when compared to the map (Mdn=5.5), z=129.00,p=0.49.

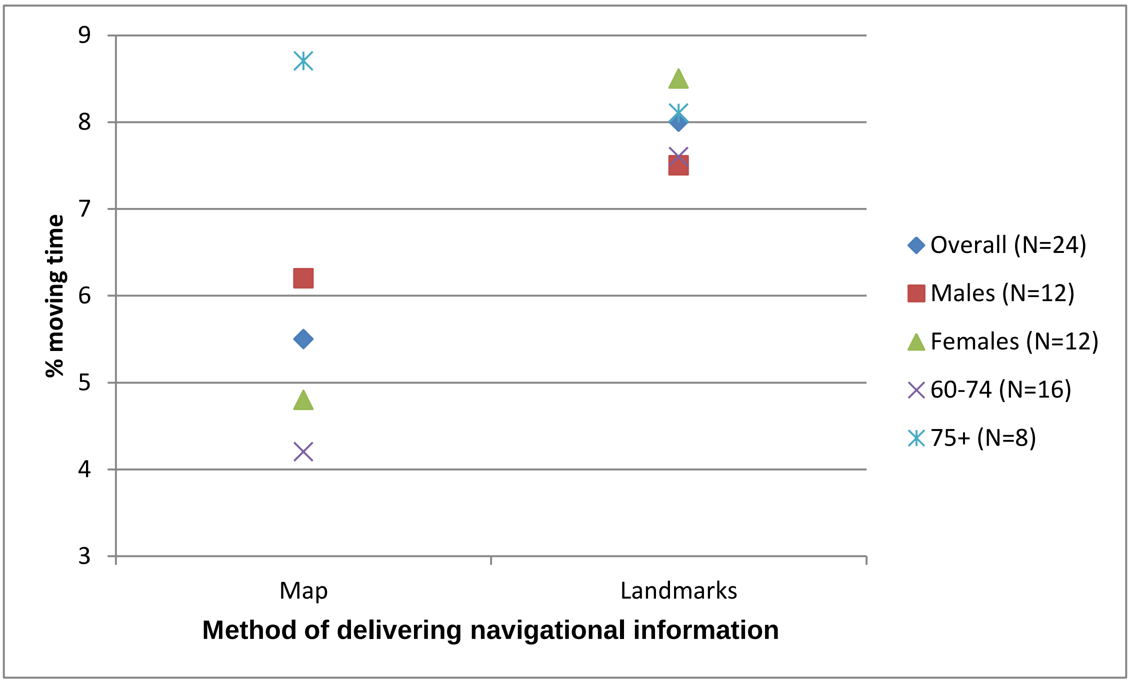


Figure 6.8 Percentage of time spent glancing to the map or landmark-based information while driving

Wilcoxon Signed-Rank determined if there were statistically significant differences in glance allocation for the two forms of navigational information for the genders and age group. There was a statistically significant change in glance allocation for females between the map (Mdn=3.8) and landmarks (Mdn=7.5), z=64.00,p=.050. However, there was no statistically significant change in glance allocation between maps and landmarks for the male participants. The glance allocation provided the first statistically significant gender difference in the visual glance analysis. When females were presented with landmark-based information they were statistically significantly more likely to look at the display compared to when using a map whilst driving. For the age group 60-74 there was a statistically significant difference in glance allocation for the map (Mdn=3.55) and landmarks (Mdn=6.24), Z=2.275, p=.023. However, there was no statistically significant change between maps and landmarks for those aged 74 and over. However, a Mann-Whitey U test found statistically significant difference between the age range 60-74 (Mdn=3.55) and 75+ (Mdn=7.81) for the maps, U=100,p-.027.

Visual Glance Analysis for Landmarks and Map: Key findings

- The visual glance analysis seems to suggest that the provision of landmarks increased the visual demand compared to when navigating with a map. The combined landmark-based information scored significantly higher for glance frequency and allocation. However, older drivers would glance for longer at the map than the landmark information. Although, not statistically significantly longer.
- Providing landmark-based information through only a visual display scored a higher glance demand compared to the combined audio and visual display. Furthermore, the audio and visual display in combination scored, overall, in a very similar way to the use of the map.
- The visual glance analysis did not provide any statistically significant difference between the genders. The genders scores mirrored that of the combined scores. This suggests that there is no gender difference in visual behaviour.
- Visual glance duration and allocation were higher in those aged 75+ compared to the 60-74 age group, indicating a potential age difference in

visual glance behaviour within older drivers and reflecting possible deterioration due to ageing.

- These findings are expanded upon in Section 6.4.2.

6.3.3 Visual Glance Analysis of Landmarks on the Roadside

This section will report the glance behaviour of the participants towards the landmarks in the road network according to frequency, duration and allocation.

6.3.3.1 Glance Frequency

Figure 6.9 shows the mean number of glances the participants made for a landmark on the road network. The number of glances towards the landmarks was different for each method delivered to the participant. A repeated measures ANOVA was conducted to determine whether there were significant differences in the number of glances made towards landmarks for the three forms of delivering navigational information. The assumption of sphericity was violated, as assessed by Manuchly's Test of Sphericity $X^2(2) = 3.567, p=0.039$ therefore a correction was applied. The method of delivering information elicited statistical changes in the number of glances, $F(1.594,38.949)=20.328$, $p <.05$, partial $n^2 =0.344$. Post-hoc analysis with a Bonferroni adjustment found that there were fewer glances towards a landmark when provided with information from audio and visual combination 1.5 (SD=0.98) compared to the audio information alone, 2.8 (SD=1.12), a statistically significant decrease of 1.3 (95% CI, 0.68 to 1.9),p<.05. There were also fewer glances towards a landmark when presented with navigational information in the audio and visual combination, 1.5 (SD=0.98) compared to the visual display on its own 3.1 (SD=1.12). This was a statistically significant decrease of 1.5 (95% CI, 0.570 to 2.59), p=0.002.

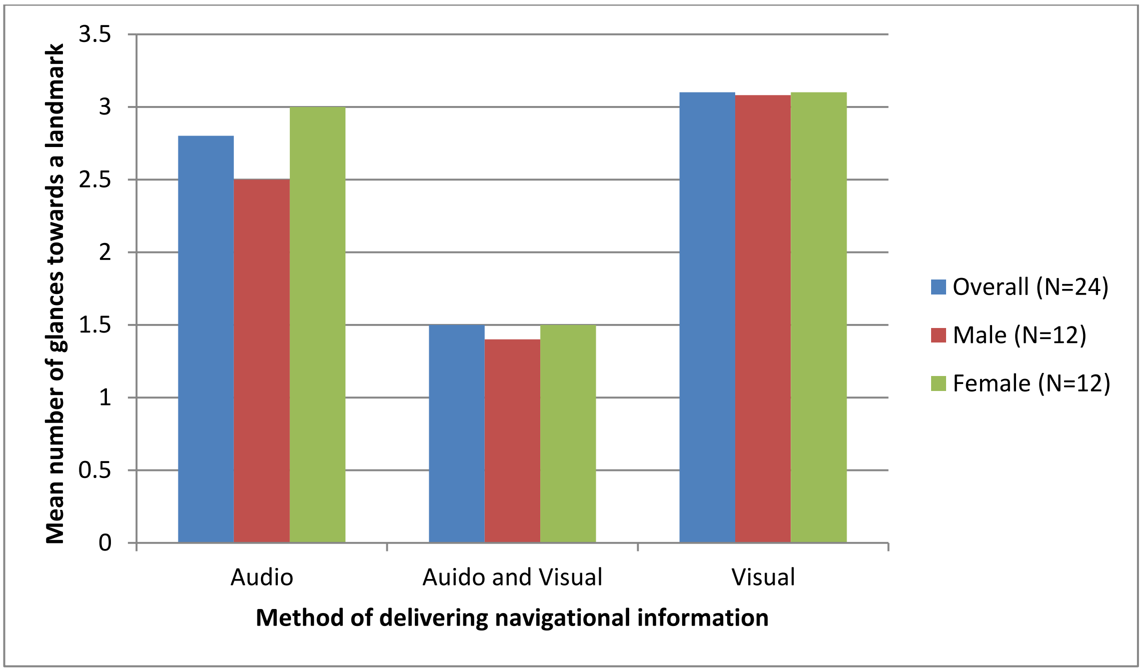


Figure 6.9 Mean number of glances towards a landmark in the road network according to method of delivery.

Figure 6.9 shows that for males, glances towards a landmark changed for each delivery method. A repeated measures ANOVA for the male scores tested the statistical significance of the difference in glance behaviour. The assumption of sphericity was not violated, $X^2(2) = 3.481$, p=.175. The method of delivering information elicited statistically significant changes in the number of glances, $F(2,22)=5.359$, p=.013, partial $n^2 = 0.328$. Post-hoc analysis with a Bonferroni adjustment found that there was a statistically significant decrease in glances to landmark from receiving audio instructions 2.58 (SD=1.16) compared to receiving audio as well as visual information 1.45 (SD=.99) with a statistically significant decrease of 1.25 (95% CI, 2.1 to 0.153), p=.023. In addition, there was a statistically significant decrease in glances to a landmark when receiving visual information 3.08 (SD=1.53) compared to audio and visual instructions 1.45 (SD=.99), a statistically significant change of 1.62 (95% CI, 3.26 to .016), p=.045.

Figure 6.9 also indicates that the female participant's glances towards the landmark were statistically significantly different for each delivery method. A repeated measures ANOVA was undertaken and the assumption of sphericity was not violated, $X^2(2) = 2.66$, p=.265. The method of delivering information elicited statistically significant changes in the number of glances, $F(2,22)=6.626$, p=.006, partial $n^2 = 0.376$ across all methods. Post-hoc analysis with a

Bonferroni adjustment found that there was a statistically significant decrease in mean glances to a landmark from receiving visual information 3.1 (SD=1.55) to audio and visual 1.58 (SD=1.02), a statistically significant difference of 1.54 (95% CI, 3.1 to 0.118), $p<.05$. The number of mean glances towards a landmark decreased from audio information to 3.08 (SD=1.08) to audio and visual 1.58 (SD=1.02) with a statistically significant difference of 1.5 (95% CI, 2.48 to 0.514), $p=0.004$.

The potential of gender difference in glance frequency found no statistically significant difference, as assessed by independent samples t-test.

6.3.3.2 Glance Duration

Figure 6.10 illustrates that the participants would have the shortest glances towards the roadside landmarks when navigated with an audio and visual display.

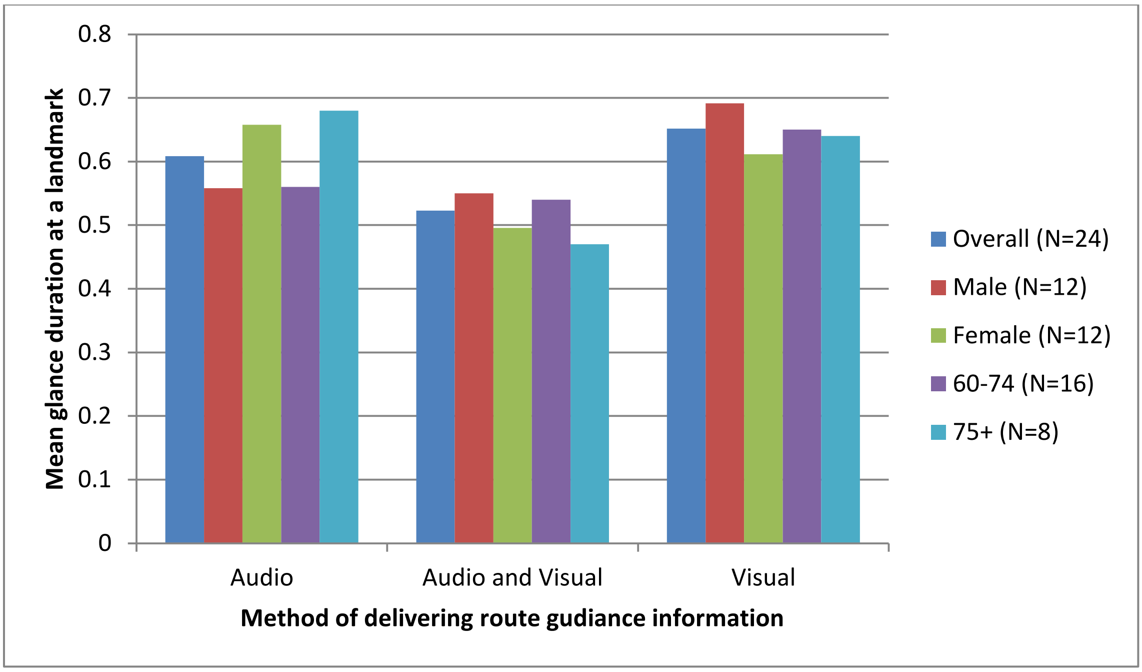


Figure 6.10 Glance duration towards physical landmark

There was no statistically significant difference between the glances duration for each form of delivery, as assessed by a repeated measures ANOVA. In addition, there was no statistically significant difference in the delivery method for glance duration for each gender or age, as assessed by repeated measures ANOVA. Moreover, independent-samples t-tests returned no statistically significant difference between the genders or age for each method of delivering route guidance information.

6.3.3.3 Glance Allocation

Figure 6.11 shows that the highest percentage of glancing at the roadside landmarks when driving occurred when the participants were navigated with just the visual display. A repeated measures ANOVA was conducted to determine whether there were statistically significant differences in the glance allocation towards a landmark for the three forms of delivering navigational information. The assumption of sphericity was violated, assessed by Manuchly's Test of Sphericity, $X^2(2)$ =6.635,p=0.036 therefore a correction applied. The method of delivering information elicited statistically significant changes in the number of glances, $F(1.685,38.758)=12.923$, p <.05, partial n^2 =0.360. Post-hoc analysis with a Bonferroni adjustment found that glance allocation decreased from 9.67(SD=4.76) when navigating with the visual display to 6.02 (SD=4.14) compared to when navigating with audio instruction, a statistically significant change of 3.65 (95% CI, 6.74 to 0.56), p=0.017. The allocation also decreased from 9.67(SD=4.76) when navigating with the visual display to 4.91 (SD=3.25) when following audio and visual instructions, a statistically significant decrease of 4.76 (95% CI, 6.744 to 2.758), p<0.05.

A repeated measures ANOVA was conducted to determine if there was a statistically significant change in allocation between genders. The male participant's scores did not violate the assumption of sphericity, as assessed by a Manuchly's Test of Sphericity $X^2(2)$ =3.425,p=0.180. The method of delivering information elicited statistically significant changes in glance allocation, $F(2,22)=6.529$, p=0.006, partial n^2 =0.372. Post-hoc analysis with a Bonferroni adjustment found that glance allocation decreased from 9.29 (SD=3.6) when navigating with a visual display to 4.45 (S=3.14) when navigating with audio and visual instructions, a statistically significant decrease of 4.847 (95% CI, 7.79 to 1.893), p=0.002.

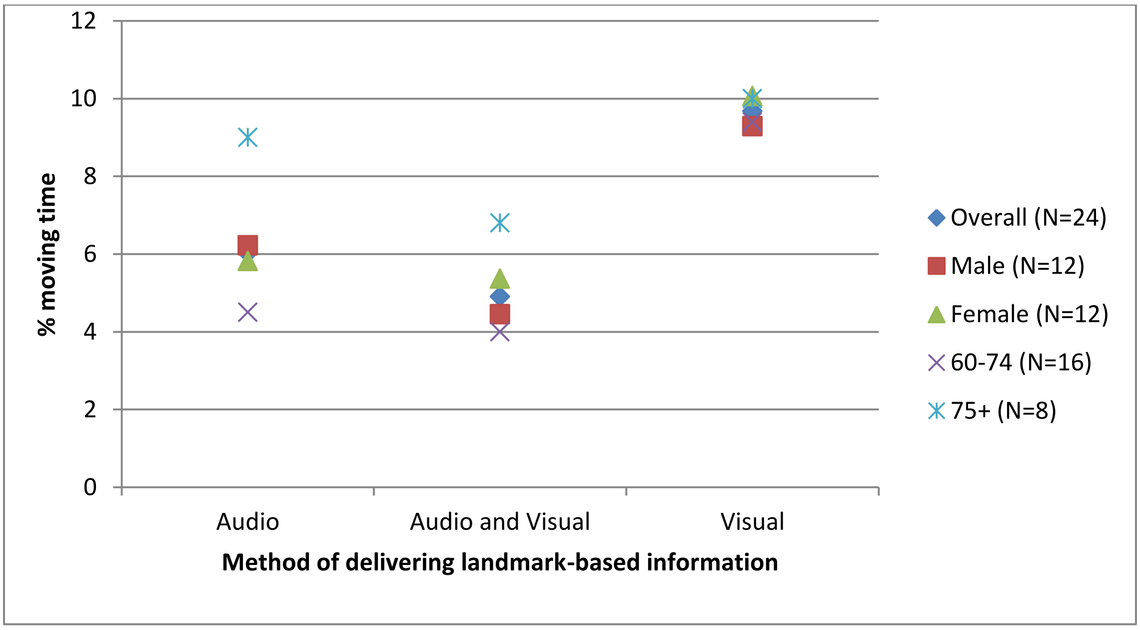


Figure 6.11 Glance allocation of physical landmarks

The female participants scores did not violate the assumption of sphericity, as assessed by a Manuchly's Test of Sphericity $X^2(2)$ =2.696,p=0.260. The method of delivering information elicited statistically significant changes in glance allocation, $F(2,22)=6.271$, p=0.007, partial n^2 =0.363. Post-hoc analysis with a Bonferroni adjustment found that glance allocation decreased from 10.06 (SD=4.33) when navigating with the visual display to 5.37 (SD=3.14) when navigating with the audio and visual display a significant decrease of 4.69 (95% CI 8.06 to 1.31), p=0.007.

There was no statistically significant difference between the genders for each delivery method, as assessed by independent-samples t-tests.

A repeated measures ANOVA was conducted to determine if there was a statistically significant change in allocation for age groups, 60-74 and 75+. There was no statistically significant difference for the 75+ participants. The 60-74 participants' scores had violated the assumption of sphericity, $X^2(2)$=7.178,p=.028, and a correction was applied. The method of delivering information elicited statistically significant changes in glance allocation, $F(1.427,21.411)=14.955$, p=<.05, partial n^2 =0.49. Post-hoc analysis with Bonferroni adjustment found that glance allocation decreased from 9.86 (SD=5) when using the visual display to 4.5 (SD=3) when navigating with audio and visual, a statistically significant decrease of 4.963 (95% CI, 1.78 to 8.748), p=<.05. Glance allocation also statistically significantly decreased from 9.86

(SD=5) when using the visual screen to 4.523 (SD=4) when navigating with audio, a statistically significant decrease of 5.463 (95% CI, 3.2 to 7.7), p=.009.

An independent-samples t-tests found statistically signifcant difference mean glance allocation between 60-74 4.5(SD=3) and 75+ 9(SD=4) when navigating with audio only, -4.51(95%CI-7.7 to -1.2) $t(22)=-2.893$, p=.008

Visual Glance Analysis for Roadside Landmarks: Key findings

- The combination of audio and visual navigational information resulted in the lowest glance frequency and allocation for the older drivers. This means that this combination allowed the drivers to find the roadside landmark with the least impact on visual behaviour.
- The visual glance analysis did not provide any statistically significant difference between the genders.
- Glance allocation and duration was highest for those aged 75 and over. The 75+ participants' allocation and duration scores reduced when provided with audio and visual combination.
- These findings are expanded upon in Section 6.4.2.

6.3.4 Navigational Errors

This section of the results will focus on the navigation errors that were observed by the researcher during each driving scenario. Figure 6.12 illustrates that when the participants followed just the visual display this resulted in the highest number of navigational errors. When the participants navigated themselves with the map it resulted in the second highest number of errors. The number of navigational errors dramatically drops when landmark information is provided through the audio instructions and the combination of the audio and visual display.

A repeated measure ANOVA was conducted to determine whether there were statistical differences in navigational errors over the four forms of information delivery. The assumption of sphericity was violated, as assessed by Mauchly's Test of Sphericity, $X^2(5)=14.850$, p=.011 and a correction applied. Navigational errors observed were statistically different for each delivery method, $F(2.63,76.39)=15.615$, p=<.005, partial $n^2=0.350$. The delivery of information resulted in a decrease of errors from using the map (M=1.56, SD=1.35) to relying on the audio (M=0.46, SD=0.57) and audio and visual (M=0.6, SD=0.62). However, increased for the visual display (M=1.96, SD=1.12). Post-hoc analysis with a Bonferroni adjustment revealed that relying on audio information resulted in a statistically significant decrease in navigation errors from using the map (1.1 (95% CI, 1.823 to 0.377) p=.001) and when using the visual screen (1.5 (95% CI, 2.215 to 0.785) p=.001). Although, not from receiving the information from the combination of audio and visual screen. Additionally, when relying on the audio and visual combination this resulted in statistically significantly fewer navigational errors when compared to using the map (0.967(95% CI, 1.1830 to 0.103) p=.022) and using the visual screen (1.367(95% CI, 2.091 to 0.642) p=.001).

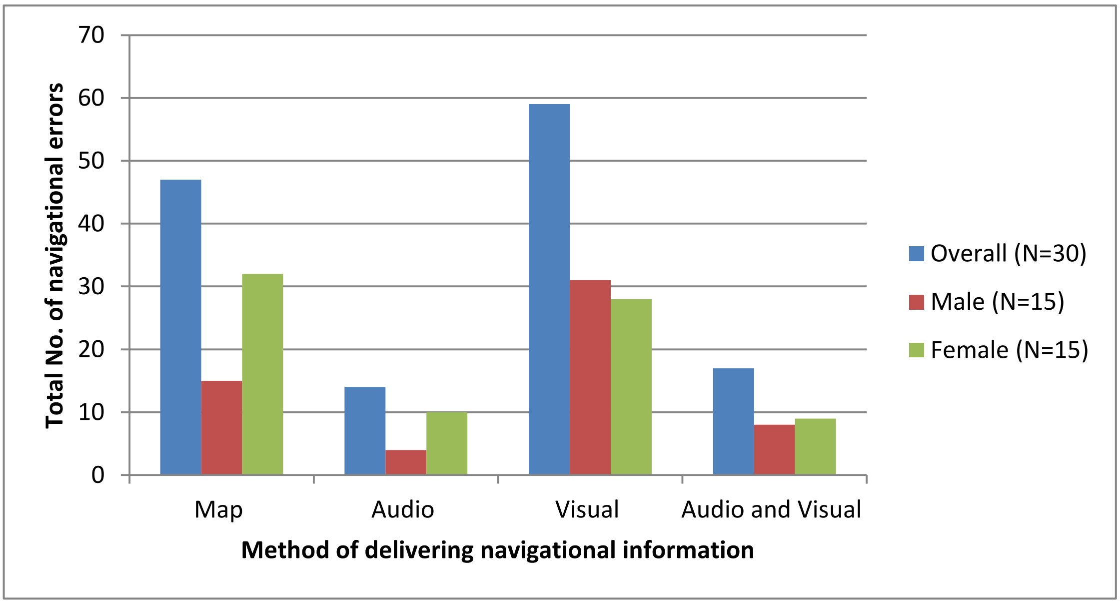


Figure 6.12 Total number of navigation errors made for each method of delivering navigational information

Figure 6.12 illustrates that the female participants incurred more navigational errors for all methods apart from the visual display. The largest difference between the genders occurred when using the map to navigate. Friedman tests were run to determine if there were any statistically significant differences in the number of errors for each method by gender. There were statistically significant differences in the number of navigational errors occurred by the male participants across the four forms of information delivery, $X^2(3)=13.975$, $p=.003$. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. This found statistically significant differences between using the audio (Mdn=0) to visual only (Mdn=2), p=.005.

Also there were statistically significant differences in the number of navigational errors by the female participants across the four forms of information delivery, $X^2(3)=13.338$, p=.004. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. This found statistically significant differences between audio only (Mdn=0) to visual only (Mdn=2), p=.016; and audio only (Mdn=0) to using the map (Mdn=1), p=.028.

An independent-samples t-test was carried out to determine if there were statistically significant differences in the total number of navigational errors in each method between male and females. More navigational errors were made by female participants (2.1, SD=1.5) than male participants (1, SD=0.84) when using the map, a statistical significant difference of -1.13 (95% CI, -1.186 to -2.08), *t(*21.63)=2.48, p=.021.

Navigational Errors: Navigating with a Map Compared to Landmark-Based Information

Figure 6.13 illustrates that more navigational errors were committed when the participants navigated themselves, compared to when relying on the landmark-based information. A paired-samples t-test was used to clarify whether there were statistically significant mean differences between the numbers of navigational errors that occurred between the two forms of navigational information. Participants incurred fewer navigational errors when they used the route guidance information containing landmarks 1.01 (SD=0.37) as opposed to navigating themselves with a map 1.56 (SD=1.35); a statistically significant decrease *t(*29)=2.130, p=.042, d=0.38.

Figure 6.13 shows that when the female participants navigated themselves with the map this resulted in a large increase in errors compared to male participants using the map. Additionally, the number of navigational errors the female participants incurred is lower when they relied on landmark-based route guidance information. The number of errors that male participants incurred remained static between both forms of navigation methods.

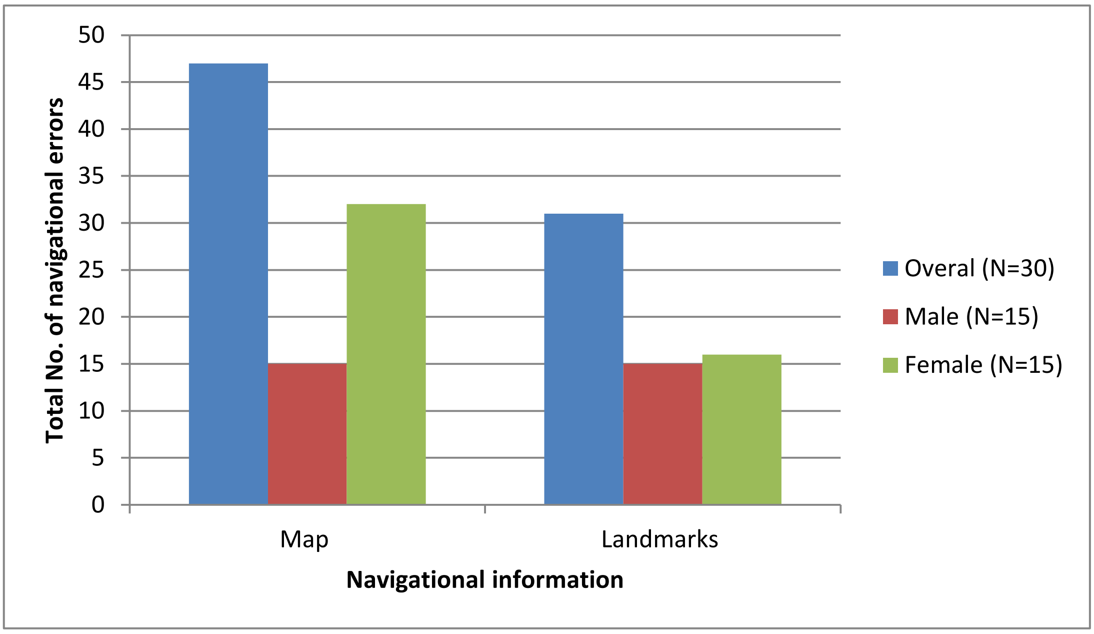


Figure 6.13 Total number of navigation errors from relying on the map or landmark-based information

A paired sampled t-test was used to determine whether there were statistically significant mean differences in navigational errors between using the map and landmark information for the female participants. The female participants using the map to navigate resulted in statistically significant more navigational errors 2.13 (SD=1.55) than when receiving information from the landmark-based route guidance system 1.04 (SD=0.33); a statistically significant decrease *t(*14)2.471,p=.027, d=0.638.

Earlier independent-sample t-test found females would, with statistically significant confidence, make more navigational errors when using the map to navigate than the male participants. An independent-samples t-test between the males and females using landmark information found no statistically significant difference.

Navigational Errors: Key findings

- The number of navigational errors significantly dropped (from 47 to 31) when landmark-based information was provided compared to the map.
- Audio and the combination of audio and visual produced the lowest number of navigational errors.

- Females benefited with statistically significantly confidence when landmark-based route guidance information was provided.
- These findings are expanded upon in Section 6.4.3.

6.3.5 Workload

This section focuses on the results from the NASA-RTLX questionnaire. For the NASA-RTLX each participant rated on six components of perceived workload on a scale from 0 to 100 (mental demand, mental effort, physical demand, time pressure, distraction and stress level). The sum of the component values are divided by six to calculate each participant's overall perceived workload score. A score of 0 is low and a score closer to 100 is high.

Figure 6.14 shows that overall workload was perceived to be highest when using the map (36.9, SD=27.6). The perceived workload was only marginally fewer for the visual screen than the map (36.1, SD=25.5). The lowest perceived workload was reported when the participant received audio navigational information (22.5, SD=16.7). However, the participants only reported the audio and visual information to be just slightly higher at 23.1 (SD=18.5).

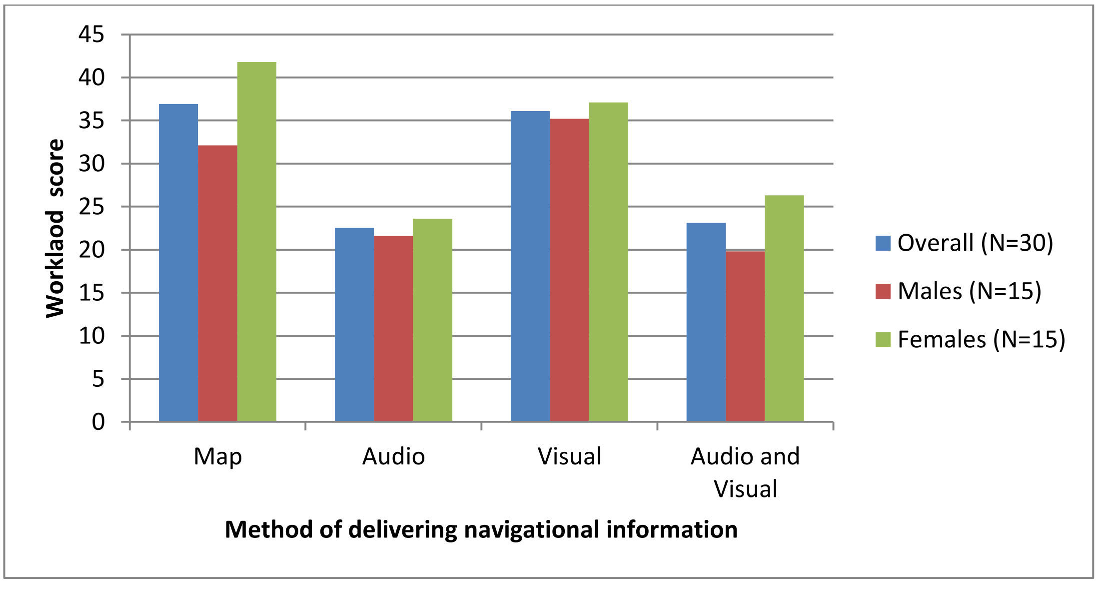


Figure 6.14 Workload scores for the four forms of information delivery

A repeated measures ANOVA was conducted to determine whether there were any statistically significant differences in workload over the four forms of delivering navigational information. The assumption of sphericity was violated, as assessed by Mauchly's Test of Sphericity, $X^2(5) = 75.683$, p = <.001 and a correction was applied. The workload scores were statistically different for the four different route guidance information types delivered, *F(*2.478, 443.515)=42.796, p<.005, partial n^2 =0.193. Post-hoc analysis with a Bonferroni adjustment revealed that workload was statistically significantly decreased from using the map to the audio and to the combination of the audio and visual. The workload scores decreased from 36.9 when using the map to 22.5 when using the audio (14.417 (95% CI, -19.335 to 9.478) p=.001), and to 23.1 when using the audio and visual combination (13.917 (95% CI, -19.347, -8.487) p=.001). There was no statistically significant change in the workload scores between using the map and the visual screen. However, there was statistically significant decrease in workload from receiving information from the visual screen to the audio and combination of audio and visual. The workload score decreased from 36.1 when using the visual screen to 22.5 when using the audio information (13.583 (95% CI, 9.146 to 18.020) p=.001), and to 23.1 when using the audio and visual combination (13.083 (98% CI, 8.769 to 17.398) p=.001).

Table 6.5 displays the overall scores of each component of the NASA-RTLX for the four forms of information delivery. The use of the information delivered by the map and visual screen was rated higher on all workload components in comparisons to audio and audio and visual. In particular, mental demand, mental effort, distraction and stress level were marked considerably higher. The table also shows that the use of the information delivered by the map and visual screen were rated higher on all workload components in comparison to audio information and audio and visual.

	Map (N=30)	Audio (N=30)	Visual (N=30)	Audio and Visual (N=30)
Mental Demand	57	27	46	28
Mental Effort	59	29	50	29
Physical Demand	25	19	23	20
Time Pressure	21	16	23	17
Distraction	26	19	37	20
Stress Level	36	26	33	24
Overall	37	23	36	23

Table 6.5 Mean scores of each component of the NASA-RTLX across all forms of information delivery (plus the mean overall scores)

The mean of the overall perceived workload scores associated with each delivery method by gender are shown in Figure 6.6. The females scored the workload to be higher for each delivery method compared to the male participants. A repeated measure ANOVA test was conducted to determine whether there were significant differences in workload scores for each gender over the four forms of information delivery. Across the male participants the Mauchly's Test of Sphericity indicated that the assumptions had been violated, $X^2(5)=44.889, p=<0.05$ and a correction applied. The workload scores were statistically significantly different for each delivery of information, $F(2.423,215.67)=19.906, p=.001$, partial $n2^2=0.183$. Post-hoc analysis with a Bonferroni adjustment revealed that workload scores were significantly different between:

- Map 32.1 (SD=28) to audio 21.5 (SD=17), a decrease of 10.5 (95% CI, 17.48 to 3.62), p=.001
- Map 32.1 (SD=28) to audio and visual 19.77 (SD=15), a decrease of 12.33 (95% CI, 19.67 to 4.99) p=.001
- Visual screen 35.22 (SD=25.7) to audio 21.5 (SD=17), a decrease of 13.67 (95% CI, 20.90 to 6.42), p=.001
- Visual screen 35.22 (SD=25.7) to audio and visual 19.77 (SD=15), a decrease of 15.44 (95% CI, 22.13 to 8.75), p=.001

The findings from the male repeated measures ANOVA indicated that the audio and the visual and audio combination statistically significantly reduce the workload of the driver. When compared to the visual display and map method of delivering information.

For the female repeated measures ANOVA, the Mauchly's Test of Sphericity indicated that the assumptions had been violated, $X^2(5)=48.124, p=<0.05$ and a correction was applied. The workload scores were statistically significant different for each delivery of information, $F(2.221,197.683)=25.754, p=.001$, partial $n^2=0.224$. Post-hoc analysis with a Bonferroni adjustment revealed that workload scores were statistically significantly different between:

- Map 41.8 (SD=25.8) to audio 23.5 (SD=16.35), a decrease of 18.2 (95% CI, 11.21 to 11.21), p=.001
- Map to 41.8 (SD=25.8) to audio and visual 26.3 (SD=25.4), a decrease of 15.5 (95% CI, 23.691 to 7.309), p=.001

- Visual 37.056 (SD=25.40) to audio 23.556 (SD=16.35), a decrease of 13.5 (95% CI, 18.849 to 8.151), p=.001
- Visual 37.056 (SD=25.4) to audio and visual 26.33 (SD=25.4), a decrease 10.7 (95% CI, 16.288 to 5.156), p=.001

The findings from the female participants echoed that of the males. The audio and the visual and audio combination statistically significantly reduce the perceived workload, in comparison to the visual display and navigating with a map.

Independent-samples t-tests were conducted to compare each method between the genders. Females reported that when using the map (41.8, SD=25.8) it led to higher perceived workload then males (32.1, SD=28.6), a statistical significant difference of 9.72 (95% CI,-1.70 to -17.74), $t(178)=-2.392$, p=.018, d=0.36. The three remaining methods produced no statistically significant difference.

Table 6.6 reports the mean ratings made for the different components of the workload across all forms of information by gender. Table 6.6 corroborates the findings from the analysis above. Females reported higher workload scores for every form of information delivery. The biggest difference between the workload scores was reported when the participants navigated themselves with the map.

	Map		Audio		Visual		Audio and Visual	
	Male (N=30)	Female (N=30)	Male (N=30)	Female (N=30)	Male (N=30)	Female (N=30)	Male (N=30)	Female (N=30)
Mental Demand	47	66	24	29	44	49	25	31
Mental Effort	55	61	28	30	51	50	26	32
Physical Demand	22	28	16	21	22	23	15	24
Time Pressure	20	21	17	15	24	22	16	19
Distraction	25	26	20	18	37	36	17	23
Stress Level	22	49	24	28	34	43	19	29
Overall	32	42	22	24	35	37	20	26

Table 6.6 Mean scores of each component of the NASA-RTLX across the all forms of information delivery and by gender (plus the mean overall scores)

Workload: Navigating with a Map Compared to Landmark-Based Information

Figure 6.15 shows the workload score when the participants used the map was higher than the landmark-based information. A Wilcoxon Signed-Rank test was run to determine if there were statistically difference in the workload scores when the participants navigated themselves with a map to relying on the landmark-based information. There was a statistically significant decrease in perceived workload when participants relied on the landmark information (Mdn = 27) compared to using the map (Mdn = 37), Z=-4.641, p=.001.

Additionally, Figure 6.15 illustrates that the female participants perceived workload was higher than men for both navigating with a map and when relying on landmark information. An earlier Independent-samples t-test found with statistically significant confidence women scored workload to be higher when using the map compared to the males. An independent-samples t-test on the difference between landmark information found no statistically significant differences.

Paired t-tests were undertaken to determine if there were any statistical significant difference between the scores for the male and female participants. For the male participants, four outliers were detected that were more than 1.5 box-lengths from the edge of the box in a boxplot. Inspection of their values did not reveal them to be extreme and therefore were kept in the analysis. The male participants reported higher workload when using the map (32.11, SD=28.6) than landmarks (25, SD=15.3); a statistically significant decrease of 6.6 (95% CI, 2.26 to 10.91) *t(*89)=3.03, p=0.003, d=.032.

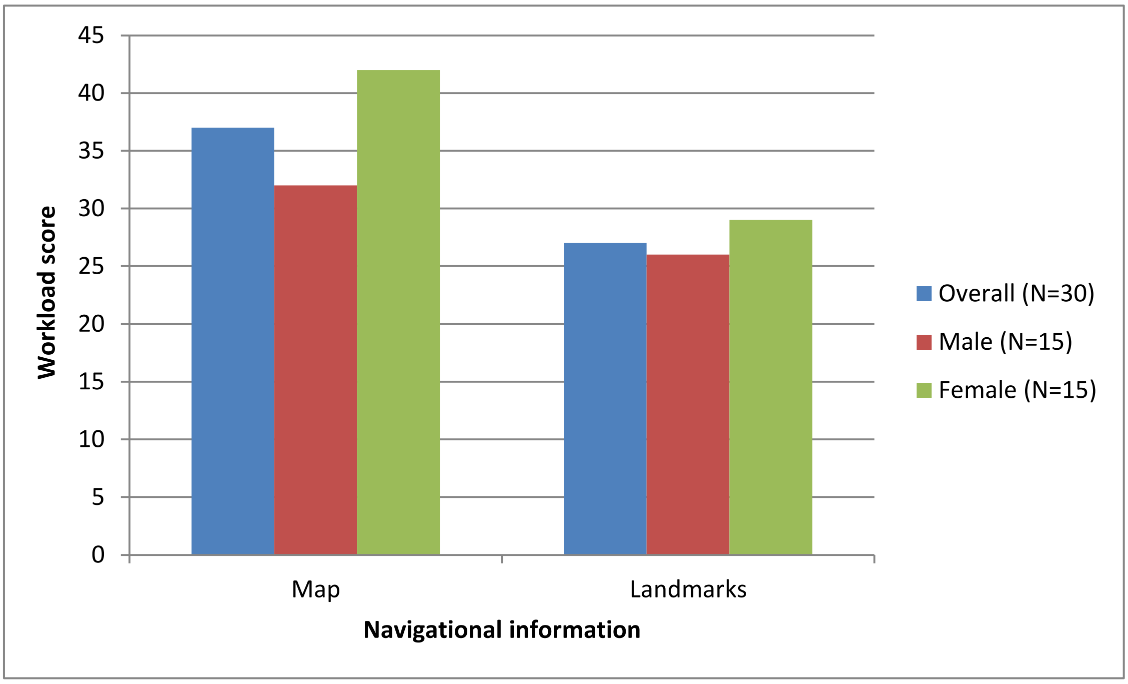


Figure 6.15 Workload scores when navigating with map and landmarks

The female participants reported higher perceived workload when using the map (41.8, SD=25.8) than receiving route guidance information including landmarks (28.9, SD=18.5); a statistically significant decrease of 12.8 (95% CI,-7.64 to -18.05), $t(89)=-4.03$, $p=.001$, $d=0.5$.

Workload: Key findings

- The participants scored their workload to be highest when using the map.
- The workload scores were statistically significantly lower when the navigational information was delivered through audible instructions.
- The females scored their workload when using the map to be statistically significantly higher than the males.
- These findings are expanded upon in Section 6.4.4.

6.3.6 Attitudinal Measurements

After each of the four driving scenario was undertaken, all the participants completed a questionnaire. The questionnaire aimed to assess their attitudes towards each method of delivering navigational information based on the three keys areas of usability: effectiveness, efficiency, and satisfaction (see Section 3.3.1). Table 6.7 provides a breakdown of the responses across the four scenarios. The wording of each question has been shorted for the purposes of presenting the information in one table. The figures in the table refer to the medians and numbers in the brackets are the percentages to which the participants answered ‘7, 6 or 5’ on the scale (7=strongly agree and 1=strongly disagree). Under each form of information delivery the results are divided by the total (T, N=30), males (M, N=15) and females (F, N=15). The table shows a wealth of information but it is important to display it all together as each measurement was taken after each driving scenario. Therefore, it is possible to examine the likely differences according to each method of information delivery. In addition, the questionnaire addressed the participant’s opinion of using the map to navigate, and whether the information was provided with enough time before each turn. These two issues provide clarity to the results overall.

	Map			Audio			Visual			Audio and Visual		
	T	M	F	T	M	F	T	M	F	T	M	F
1) The information was effective at navigating me	6 (83)	7 (93)	6 (73)	7 (97)	7 (100)	7 (93)	6 (87)	6 (87)	6 (87)	7 (93)	7 (87)	7 (100)
2) The information was easy to follow on this journey	5.5 (60)	6 (73)	4 (47)	7 (97)	7 (93)	7 (100)	6 (80)	6 (73)	6 (87)	7 (97)	7 (93)	7 (100)
3) The information made me confident with navigating the journey	6 (80)	6 (87)	6 (73)	7 (94)	7 (100)	7 (100)	6 (77)	6 (93)	6 (73)	7 (93)	7 (93)	7 (100)
4) The information was not a distraction	5 (53)	4 (47)	5 (60)	7 (94)	7 (87)	7 (100)	5 (53)	5 (53)	5 (53)	7 (80)	7 (86)	7 (73)
5) The drive was a fair reflection of my usual performance	5 (70)	5 (80)	5 (60)									
6) I thought the information was provided to me with enough time before each turning				7 (93)	7 (100)	7 (100)	6 (83)	6 (93)	7 (73)	7 (97)	7 (93)	7 (100)
7) I found the landmarks useful when navigating				7 (93)	7 (93)	7 (100)	6.5 (87)	6 (80)	7 (87)	7 (97)	7 (93)	7 (100)

Table 6.7 Breakdown of attitudinal measurements for each driving scenario

Participants Navigating with the Map

The fifth question on Table 6.7 found that 70% of the participants considered their navigational performance in this investigation to be a fair reflection. This provides evidence that the results from the visual glance analysis, workload scores and navigational errors are not biased by the use of a driving simulator or the design of the investigation.

Was the Information Provided in Enough Time Before the Turning?

The audio and audio and visual combined both scored highly, 93.3% and 96.7% respectively. The visual only was scored slightly lower at 83.4%. Nonetheless, the results provide an indication the information was delivered in sufficient time before each manoeuvre. This provides evidence that the timing of the route guidance information did not influence navigational performance.

Effectiveness

The first question in Table 6.7 assessed the effectiveness of the information delivered. In other words, asking the participants if they reached the destination with no navigation difficulties. 96.7% reported the audio landmark information was effective at navigating them; this was followed by audio and visual (93.3%). The visual only was 86.7% and the map considered the least effective from this investigation (83.4%). A Friedman test found the effectiveness scores were statistically significantly different across the four forms of information delivery, $X^2(3)=16.358$, $p=.001$. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. Effectiveness scores were statistically significantly different between using the map and audio (p=.034) and the map and the audio and visual combination (p=0.042). Wilcoxon Signed-Ranks tests were carried out to determine if there were differences in the effectiveness scores by gender. There was statistically significant increase in effectiveness score by females from using the map (Mdn=6) to the audio (Mdn=7), z=55.00,p=.004; and from the map (Mdn=6) to audio and visual (Mdn=7) z=87.0,p=.003. No statistically significant changes were found for the male participants.

Efficiency

The second and fourth questions were aimed at assessing the efficiency of the information delivered. These questions would be complemented by the NASA-RTLX and navigational errors results. By assessing the ease by which the participant could follow the information and whether the method was considered a distraction. The audio and combination of visual and audio were considered the easiest to follow, both scored 96.7% respectively. The visual screen scored 80% whereas the map, where the participants navigated themselves, scored 60%. A similar result was found when analysing the degree to which the participants felt the information delivery was as distraction. The map and visual display was considered not to be a distraction by just over half the participants (53.3%). Whereas audio and visual was considered not be a distraction by 80% of the participants and audio by 93.4%. This shows that there is a divide between the visual demands placed on the driver by the map and visual screen compared to those that include audible instructions. Friedman tests were conducted to assess the efficiency of the delivery method. The Friedman test for the ease of following the information was found to be statistically significantly different between the different methods of delivering the information, $X^2(3)=30.616$, $p=.001$. Post-hoc analysis with pairwise comparisons with a Bonferroni correction for multiple comparisons revealed statistically significant difference in method of delivering information from:

- Map (Mdn=5.5) to audio (Mdn=7), p=.001
- Map (Mdn=5.5) to audio and visual (Mdn=7), p= .001

- Visual (Mdn=6) to the audio (Mdn=7), p=.019
- Visual (Mdn=6) to the audio and visual (Mdn=7), p=.019

A Friedman test found distraction scores were statistically significantly different during the four methods of delivering the information, $X^2(3)=27.996$, p=.001. Post-hoc analysis with a Bonferroni correction for multiple comparisons found statistically significantly difference in distraction scores from:

- Map (Mdn= 5) to audio (Mdn= 7), p=.002
- Map (Mdn= 5) to audio and visual (Mdn=7), p=.007
- Visual display (Mdn=5) to audio (Mdn= 7), p=.007
- Visual display (Mdn=5) to audio and visual (Mdn=7), p=.022

Satisfaction

The satisfaction with the method of delivering the information will affect users' opinion on the method and appropriateness of this approach. This was assessed by the third and seventh questions. The audio and the visual and audio combination both tied as the method that provided the greatest level of confidence (both 93.3%, respectively). The visual information produced the lowest confidence scoring (76.7%), and the map scored slightly higher with 80%. The visual display and map both required the participant to take their eyes away from the road and this has influenced the result. A Friedman test revealed statistically significant difference in the scores across the four methods of delivering information, $X^2(3)=17.273$,p=.001. Post-hoc analysis found statistically significant difference in distraction scores from:

- Map (Mdn=6) to audio (Mdn= 7), z=2.760,p=.006
- Map (Mdn=6) to audio and visual (Mdn=7), z=2.637,p=.008
- Visual display (Mdn=6) to audio (Mdn= 7),z=-2.945 p=.003
- Visual display (Mdn=6) to audio and visual (Mdn=7),z=-3.062 p=.002

The seventh question aimed to examine if the participants found satisfaction in the landmarks being delivered to them through each of the three methods. The audio and visual method was found to be the most useful form of delivering landmarks (96.7%), followed by audio (93.4) then visual (86.6). A Friedman test revealed statistically significant difference in the scores across the four methods of delivering information, $X^2(2)=9.593$, p=.008. Post-hoc analysis found statistically significant difference in distraction scores for audio (Mdn=7) to visual (Mdn= 7), z=-2.038,p=.042, but no other statistically significant changes were found.

Attitudinal Measurements: Navigating with a Map Compared to Landmark-Based Information

Table 6.8 displays the results from the four questions that can compare navigating with the map to the landmark-based information. The wording of the questions have been shortened for the purpose of presenting the information in one summary table. The figures refer to the medians and numbers in the brackets are the percentages of participants that answered ‘7,6 or 5’ on the scale (7=strongly agree and 1=strongly disagree). Under each form of information delivery the results are divided by the total (T, N=30), males (M, N=15) and females (F, N=15).

	Map			Landmarks		
	T	M	F	T	M	F
The information was effective at navigating me	6 (83)	7 (93)	6 (73)	7 (97)	6 (93)	7 (100)
The information was easy to follow on this journey	5.5 (60)	6 (73)	4 (47)	6 (97)	6 (93)	6 (93)
The information made me confident with navigating the journey	6 (80)	6 (87)	6 (73)	6 (90)	6 (87)	6 (93)
The information was not a distraction	5 (53)	4 (47)	5 (60)	6 (83)	6 (87)	6 (80)

Table 6.8 Breakdown of attitudinal measurements between using the map to navigate and landmark-based route guidance information

This question again provides additional correlations to other methods of data collection and covers the three key areas of usability. Statistically significantly difference between the genders are presented where appropriate

Effectiveness

The landmarks scored 96.7% compared to 83.4% for the map when the participants rated the effectiveness. A Wilcoxon Signed-Ranks test was run to determine if there were differences in the effectiveness scores when the participants using the map to navigate compared the landmark information. There was a significant increase in the effectiveness score when the participants followed the landmark information (Mdn=7) compared to the map

(Mdn=6),z=2.055, p=.040. Wilcoxon Signed-Rank tests were run to determine if there were differences for males and females for effectiveness scores. There were statistically significant increases in scores for females using the map (Mdn=6) compared to using landmarks (Mdn=7), z=2.395,p=.017. No statistically significant change was found for the male participants.

Efficiency

The second and fourth question aimed to assess the efficiency of the navigational approach. The landmark information was rated easier to follow (96.7%) than the map (60%). A Wilcoxon Signed-Ranks test was carried out to determine if there were differences in the efficiency scores when the participants are using the map to navigate compared to the landmark information. There was a statistically significant increase in the effectiveness score when the participants followed the landmark information (Mdn=6) compared to the map (Mdn=5.5),z=2.96, p=.003. Wilcoxon Signed-Rank tests were carried out to determine if there were differences for males and females for the ease of following and distraction scores. There were statistically significant increases in the ease of following scores:

- Males found it easier to follow the route from the map (Mdn=6) than females did (Mdn=4),z=-2.060,p=.039
- Females found is easier to follow the landmarks (Mdn=6) than following the map (Mdn=4),z=3.110,p=.002

The landmark information was scored not as a distraction by 83.4% compared to 53.3% for the map. A Wilcoxon Signed-Ranks was carried out to determine if there were differences in the distraction scores when the participants navigated with the map compared to landmark-based information. There was a statistically significant increase in the method not being a distraction when the participants followed the landmark information (Mdn=6) compared to the map (Mdn=5),z=2.809, p=.005. Males also found the use of landmarks less of a distraction (Mdn=6) than using the map (Mdn=4), z=2.75,p=0.006.

Satisfaction

The landmarks scored a higher rating for confidence (90%) than the use of the map (80%). A Wilcoxon Signed-Ranks test was run to determine if there were differences in the confidence scores when the participants using the map to navigate compared the landmark information. There was no significant change in the confidence scores between the map (Mdn=6) and landmarks (Mdn=6), $z=1.668$, $p=.095$. Multiple Wilcoxon Signed-Rank tests were run to determine if there were differences for males and females the confidence scores. There were statistically significant increases in female's confidence from using the map (Mdn=6) to using the landmarks (Mdn=6),$z=2.046$,$p=0.041$.

Attitudinal Measurements: Key findings

- The use of landmarks in the route guidance information statistically significantly outscored the paper map.
- Audio and the combination of audio and visual display were rated statistically significantly greater than the visual screen for all the attitudinal measurements.
- Female participants perceived a greater benefit in the use of the landmarks than the male participants.
- These findings will be expanded upon in the discussion Section 6.4.5.

6.3.7 Post-Investigation

After the final driving scenario, the participants completed a final questionnaire and a short face-to-face semi-structured interview (see Section 3.4.3 for more details). The aim of this was to identify the opinions of the use of landmarks within the route guidance information. The results of the questionnaire and interview are presented together. The results report the preferred method of information delivery, use of landmarks in the route guidance information, and the benefit of providing landmark-based information. Significant statistical differences between the genders are presented where appropriate.

Preferred Method of Delivering Route Guidance Information

The post-investigation questionnaire attempted to identify the participant's preferred method of information delivery. The participants ranked (from 1=best to 4=worst) the four forms of navigational information delivery. Figure 6.16 illustrates the ranking results across the four forms of navigational information. The results show that there is a clear divide between the reported best and worst forms of information delivery. Audio only was the most preferred method of information (46% of participants), followed closely by audio and visual information (40% of participants). In comparison, half of the participants considered the use of the map (50%) to be the worst form of information delivery. This was closely followed the visual screen (40%). The visual screen was ranked in the bottom two on the scale by 40% of the participants, 38% ranked the map in the bottom two. This clearly shows in this investigation that the visual screen on its own was not considered an appropriate method of delivering information. In contrast the audio and visual screen was chosen in the top two methods by 40% of people, audio was chosen in the top two by 38%. This highlights that the participants preferred the audio information and found the combination of audio with the visual display to be beneficial to them. No discernible difference can be found between the male and female participants.

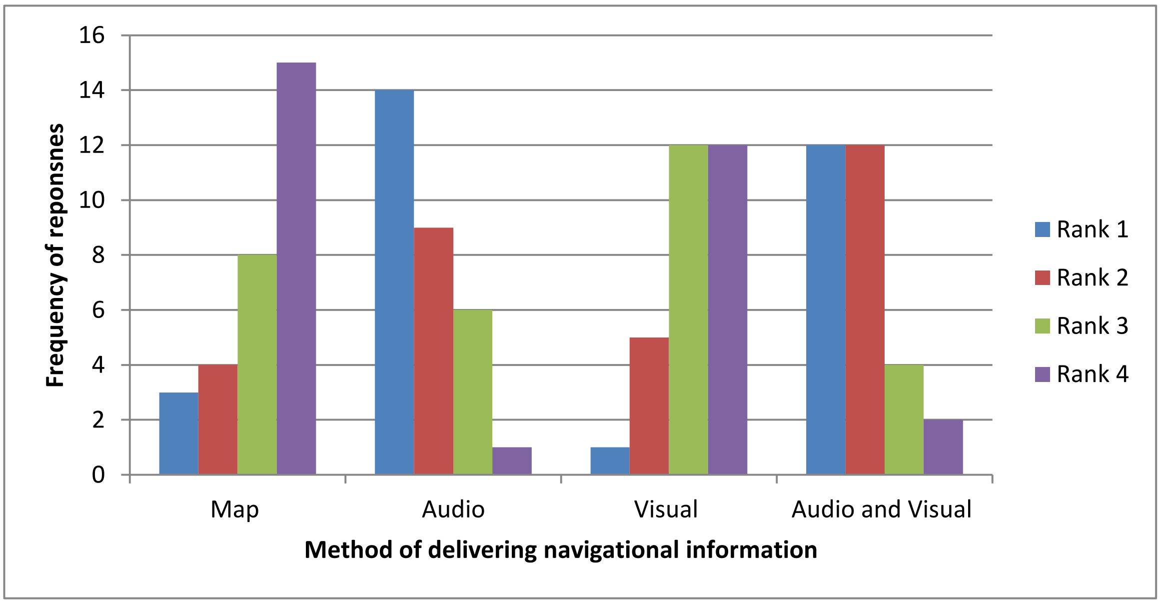


Figure 6.16 Ranking of delivery of method navigational

The interview produced findings that confirmed the results from post-investigation questionnaire. The participants felt that audio information provided clear and concise instructions that made it relatively easy to follow. They also found the visual screen to be of benefit in locating the turning. The visual display provided added confirmation that they understood the audio instructions. However, the visual screen on its own was not found to be beneficial. As they felt they spent too long looking at the display.

Use of Landmarks in the Route Guidance Information

Table 6.9 outlines the participants' responses to four questions in the post-investigation questionnaire. These questions aimed at assessing the participant's opinion towards the use of landmarks within route guidance information. The figures refer to the median score, and in the brackets the percentage of participants who responded '7, 6 or 5' from a 7-point scale (where 7=very good, and 1= very bad). The results are shown overall and by gender. The results demonstrate that, overall, the use of landmarks in the route guidance information was well received. Only 10% of the participants considered the use of landmarks to not be at least 'good'. In addition, there was a difference in the perceived 'goodness' of providing the information through audio and visual modalities. Providing route guidance information from just the visual screen was found to be scoring lower than all other forms of delivering the information.

	Total (N=30)	Male (N=15)	Female (N=15)
How did you rate the use of landmarks within the navigation information	7 (90)	6 (80)	7 (100)
How did you rate the use of landmarks within the visual navigation information	6 (83)	6 (67)	6 (100)
How did you rate the use of landmarks within the audio information	7 (97)	7 (93)	7 (100)
How did you rate the use of landmarks within the audio and visual information	7(97)	7(93)	7(100)

Table 6.9 Results from four attitudinal measurements

Although not statistically significant from the questionnaire responses, there was a differing of enthusiasm of the use of landmarks in the route guidance information. 100% of the female participants thought the use of landmarks within the navigation information was at least 'good'. Whereas 66.7% males thought it was at least 'good'. The interview further investigated this and found that the females were more open to the use of landmarks in route guidance compared to the males, who were keener on the map with the notes method.

Benefit of Providing Landmark-Based Route Guidance Information

A section of the post-investigation questionnaire was aimed at understanding the potential benefits of an IVNS that included landmarks within the route guidance information. Additionally, the participants were asked to consider the driving behaviour without assistance in the car navigation task. Table 6.10 shows that the results overall and by gender. The figures refer to the median score, and in the brackets the percentage of participants who responded '7, 6 or 5' from a 7-point scale (where 7= strongly agree, and 1=strongly disagree).

	Total (N=30)	Male (N=15)	Female (N=15)
Without help with car navigation I will start to drive less	3 (20)	3 (0)	4 (40)
Without help with car navigation I will start to drive less to unfamiliar locations	4 (30)	3 (13)	4 (47)
I found the use of landmarks of benefit to my navigation	7 (87)	6 (80)	7 (93)
I would like to use a navigation system that uses landmarks in my car	5 (57)	5 (53)	5 (60)
I would travel more to unfamiliar journeys if I was navigated by landmarks	4 (43)	4 (41)	4 (47)

Table 6.10 Responses to attitudinal measurements after the investigation

20% of the participants felt that without assistance in navigating they will start to drive less, and all of those were women. A relatively small number, yet it is still six of the 30 participants highlighting that they see navigating as a major issue in their mobility. Although no statistically significant difference could be found, as assessed by a Mann Whitney test, it seems that without proper navigational support it is older female drivers that will be most affected by increasing difficulties in navigating.

29.9% of the participants felt that without help in car navigation they would start to drive less to unfamiliar locations. These participants have suggested that they have identified navigation as an obstacle to accessing unfamiliar locations. From this sample, females were found to have identified navigation as an on-going issue.

The interview produced similar results, in that, it indicated that as the female participants were more open to the difficulties they face with navigation, compared to the male participants. The female participants highlighted the anxiety of navigation had made them consider whether the journey was actually necessary. This potentially removes the spontaneity of travel that access to a private car can provide to older drivers.

The final three questions tried to examine the potential advantages of including landmarks in the route guidance information. 86.7% of participants felt the use of landmarks to be of benefit to their navigation. This was higher for females (93.3%) than for males (80%). Over half of the participants (56.7%) felt that they would like to use an IVNS that used landmark information. Additionally, 43.3%

felt that they would make more unfamiliar journeys if landmarks were used in IVNS. This was higher for female participants (46.7%) than for than the men (39.9%). The post-investigation interview again found similar findings. As the female participants felt that using landmarks in the route guidance information would provide them with added confidence on a journey, there was a degree of consistency with the fact they also indicated the increased potential for them to travel on their own on an unfamiliar journey.

Post-Investigation: Key Findings

- Participants would receive benefit in using landmarks in the route guidance information to help them navigate.
- Audio and visual in combination and audio were the preferred method of delivering landmark information.
- The female participants are particularly keen to have an IVNS that provided landmark-based information.
- These findings are expanded upon in Section 6.4.6.

6.4 Discussion

This section will discuss the findings from each data collection method in turn. The chapter will then draw conclusions in Section 6.5.

6.4.1 Pre-Investigation Questionnaire

The participants' navigational behaviour reflected that of the volunteers in the first two investigations in this study. The majority of their driving was on familiar roads. The pre-investigation questionnaire reviewed also their perceived current map reading abilities. Overall, the participants rated their map reading ability highly. The findings in Chapter 4 and 5 found that older adults are proud of their map-reading ability. Even to the point of being critical of younger generations' lack-of map-reading abilities and preference for technology. This is complementary to view that drivers' perceive maps to be a useful navigation tool (Bryden *et al.*, 2013). This is despite maps being found to not be the most effective and efficient method of navigation (Streeter and Vitello, 1986; Petchenik, 1989; Dingus *et al.,* 1997). Dingus *et al*. (1997) found that when older drivers navigate with a map there are significant safety concerns highlighting the increase in visual demand and lane positioning deviations that navigating with a map places on older drivers. Although their safety performance was not assessed in this investigation, because this stage of the research used a driving simulator, their navigation performance did suffer when using the map compared to the landmark-based route guidance information. This will be discussed further in Section 6.4.3. In addition, the male participants did rate their map reading ability higher than the females, although no statistical significance could be found. Males have been found to rate their navigational ability higher than females (Cutmore *et al.*, 2000; Turano *et al.*, 2009). This pre-investigation questionnaire provided the first indication of a potential gender difference within navigation behaviour and preference for route guidance information in the investigation.

6.4.2 Visual Glance Behaviour

Landmark-based Route Guidance Information and the Map

The visual glance analysis found that participants would make five times more glances towards the visual display than the map. Clearly, this number of glances is far too high when compared to the use of a traditional map in this investigation. Even when the participants navigated with the visual display and audio information in combination, they made more glances to the visual display. However, the participants planned their map-based journey before driving on the simulator and this trip generally only involved four turnings. Therefore, the participants were perhaps not sufficiently tasked with relying on the map and their written instructions as expected. This was the result of the limitations a driving simulator placed on the investigation (see Section 3.3.2). In contrast the participants were 100% reliant on the landmark-based information provided *en route* rather than pre-planned information. Thus, the participants had no option but to frequently glance at the visual display to seek navigational information. This would naturally result in a higher glance frequency compared to the map.

Although the participants did glance at the visual display more times than the map, they had higher glance duration towards the map; meaning that it took the participants longer to comprehend the information from the map then visual display on its own and in combination with audio instructions. Rockwell (1988) proposed that drivers should not take their eyes off the road for longer than 2 seconds. The highest mean duration for the participant was recorded when they used the map (0.63 seconds) despite the limitations of task complexity highlighted above. The use of the map was found to have significantly lower percentage of time spent glancing while in motion than the visual display. This statistically would suggest, again, that the use of a visual screen on its own increases the visual demand on the driver. This is not a surprising finding in itself. Previous research has found the visual displays incur a greater visual demand on the driver, especially older drivers (Liu, 2001; Birrell and Young, 2011).

The icon-based display and audio landmark information was found to have lower glance durations (0.52 seconds) than similar studies that examined a moving-map based display and distance-to-turn information. In a simulator study where older drivers drove with an IVNS, Zhang *et al*. (2012) reported a mean glance duration of just over a second (1.38). An on-the-road trial found older drivers' mean glance duration towards a moving map display to be 1.08 seconds (May *et al.,* 2005). Further investigation is required to assess the benefits of an icon-based display compared to a moving map display for older adults.

The result from the visual analysis provides a strong indication of the level of demand each method of navigational information places on the driver. The combination of audio and a visual display resulted in the least visually demanding delivery. This approach scored the lowest percentage moving time, the lowest glance duration scores and the second lowest mean glance frequency. In comparison, the visual display on its own resulted in a high visual demand towards the participants. The findings are consistent with previous research, as the in-vehicle display was found to increase visual demand (Liu, 2000; Liu, 2001; Birrell and Young, 2011; Kim *et al.,* 2011), although this is one of the few investigations that have solely focused on older drivers.

The analysis found that there was a higher glance frequency towards the map then the landmark information. The participants not only glanced more frequently to the visual landmark information but also were observed having a higher percentage spent looking towards the display when driving. This seems to suggest that the visual demand was higher for the visual landmark information than the map. Although, the previous concerns with the task complexity the map provided should be considered. The participants however did glance for longer at the map then the visual landmark-based information. This indicates that the participants were required to glance longer at the map to obtain the required information than for the visual landmark information.

Furthermore, the visual glance behaviour highlighted the potential difference between males and females in the visual demand through the different forms of delivering navigational information. Although no statistically significant difference could be consistently found across the visual demand analysis, the indications in the data seem to suggest that there are potential differences. For example, the female participants glanced more frequently to the map, visual display and display when combined with audio than the males. The findings support the view that there are spatial navigational abilities and visual capability differences between the genders (Cutmore *et al.,* 2000; Lin and Chen, 2013).

Additionally, visual glance analysis for duration and allocation for two age groups, 60-74 and 75+, found that there are potential age differences. The 75+ participants' duration scores were significantly higher for glance duration when navigating with a map. The 75+ age groups' scores were significantly reduced when provided with the audio and visual combination. The difference in the visual glance analysis for the older age group provides evidence of the need for way-finding support.

Visual Glance Analysis of Landmarks on the Roadside

The analysis of the participants' visual behaviour found that delivering landmark-based route guidance through the combination of audio and visual information resulted in the least impact to the drivers' visual behaviour. The combination of audio and visual resulted in an average 1.5 glances at a landmark for each manoeuvre. This was statistically significantly fewer compared to the information provided by only the visual display (3.1) and audio information (2.8). The glance duration was the lowest for the combination, although not statistically significantly. In addition, the glance allocation was statistically significantly lower than the visual display. The overall results were repeated for the genders and age groups.

The results provide an indication that providing landmark-based route guidance information does not adversely affect older drivers' visual behaviour if the information is delivered through a combination of audio and visual instructions. The participant's glance frequency, duration and allocation were all greater when they were navigated with just the visual display.

6.4.3 Navigational Errors

Just over 60% of all the navigational errors resulted when the participants used the map to navigate themselves. The participants were statistically significantly more likely to commit a navigational error when navigating with the map rather than the landmark information. This is a significant finding given that each participant only had to plan a journey of four turnings. When investigating the possible reason why this occurred the gender analysis provided clarity. The female participants produced a significantly higher number of navigation errors when using the map than male participants. Lawton (1994) found that women are more likely to focus on route strategy and learn the journey. In this instance, this strategy was not effective in allowing them to navigate the unfamiliar route. Males have been found to perform better than females in map based tests (Henrie *et al.,* 1997) and have higher spatial abilities than females (Voyer *et al.,* 1995). The results from this map task found that males performed significantly better than females. However, the number of navigational errors that the female participants received when provided with landmarks significantly drop. In fact, the females' errors reduce by over half. Whereas, the male participant's navigational errors remained static between the map and landmark information. This does provide some support to Cutmore *et al*. (2000) hypothesis that females would benefit most from route learning cues, such as landmarks.

When examining the method of delivering navigational information to older drivers then the visual only information produced the highest number of navigational errors. In comparison, the participants were just under six times more likely to commit a navigational error with visual display compared to audio and visual combination. Providing information through only the auditory modality also scored significantly lower navigational errors than the visual screen. The benefit of receiving information from audio only and audio combined with a visual display has been found in the literature (Green, 1993; Liu, 2001; Hölscher *et al.,* 2011).

The examination of the differences between the genders found males produced slightly more navigational errors (31 to 28) then females when using the visual display. This is surprising, as males are considered to have a greater visual capacity than females (Lin and Chen, 2013). This may have been a result of the male drivers ignoring the visual display, given their greater dislike for the visual display than the female participants. The male participants, however, produced lower errors with all other forms of navigational information. Females scored the lowest number errors with the combination of audio and visual screens whereas males scored the lowest with audio only. The findings from the males and females followed that of the overall score. The visual display and map resulted in a greater number of navigational errors when compared to when the information was provided through audio and the audio and visual combination.

The analysis of the navigational errors found that the use of landmark-based route guidance information produced significantly lower number of errors compared to the map. As the map is the traditional method of navigating an unfamiliar journey this is significant. Previous research has found that when ‘good’ landmarks are used they can improve navigational performance compared to ‘poor’ landmarks (May and Ross, 2006). This investigation has found that the use of ‘good’ landmarks produced significantly less navigational errors than a printed map. Furthermore, the female participants produced significantly more navigational errors when using the map then the males. Given that the map based task was short and relatively ‘easy’ (four turnings) this result is even more compelling.

6.4.4 Workload

On average, according to the NASA-RTLX scale, the participants’ rated their workload to be highest when navigating themselves with the map. Female participants produced higher workload scores for both the map and landmark information than the males. In fact, females significantly scored their workload higher for the map than the males. However, both male and female’s workload scores significantly decreased when relying on landmark-based information compared to the map.

The map and visual display scored the highest out of the four forms of information delivery. In comparison, the audio only and audio and visual scores were significantly lower. This insight provides a clear distinction on how the information should be presented. The visual only display resulted in significant issues in visual glance behaviour, navigation errors and workload.

The individual scores on the NASA-RTLX (see Table 6.8) found that drivers rated their mental demand to be highest when using the map to navigate. The lowest score was recorded when the participants used the audio information (mean of 56.5 versus 26.5 for the map). When the participants used the visual screen to navigate, this also resulted in a high mental demand score (46.3) compared to audio only (26.5) and audio and visual (28.2). The findings suggest that the use of a traditional map does incur high levels of mental demand. Moreover, the audio modality is significantly lower than with the map or visual screen. When the audio is delivered in combination with visual screen then the mental demand is only slightly higher.

When considering the use of landmark information compared to the traditional map, then the landmark information was rated lower (33.7) than the map (56.5).This is a particularly key result when considering the high rated ability in map reading found in the pre-investigation questionnaire. In the simulator investigation the use of a road map was found to incur significant mental demand. Compared to this, when the participants received landmark-based route guidance it scored lower than the map. This may be a result of the prominence of landmarks within people's own cognitive maps. The use of landmarks has been highlighted in this study (Chapter 5) and in previous research to play a crucial role in formulating cognitive maps and for day-to-day directions (Lynch, 1960; Daimon *et al.,* 2000; Burnett *et al.,* 2001; May and Ross, 2006). Therefore, it would seem that the day-to-day use of landmarks makes them familiar and a good form of navigational information to deliver to older drivers.

The mental effort scores provide an indication of the concentration required during the course of the journey. The use of the map produced the greatest mental effort score (58.2), aggregated landmark score was considerably lower (36.1). Therefore, it would appear the use of landmarks did not require a great deal of concentration from the drivers. This can be a direct result of the landmarks chosen to already be considered 'good'. Given the results of May and Ross (2006) research that if ‘poor’ landmarks were used the score would have considerably closer to the map. When considering the method of delivering landmark-based route guidance information then the audio (29) and audio and visual (29.2) scored considerably lower than the visual method (50.3). The use of the audio and audio and visual would therefore provide the lowest level of workload demand for the driver. A significant benefit as driving has been found to become difficult as you age.

The scores from the mental demand and effort provide evidence that the use of landmarks is beneficial to older drivers. Their scores are significantly lower than the use of a printed road map. The possible concerns over drivers being forced to the search and locate landmarks from the roadside have been disproven. The distraction scores for landmark information (25.3) are marginally lower than for the map (25.8). The landmark information from the audio (19.2) and audio and visual combination (20.2) both scored lower than the map. This would suggest that the visual display (36.7) is a significant distraction. Yet when provided with audio then the distraction to the driver is dramatically reduced.

The findings from the NASA-RTLX provide a clear indication that landmark-based information results in lower workload scores (27) compared to the map (37). This provides clear evidence to the benefits to using landmarks within route guidance information. Additionally, the audio only or the combination of audio and visual information provides significantly lower workload scores compared to visual information.

6.4.5 Attitudinal Measurements

An attitudinal measurements questionnaire was administered after each scenario. The questions aimed to address different elements of usability. The results found that the landmarks were considered to be usable in the route guidance information compared to a map; and the audio and audio and visual combinations once again scored significantly high for the most effective method of delivering landmark information.

When considering the comparison between using a map or landmark-based information to navigate, the results found no statistically significant difference. The landmark-based information did score higher but not significantly so. Given the relatively short drives for each scenario this could perhaps be expected. Furthermore, drivers consider maps an effective method of navigation even if research suggests otherwise. The participants, additionally, scored the landmarks satisfaction higher than the map, although not statistically significantly. Again, this can be considered a reflection of the comfort of knowing the map against the unfamiliar delivery of landmark information. The participants however did consider the landmarks to be significantly more efficient at navigating them than the map. This is surprising given how highly they rated themselves at map reading in the pre-investigation questionnaire. The map was also considered to be of a greater distraction to them than the landmark information in the NASA-RTLX and post-investigation questionnaire.

The results from each method of delivering route guidance information found audio and visual and audio combination to score the highest. The map actually scored the lowest from the four forms of delivering information. Given the high scores of maps as a navigation tool this may be a reflection of the quality of the map provided, although this remains unclear. In terms of satisfaction, then the audio and audio and visual combination was statistically significantly found to provide more satisfaction than the map or visual screen. There was no statistically significant difference between the audio and visual and audio combination.

6.4.6 Post-Investigation

The post-investigation data consisted of a questionnaire and a short face-to-face semi structured interview. The results follow the findings from the other data collection methods. The audio and audio and visual combination scored highly. The participants reported the preference for the audio information and of receiving increased confidence with the landmarks in the visual screen. Yet the visual display on its own and map scored poorly.

One of the key findings from this stage was the gender difference in navigation behaviour. Only a small percentage (13%) of male participants highlighted any perceived future difficulties with navigation. In comparison, 40% of female participants suggested they would start to drive less without assistance with navigation. Additionally 46% of females suggested that without navigation assistance they will start to driver less to unfamiliar locations, a process of self-regulation that can lead to early driving cessation. Previous research has shown that gender can affect navigation behaviour. Women, both young and old, have been found to have increased anxiety over navigating journeys (Ragland *et al.,* 2004), and actively avoid travelling on unfamiliar journeys (Peel *et al.,* 1995; Turano *et al.,* 2009). The findings from the post-investigation interview and questionnaire therefore can be seen as significant. The female participants in this investigation are aware of the difficulties they face with navigation and feel that assistance is required.

When considering whether landmark-based route guidance information can provide that assistance. All of the females positively rated the use of landmarks overall and in each delivery method. The female's participants therefore perceived the use of landmarks as a great method to navigate them. Overall, nearly all the participants found some benefit from the provision of landmarks. Goodman *et al*. (2004) found that landmarks are of benefit to older people when navigating on foot. This investigation has provided further evidence to the need for inclusion of landmarks within car based route guidance information.

6.5 Conclusions

This investigation aimed to examine three areas. Firstly landmark-based information was compared to the traditional paper road map for navigation on a car journey. This driving simulator investigation has found significant benefits to providing landmark-based information compared to the traditional map. The landmark-based information resulted in workload being perceived to be lower (27) than when using the printed map (37). Moreover, the use of landmarks in the route guidance information resulted in a lower total number of navigational errors (31) compared to when using the traditional road map (47). In addition, the participants rated highly their preference to the use of landmarks during and after the simulator investigation. This suggests that the use of landmark-based information was found to be more efficient at navigating to older drivers.

However, the landmarks based visual display did incur more glances (33) than the map (18) and a greater glance allocation to the display when the vehicle was in motion. This result taken in isolation would seem to suggest that the visual display resulted in a high visual demand for the driver. Yet when the participants relied on the paper map to navigate, their glance duration was higher (0.63 seconds) compared to the landmark-based information (0.53 seconds). Neither method resulted in the driver removing their eyes from the road for a significantly dangerous period of time, based on the Rockwell (1988) 2 second rule.

Secondly, this investigation aimed to assess the most effective method of delivering landmark-based route guidance information to older drivers. The findings appear to suggest that the combination of an audio and visual display provided the most beneficial method to older drivers, through the parameters measured and observed below:

- Lowest visual demand scores;
    - fewest number of glances (21 compared to 45 for the visual display on its own)
    - lowest glance duration (0.52 seconds compared to the visual display 0.56 seconds and map 0.63 seconds)
- Significantly fewer total number of navigation errors (17 compared to the map 47 and visual display 59);
- Least impact on the participants' visual behaviour when searching for the landmark (lowest mean glance frequency, duration and allocation towards a landmark for a manoeuvre); and
- Low workload score (23.1 compared to the map and visual display 36.9 and 36.1, respectively).

Finally, this investigation aimed to examine any potential gender difference with the use landmark-based route guidance information. It is important to note that all the participants navigated more efficiently from the landmark-based route guidance compared to the road map. However, the findings appear to suggest that there are gender differences. The female participants received more benefit from the use of landmarks than the males. Their workload scores reduced significantly from using the map to landmark information. When examining the total number of navigational errors for each method then the female participants' dramatically reduced their errors when navigating with landmarks (16) compared to using a map (32). In comparison, the male participants' errors remain the same (15) for both methods. Landmark navigational information was particularly found to be effective by females within the attitudinal measurements. Therefore, it would seem that it is with the perceived benefit that the greatest differences are apparent. The females highlighted the greater navigational concerns with future navigational needs and clearly indicated that landmarks were a much more effective method to navigate them. Whereas the male participants overall did not suggest any future difficulties with navigation, or that landmarks were particularly of benefit to them. Consequently, older female drivers may gain more from the inclusion of landmarks than males. This may have implications for the future use and design of IVNS. The design of the next generation of IVNS is outlined in the next chapter.

Chapter 7. Recommendations for an IVNS More Suited to Older Drivers Needs

7.1 Recommendations

This study has identified and highlighted that older drivers have difficulties with the pre-trip planning and way-finding stages of car navigation. There are statistically significant usability issues with current IVNS, and it has been found that landmark-based route guidance information is effective at navigating older drivers. Within the scope of the aims and objectives, this thesis never intended to build a prototype IVNS. However, this chapter suggests recommendations for the design of a future IVNS that is specifically considered for older drivers, to complete the learning process by using the data and knowledge gathered in this research programme. The majority of recommendations would be relatively easy and cost effective to incorporate in a future generation of IVNS. There are, however, recommendations that require additional research to determine their effectiveness and safety, for example, Head-Up Displays (HUD). These will be covered in greater detail in Section 8.2. Table 7.1 details the recommendations based on the knowledge gained during the research. The shaded boxes are recommendations that emerged directly from the research.

Overall Design	
Input controls	The touch screen technology was found to be particularly difficult to use on current IVNS. IVNS need to be used indoors and inside the vehicle – although not while driving – and in a variety of different conditions (darkness, bright light and while wearing gloves). Given the difficulties older adults faced with understanding whether they had hit the correct button or not a form of haptic feedback from the touch screen would be advantageous. In addition, the inclusion of a stylus or physical button controls would be beneficial as older drivers, with dry skin find it difficult to register a finger stroke on a touch screen device (Burkhard and Koch, 2012).
Large visual screens / HUD	The benefit of the larger screens (although the size is limited by UK law) would be an increase in the size of text

	and visual icons. This is in both the pre-trip planning and way-finding stages of navigation. There is the potential for Heads-Up Display (HUD) to be able to provide the required information to the driver more effectively than current Heads-Down Displays (HDD). It may be possible to deliver a greater range of navigational information to drivers through a combination of HUD and HDD. The information could be presented dependent on the two stages of navigation. The HDD could contain the pre-trip planning information, whereas the way-finding information could be made available on a HUD. The information presented can include real-time data and contextual information for that particular journey (Akamatsu *et al.*, 2013; Huang *et al.*, 2013), research on the distraction and safety issues associated with the new mechanisms of presenting information in the vehicle would be required.
User specific IVNS	It may be possible to determine navigational behaviour and preferences at the point of sale of IVNS through a questionnaire. This approach could allow route guidance information to be optimised for content and presentation for specific user groups. For instance, there is a difference in navigational preferences between the genders. Older female drivers' navigational performance improved significantly when provided with landmark-based information, whereas the male performance improved to a lesser extent. A setting could adjust the amount of landmark-based information received from the audio instructions depending on the gender of the user. These customised settings could be made by the user at home – or through a machine learning process (Adler and Blue, 1998; Cristea and Delhomme, 2014) which determines preferences from previous usages of the device.
Companionship	Future IVNS can be designed to increase the companionship to the driver. This would not be appropriate

	for every journey but would be an option to select during the pre-trip planning stage. The increased companionship could include: • Supportive audio messages on the stage of a journey that requires no manoeuvres for numerous miles; • Greater personalisation of messages towards the driver, although not at time critical times; • Visual indication that the driver is achieving their goal of reaching the destination; and • To choose voice and personality of audio to their personal preference – this will allow the route guidance information to be delivered according to the drivers' needs.
Highlight only the key features in the IVNS	It is recommended that there should be an option to hide or disable features on current IVNS. This will remove the number of features on display and streamline the process of planning and navigating that journey. In particular, planning a journey with coordinates or an ordinance survey grid reference should be made a more accessible option in the planning stage.
Provide features that take into account age-related declines	There are a number of age-related declines that affect the older driver's ability to operate IVNS safety. Specifically, the design of the next generation of IVNS should consider the declines in: • Hearing – This study would recommend that settings are made available to change the audible speech level and rate. In addition, it may be possible to create an audio induction loop in older drivers' cars. This would allow the audio instructions to be heard through driver's existing hearing aids; • Vision – There should be settings to allow for display contrast and brightness to be changed according to the vision abilities of the driver. In addition, the use of an HUD may compensate for declining eye-sight of older

	drivers compared to than current IVNS. This is particular true for older adults who may have long and short sightedness, requiring two sets of glasses; and • Short-term memory – Option to increase the repetitions of appropriate way-finding instructions when approaching a manoeuvre.
Co-piloting settings	It is recommended that IVNS have a co-pilot setting. The information displayed on the screen and audio instructions could be tailored to the co-pilot rather than the driver. This would allow for an increased amount of navigational information to be presented visually. There may be an option to provide this information through a HUD that only displays to the passenger. In addition, as the information is provided to the passenger it would allow for interaction during driving and provide contextual information that would be deemed unnecessary and potentially cause information overload if provided to the driver.
Manual	A manual should be created for older drivers specifically. This would include a greater breakdown of functions and information provision then currently provided. A paper manual should be provided with the device in addition to an online or CD version that includes video instructions. Moreover, the manual should be developed under the advice and input from the older driving cohort.
Pre-Trip Planning	
Provide a detailed breakdown of the planned route	It is recommended that during pre-trip planning an IVNS should provide information on: • The different class of roads on the route; • Length of time driving on each road type; • Category of junctions encountered (size and whether they are controlled by signals); • Key milestones on route (preferably with images); • Option to virtually drive sections of the route; • Potential stopping points on route;

	• Number of right turns at non-signalised junctions; • Landmarks on route; • Level of light for arrival time; and • Surrounding places on route. In addition, re-programming the route should be provided according to: • Reduction of driving on certain class of road, depending on personal preference; • Avoidance of certain junction categories for example, right-hand turns with no signals; and • Travel via options (e.g. cities, points of interest (POI) or postcode).
Re-order the process of inputting pre-trip planning information	IVNS allows for two planning methods to a known location. Either inputting a postcode and then the house number or, inputting of city, house number and then street name. A recommendation would be to re-order the inputting of the information to be more in line with a traditional address you would use on a letter. This would provide older adults with an increased confidence that the destination entered is the correct one.
Allow for the ability to plan a journey on the PC and transfer it over to the IVNS	Older drivers plan unfamiliar journeys online according to their preferences. A recommendation would be for the planned journey online to be transferred onto an IVNS, so planned journey is the guided journey – with all the preferences selected included. This would mean that the journey would have been completely planned by the user and the IVNS could then way-find them through their planned journey. It would be important for an IVNS to confirm that the journey planned is the one created by the driver on the PC. This was a clear requirement from older drivers who require an increased control at the pre-trip planning stage of navigation.
Programmable self-regulation	An IVNS should allow older adults to specify their driving preference and behaviour. This information can then be

preferences	used to plan all the journeys. Options should include avoidance of: • Motorways; • Dual-carriages; • Right-turns at non-signalled junctions (where drivers have to judge the headway of oncoming vehicles to make decision to turn right safely; • Peak travelling time (likely congestion, or on a school run); • Weather conditions; • Large and complex junctions; and • Time of day, level of light at time of arrival.
Context specific information	The travel behaviour of older drivers is largely leisure driven. Generally, getting from A to B in the fastest possible time is not a critical factor in the planning of journeys. Algorithms that factor in distance and time currently the trip planning by IVNS (Burnett 1998). There is the potential of IVNS to take into account a range of different settings when planning a journey for example, the more scenic route. It would not be suitable for all journeys to provide this level of information. However, the option for the older drivers to opt-in would allow the IVNS to provide information on the surrounding area for more leisurely drives, potentially POI in the nearby area. This could be particularly useful if provided to any potential passengers in the car.
Way-Finding	
Provision of landmarks in the route guidance information	Landmarks should be included in the route guidance information to assist older drivers successfully navigating a journey. The use of more advanced data storage, for instance SD cards and USB devices, will enable the inclusion of a wide range and detailed landmarks, and even elements of ‘street view’ – a feature found on online route planners. This will include the use of landmarks on the visual display and range of voice instructions provided to the

	older driver. This will provide a greater level of accuracy when using landmarks in a real-world environment. There will additionally be the scope to include more context specific forms of information. The use of online planners at the pre-trip planning stage of the journey may allow users to highlight particular landmarks on route that can be used to locate a turning, as a milestone or as indications of reassurance. Allowing landmarks to be chosen on 'street-view' options online would increase the familiarity of the journey overall and the landmarks used in the way-finding task. In addition, there is a challenge of keeping any potential landmark database up to date due the changing nature of physical landmarks for example, a red house changing colour or bank becoming a pub.
Speed limits and changes	The current speed limit of the road icon on the visual display should be increased in size, and IVNS should provide an audible indication of upcoming changes to the speed limit. This could be in the form of haptic feedback on the steering wheel, an audible sound or a visual indication on a HUD/ HDD display. In addition, there may be potential to use elements of Intelligent Speed Control (ISC) within an IVNS (Guo *et al.,* 2013). This would allow ISC to become a sub-function of IVNS.
Road Signs	There is an argument that IVNS makes road signs redundant (Burnett and Joyner, 1996; Eby and Molnar, 2001). However, older adults are familiar with roads signs and the information they provide. Moreover, IVNS have the potential to bring the road sign into the car. IVNS could provide an image of the road sign on the visual display. Allowing the driver to process the sign while driving and, importantly, in their own time. Also, it would be possible for the road sign to be displayed before it appears on the roadside. This would allow the driver a greater amount of time to process the information and react accordingly. In

	addition, given the safety implications that reading road signs has, this system could be used for all journeys and act as a safety feature and not purely a navigational feature. Moreover, with the perceived trend of road sign pollution – the IVNS would filter the signs so that only the most important information from the plethora of road signs is displayed to the driver.
Deliver navigational information through the combination of an audio instructions and a visual display	The combination of audio and a visual display was an effective method of delivering route guidance information. Audio instructions was the information older drivers rely on the most but a non-moving visual display in combination provided greater confidence in locating and executing the correct turnings. Moreover, due to the age-related declines in hearing and vision the combination of audio and visual instructions allows users to adapt to their changing abilities. Delivering route guidance information through one modality would be too restrictive.
Icon-based visual screen	The use of an icon-based visual screen is a viable alternative to the current moving map-based display. The display for older drivers should provide visual confirmation to the audio instructions, if required by the driver, and not cause a distraction that current moving maps have been found to incur. Icons on the menus were found to be beneficial to older drivers when planning a journey. The icons of arrows in the driving simulator trial were thought to be easy to interpret and follow by the participants. In addition, icons have the benefit of being cross-lingual (Song *et al.*, 2013). Relying on a moving-map and audio instructions may be difficult if the system does not provide the audio instructions in the driver's language.
Reassurance and confirmation	It is recommended that providing reassurance that they are on the correct route is particularly important on long stretches of road. Older drivers found that IVNS would become 'quiet' in these circumstances and this left them

	anxious that they were still on the correct course. On long stretches of road, audio instructions can maintain the link to the driver. Through providing reassurance for example, ‘continue straight on, under a bridge’. The frequency of reassurance on long stretches will need to be tested to find the optimum number. Landmarks can play a key role in both reassurance and confirmation. Providing a way-finding instruction that includes a landmark is in effect a confirmation that they are taking the correct manoeuvre. In addition, the provision of landmarks in the surrounding areas on a visual display can provide reassurance that they are on the correct route.
Context specific information	Within each journey there is contextual information that would benefit the driver. The provision of this information would only assist the drivers to navigate a journey safely and effectively. The information provided would be determined on each journey as each trip is different. The types of information that could be provided could include: • Landmarks; • Weather; • Geometry of road; • Blind bends; • Angle of turnings – allowing the driver time to prepare for server turns which may place a strain on their physical abilities; • Speed limit changes; and • Road signs.

Table 7.1 Recommendations for the design of the next generation of IVNS

There are recommendations highlighted in Table 7.1 that would be difficult to implement. For example, HUD requires further research for its safe use in a car and for the navigational content that can then be displayed. However, other recommendations would be easier to incorporate in the next generation of IVNS and provide significant benefits to older drivers. Figure 7.1 displays the potential benefit of the recommendations from this study against the difficulty to implement them. The difficulty to implement includes the cost of incorporation, the current technological constraints, and the practicality of the recommendation.

Figure 7.1 indicates that the more technological advanced recommendations, in the context of the scale and current capabilities, are the most difficult to implement but also provide the greatest potential benefit to older drivers. As the majority of these technologies are in early research development it is in a unique position to consider older drivers at the very start of the design. Rather than addressing older drivers requirements after the product has entered the market. Examining the growing older adult population can justify this approach. They will form a greater proportion of active drivers in the future and thus those buying cars and in-vehicle technologies. Previous research has found that older adults are willing to consider and use technology if it maintains their access to the private car (Guo *et al.*, 2010; Zhan *et al.*, 2013).

In addition to those technologies that would be difficult to implement, but have great potential benefits, there are a number of recommendations that would be relatively simple to incorporate. These would provide benefits to older drivers but not to the same degree as the more advanced options. However, if a number of these were adopted within an IVNS the older drivers would find a significant overall benefit to their ability to effectively use an IVNS. For instance, the inclusion of audible speed limit changes, audio and visual reassurance sounds and images, and change in the inputting controls would all be relativity simple to incorporate. Collectively they would increase the usability of IVNS for older drivers, potentially allowing them to navigate more efficiently and thus maintain their private car independence.

The recommendations also have been coloured coded into three categories, according to their priority in providing route-guidance support to older drivers. The green boxes are the top priority. This thesis proposes that these recommendations could have the greatest impact on older drivers using IVNS to maintain their mobility and are achievable. Orange coloured boxes are the medium priorities. This includes the majority of recommendations that would have minimal benefits to older drivers on their own. However, these are also relatively easy to implement and if enough where implemented, they might have an impact on older drivers. Finally, the red coloured boxes are the aspirational recommendations. These are the recommendations that generally require the greatest advancement in technology and additional research to assess their true benefits to older drivers and IVNS.

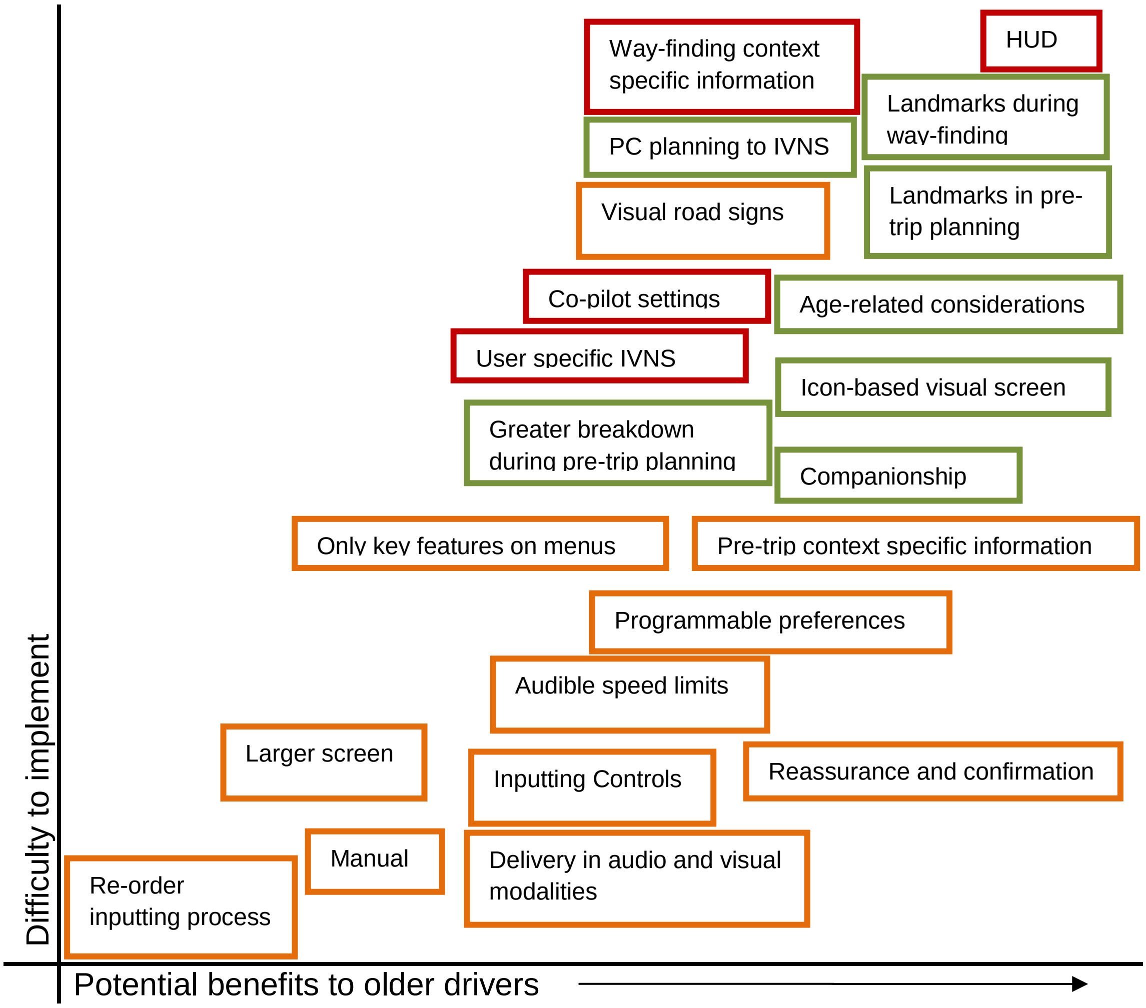


Figure 7.1 The practicality and potential benefits of the recommendations for the next generation of IVNS

Chapter 8. Conclusions

This thesis has addressed two aims:

- A) To identify older drivers' route guidance requirements; and
- B) To study older drivers' specific route guidance requirements, by investigating their navigational performance within a simulated driving environment.

The previous chapters of this thesis have described and discussed a literature review; a methodology overview; two investigations which examined older drivers' route guidance requirements and usability of IVNS; followed by a driving simulator investigation that explored the provision of landmark-based route guidance information; and finally a chapter detailing recommendations for the next generation of IVNS. The purpose of this chapter is to state the overall and most important contributions of this thesis to research knowledge, and propose areas for future work.

8.1 Major Findings

The findings will be separated into two groups. Group A will highlight the major findings associated with the study's first aim. Group B will detail the findings related to the second aim.

8.1.1 *Group A – Findings on Navigational Behaviour and Difficulties, and Route Guidance Requirements*

- **Older adults predominately plan their journeys with traditional methods, but do incorporate the use of online route planners for unfamiliar journeys.**

Published maps allow older adults to have complete control over the planning of the journey and are the main pre-trip planning tool used. When planning journeys, older drivers take into account their self-regulation preferences, for example how comfortable they are on particular roads and junction types. Having a clear understanding of the entire route during the pre-trip planning stage of navigation was fundamental to older drivers preparing to undertake a journey, especially an unfamiliar trip. Current IVNS do not provide the same level of control older drivers require at this stage of navigation. However, older drivers will use another navigation tool to assist them in pre-trip planning of journeys, online route planners.

The use of online route planners within the task of navigation has not previously been highlighted in the literature. Older drivers have incorporated online route planners in their pre-trip planning routine. This shows that older drivers are willing to incorporate new methods and tools during this stage of navigation. In particular, older drivers found the flexibility of online route planners to be a benefit to them. Online route planners allow older drivers to plan a journey according to their own self-regulation behaviour. However, the advantage of an online planner is that it provides a detailed way-finding breakdown of the route. This provides clarity of the exact road types and junctions they would encounter in their planned route. This information provides older drivers with the opportunity to alter the route according to their personal and self-regulation preferences. This finding highlights the importance of the pre-trip planning stage of navigation for older drivers. Moreover, this finding suggests that older drivers are willing to use technology to assist them in the navigation task however, for the majority of older drivers, only during the pre-trip planning stage of navigation.

- **Navigational difficulties are evident in older drivers, in both the pre-trip planning and way-finding stages.**

Older drivers do have a perceived anxiety over planning and then travelling on unfamiliar journeys. This study found that older drivers have an awareness of their declining abilities in driving and navigating. Age-related declines for example strength, memory, sight and hearing, force older adults to focus on the safe control of the vehicle, often to the detriment of navigation. This results in navigational errors that affect the confidence of the driver especially if the error resulted in driving on unfamiliar roads, away from the planned route. The consequence of the navigational difficulties is that ultimately there is a reduction or complete cessation of unfamiliar trips or even driving altogether. In particular, this thesis has highlighted potential gender differences in the reduction of driving. The female participants identified a greater concern in planning and way-finding an unfamiliar journey, and were more likely to reduce their driving on unfamiliar journeys as they aged. Moreover, they were aware that without assistance in navigation their driving behaviour may be adversely affected. This was evident as older female drivers highlighted a reduction in driving on unfamiliar journeys, which in turn reduced their confidence in driving. They would rely on others to drive them to the required destination or avoid travelling at all.

This study has found that older drivers can have difficulties in way-finding journey. For unfamiliar journeys, many older adults create written way-finding notes of their planned route. They would then use these notes to navigate themselves whilst driving. However, for unfamiliar journeys older drivers highlighted that they often become distracted by these notes or lose which way-finding step they are on. Moreover, if a wrong turn was taken then the notes could not adapt to the new environment. This shows current way-finding strategies employed by the majority of older drivers is not always effective. This was further examined and confirmed in the simulator investigation (Chapter 6). The driving simulator investigation found that when the older drivers navigated with the map compared to the landmark-based information they would glance at the map for longer than the visual display (map 0.63 seconds; landmarks 0.53 seconds); incur significantly statistically more navigational errors (map 47; landmarks 31) during the investigation; and have a significantly statistically higher workload (map 37; landmarks 27).

- **There are barriers to older drivers using IVNS.**

The most recent statistics found that only 6% of older adults in the UK currently own an IVNS (ONS, 2007). This study has found there are two main reasons for older drivers not using one: firstly, they consider their own navigational methods adequate to their driving behaviour; secondly, they believe that an IVNS would cause a distraction to their driving, especially the visual display and finally, older adults predominantly view IVNS as only suitable for younger drivers. Older drivers who view IVNS in this manner generally had no experience of using one. This study has found that IVNS with landmark-based route guidance information delivered through audio and visual modalities cause less of distraction than a map with paper map with notes. Therefore, these barriers can be overcome with a tailored IVNS for older drivers.

- **There are benefits to using IVNS for older drivers.**

A number of the participants found IVNS to be of real assistance to them. Using an IVNS allowed them to undertake trips with reduced anxiety over the planning or way-finding of that journey. This study found that some older drivers were willing to concede that the IVNS will not plan a journey to their exact preferences for instance, their self-regulation preferences. However, they believed that their IVNS will get them to their required destination even if it means travelling in conditions they would potentially feel uncomfortable. Yet, this may have safety ramifications as they will be travelling in road conditions they are not accustomed to. Moreover, this study found that older drivers travel with their IVNS for the majority of their journeys; both on familiar and unfamiliar trips. The research found that older drivers would build a bond with their IVNS. This allowed for an element of companionship to develop with their device. Older drivers who felt companionship believed they had more confidence in travelling on unfamiliar routes. This allowed them to be spontaneous in travel arrangements as they did not feel they needed to plan every detail of a journey. Relying on the pre-trip planning and way-finding guidance of the IVNS to provide all the support they required. This was particularly evident in older drivers who drive the majority of the time alone. Previous research has found that companionship is important to older drivers when undertaking an unfamiliar trip (Dingus *et al.*, 1997; Kostyniuk *et al.*, 1997). Yet that research was with a living passenger. This is the first empirical evidence that has found current IVNS users build the vital element of companionship with an IVNS.

- **Age-related declines do affect the use of IVNS.**

This study did not directly research age-related declines and navigation. However, elements of age-related declines in divided task attention were evident throughout this research. In particular, the moving map based display on current IVNS was found to be a distraction to older adults. The visual screen provided too much information that required significant time to cognitively process. Companionship and driving has been highlighted earlier, and older drivers were found to drive in pairs in unfamiliar environments. Thus, the passenger would act as the navigator and the driver would focus on the control of the vehicle. Yet, being reliant on a travelling companion limits mobility and independence. In addition, the age-related declines in memory and vision were evident in the driving simulator investigation (Chapter 6). This investigation found that navigational errors increased when the participants navigated with just the paper map and visual screen. These methods required the driver to visually obtain route-guidance information whilst driving. In comparison, the navigational errors were reduced when the navigational information was delivered through audio instructions or the combination of audio and visual.

- **There are usability issues with current IVNS for older adults.**

The majority of IVNS have touch screens. This study found older adults have significant difficulties with this form of technology. Touch screens have the advantage of the user requiring little training as it is possible to simply reach out and touch what is required (Wood *et al.,* 2005). Yet the participants in this study found this technology to be difficult to use. They would touch the screen several times before the system would respond. This was a result of age-related declines in sensitivity (Craik and Salthouse, 2000) and unfamiliarity with this form technology (Barnard *et al.*, 2013). This resulted in older adults becoming frustrated with the device and being unlikely to persist with this technology. Table 7.1 highlighted the recommendations this research would suggest to overcome this.

IVNS were not found to be effective at navigating older drivers. A key reason was found to be in the pre-trip planning stage of navigation. This study suggests that older adults enjoy the pre-trip planning stage of navigation, taking considerable care and time in this stage of navigation. In comparison, IVNS pre-trip planning takes a few minutes. Older drivers felt that the IVNS did not provide them with the relevant navigational information of the planned journey for them to undertake the trip confidently for example, the type of junctions they would be travelling on. This lack of information resulted in older drivers relying on planning a journey with a published map and largely ignoring the IVNS when driving. Therefore, this affected older drivers following the route guidance information provided from the IVNS.

Current IVNS were found to be demanding to use by the older drivers. As highlighted earlier, the touch screen was difficult to use during the pre-trip planning stage. Older drivers considered the moving map-based display to be a distraction. They would often try to ignore the screen and rely solely on the audio information. Research has found that all drivers can have difficulties with accurately interpreting the distance-to-turn information provided by an IVNS. However, older women, in particular, found the audio distance-to-turn information to be difficult to follow in this study.

The difficulties with the usability of current IVNS reduced the ability for older drivers to fully realise the potential benefits of using an IVNS. The next generation of IVNS need to consider older drivers' specific requirements – Chapter 7 outlined the recommendations from this study.

8.1.2 *Group B – Findings on the Testing of Landmark-Based Route Guidance Information in a Simulated Driving Environment*

- **Landmarks are a key requirement for route guidance for older adults, and the primary finding of this study is that landmarks are a more effective method for navigating older adults then published maps with notes.**

This research has found that older drivers use landmarks in their day-to-day navigation. Older adults highlighted the use of landmarks as an indication of where to turn and to place themselves in their environment. In particular, older women underlined the use of landmarks as an important form of information they use to navigate.

Current IVNS do not provide landmark information either on the visual display or in the audio instructions. The majority of the literature in this area has focused on defining a 'good' or 'poor' landmark. This study's investigation of older drivers' navigational performance when navigating with map or landmark-based information is one of the first of its kind. The investigation found that landmark-based route guidance information is significantly more effective at navigating older drivers than a printed map with notes. The use of landmarks in the route guidance information resulted in a lower total number of navigational errors (31) compared to when using the map (47). In addition, the participants rated their workload to be lower when receiving landmark-based route guidance information. Only 60% of the driving simulator participants rated the map with their own way-finding notes to be easy to follow. In comparison, 97% rated the landmark-based information easy to follow. The investigation concluded landmark-based route guidance information navigated the older adults more effectively than a map with notes. Thus, landmark-based route guidance information has the potential to navigate older drivers effectively, providing information that is less demanding to follow and that is intrinsically familiar to them.

- **Route guidance information, including landmarks, are most effective at navigating older adults when provided through audio instructions and an icon-based visual display.**

This study has found that route guidance information, specifically landmarks, should be delivered through a combination of audio instructions and an icon-based visual display. Research from the driving simulator investigation, established that the audio instructions delivered the route guidance information with the lowest workload score, lowest number of navigational errors, and were positively received from the participants. In comparison, when the landmark-based route guidance information was delivered just through the icon-based visual display the result was an increase in navigational errors, workload scores and visual demand. However, when the audio and visual display was delivered in combination the study found significant benefits and personal preference from older adults. The participants rated the combination as their most preferred method of delivering landmark-based information. In addition, there was no statistically significant difference between the combination of audio and visual and audio in the data collected and analysed. This highlights that the combination of these two modalities are the most effective way to delivery route guidance information. In addition, it further shows that the inclusion of the icon-based visual display does provide older drivers with a method of delivery that is effective. One of the key reasons why will be discussed below.

- **Delivering landmark-based route guidance information through a combination of audio and visual information reduces the potential hazard of drivers being distracted by landmarks on the roadside.**

There is the possibility for landmark-based route guidance information to cause a distraction as the driver is forced to search for landmarks on the roadside. However, this study has found that delivering route guidance information reduces the potential of distraction. The combination of audio and visual landmark-based route guidance information was found to be the most effective at enabling older drivers to locate the required landmark on the roadside. The combination of audio and visual information resulted in significantly fewer glances to the required landmark on the roadside (1.5) compared to audio information (2.8) and the visual display (3.1). The glance allocation was significantly lower than the visual display and the combination incurred the lowest glance duration. Therefore, this study found that audio instructions and a visual icon-based display allows the driver to locate the required landmark on the roadside without it being a potential safety hazard.

- **There are gender differences in navigation behaviour and navigation performance when navigated by landmark-based route guidance information.**

In the investigation sample, it was found that older females were more willing to discuss their navigational difficulties than males, and more likely to rely on travel alternatives than drive on an unfamiliar journey. This would include asking their partners or a more confident friend to drive to the required destination. In addition, they were more receptive to the use of landmarks in the route guidance information. For example, the female participants rated landmarks within their top three navigational requirements for unfamiliar journeys (see Table 5.4).

The driving simulator investigation found that older female drivers receive a greater benefit in their navigational performance than males. The female participants incurred 16 navigational errors when they were navigated with landmark-based information. The score was doubled to 32 when the female participants navigated themselves with a map and notes. In comparison, the male scores remained static between both navigational methods at 15 errors. The female participants' workload scores reduced by a greater extent between the two forms of navigational information methods compared to the male scores. The female participants rated their workload at 42 for the map and only 29 for landmarks, on the NASA-RTLX scale. In contrast, the male scores only reduced from 32 to 26 respectively. In addition, the female participants identified the positive benefits to their navigational performance that landmarks provided. Therefore, there are benefits to the older driver population as whole in providing landmark-based route guidance information. Yet, this is particularly evident in female older drivers. This has potentially strong implications in the design of future IVNS given that more women are driving into old age than ever before.

8.2 Limitations of the Thesis and Future Research

This study has contributed to developing a deeper understanding of older drivers' route guidance requirements. This section discusses the limitations of the thesis and areas of future research.

The study found that landmarks could act as a key route guidance requirement and could be effective in improving the navigating ability of older drivers. In addition, the combination of audio and visual information was the most effective at delivering landmark-based information. These findings are based on investigations conducted in a driving simulator, as this tool is appropriate for testing new IVS. However, the findings from this study should now be tested in an on-the-road trial. The use of an on-the-road trial would allow for a longer experimental drive with a greater degree of complexity in the route undertaken. This would allow older drivers' navigation behaviour with a printed map and landmark-based guidance to be observed in a real world environment. The experiment would have to be designed to mitigate the risks of on-road driving with a range of subjects under trial. Moreover, the landmark-based route guidance research should be delivered with the combination of an icon-based screen and audio instructions. This would provide evidence as to the effectiveness of this approach on a real-world road network.

A large scale road trial would additionally overcome the limitations of the mixed methods approach this study adopted. The mixed methods approach used small sample sizes initially to identify the requirements. A larger sample was then used for the driving simulator investigation. However, a road trial should increase the sample size again to test this study's findings. This would result in the findings being more representative of wider society, adding a greater robustness to the driving simulator findings. The use of a road trial after a driving simulator trial has been used many times when researching IVS (Santos, 2005).

This study found that when appropriate landmarks are used, navigational performance of older drivers' improves over the traditional methods of navigating. However, the availability of effective landmarks on the road network requires consideration. The driving simulator environment allowed the landmarks to be manipulated so that only proven effective landmarks were used at each navigational decision point. Research is required to identify the availability of suitable landmarks on the road network. This could be achieved through road users highlighting landmarks online (tailored IVNS or through online route planners and street view). Furthermore, consideration is required when choosing the landmarks so that they are not likely to change (colour, function or name of building). If a landmark is provided by the IVNS that is no longer prominent enough or exists then the user can report this - a similar principle to the reporting of speed cameras on current IVNS.

In addition, the use of a heads-up display (HUD) has been highlighted as possessing the potential to remove many of the current visual difficulties older drivers have with IVNS. The advantage of an HUD for older adults would be the reduced need to focus rapidly between near and far objects. Therefore, removing the barrier that declining vision imposes on a number of older adults using IVNS effectively. The design of the HUD would need to be considered for older drivers and assessed for the layout and information presented.

Furthermore, the literature review highlighted the age-related declines in hearing. The participants for the simulator all had normal to corrected normal hearing. Consequently, there are significant future research challenges in providing route guidance information that can be heard effectively by older drivers. Section 7.1 provided recommendations on how this can be potentially overcome. This is important, as the audible landmark information was very effective at navigating older adults.

Finally, companionship was highlighted as an important factor for older drivers undertaking an unfamiliar journey. IVNS have the potential to become that travel companion to older adults. This would require further research that focused on the social impact of providing an IVNS that could provide the similar level of confidence that a human co-pilot could. This would especially be relevant to those older drivers who spend the majority of their time driving alone.

8.3 Closing Statement

This thesis represents an in-depth study into older drivers' route guidance requirements. Using largely a qualitative methodological approach first, it found the salient issues within car navigation for older drivers. From these findings, a primarily quantitative methodological approach tested landmark-based navigational information in a driving environment. The study has highlighted the importance of driving to older adults and the difficulties many face with simply navigating a journey. The inclusion, where appropriate, of landmark-based route guidance information delivered through effective channels can ease the burden that navigation places on older drivers. The development of the study's key findings through future work can only improve the next generation of IVNS and other IVS and therefore the mobility of older drivers. In a country with a growing ageing population, the need for IVNS to take into account older driver's requirements to allow them to maintain their safe mobility will only become more apparent.

References

Adler, J.L. and Blue, V.J. (1998) 'Toward the design of intelligent traveler information systems', *Transportation Research Part C: Emerging Technologies*, 6(3), pp. 157-172.

Akamatsu, M., Green, P. and Bengler, K. (2013) 'Automotive Technology and Human Factors Research: Past, Present, and Future', *International Journal of Vehicular Technology*, 2013.

Akerman, J.R. (2010) ‘Cartographies of travel and navigation’, University of Chicago Press. Chicago.

Alm, H. (1993) 'Route navigation. Deciding driving infromation needs', in *Driving Future Vehicles*. First edn. London: CRC Press.

Anstey, K.J. and Wood, J. (2011) 'Chronological age and age-related cognitive deficits are associated with an increase in multiple types of driving errors in late life', *Neuropsychology*, 25(5), p. 613.

Antin, J.F., Stanley, L.M. and Cicora, K.F. (2009) 'Conventional versus moving-map navigation methods'. Transportation Reserach Record, pp. 34-41..

Baldock, M.R.J., Mathias, J.L., McLean, A.J. and Berndt, A. (2006) 'Self-regulation of driving and its relationship to driving ability among older adults', *Accident Analysis and Prevention*, 38(5), pp. 1038-1045.

Baldwin, C.L. (2002) 'Designing in-vehicle technologies for older drivers: Application of sensory-cognitive interaction theory', *Theoretical Issues in Ergonomics Science*, 3(4), pp. 307-329.

Baldwin, C.L. and Reagan, I. (2009) 'Individual differences in route-learning strategy and associated working memory resources', *Human Factors*, 51(3), pp. 368-377.

Ball, K., Owsley, C., Stalvey, B., Roenker, D.L., Sloane, M.E. and Graves, M. (1998) 'Driving avoidance and functional impairment in older drivers', *Accident Analysis & Prevention*, 30(3), pp. 313-322.

Banister, D. and Bowling, A. (2004) 'Quality of life for the elderly: the transport dimension', *Transport Policy*, 11(2), pp. 105-115.

Barnard, Y., Bradley, M.D., Hodgson, F. and Lloyd, A.D. (2013) 'Learning to use new technologies by older adults: Perceived difficulties, experimentation behaviour and usability', *Computers in Human Behavior*, 29(4), pp. 1715-1724.

Birks, M. and Mills, J. (2011) 'Grounded theory: A practical guide'. Sage Publications.

Birrell, S.A. and Young, M.S. (2011) 'The impact of smart driving aids on driving performance and driver distraction', *Transportation Research Part F: Traffic Psychology and Behaviour*, 14(6), pp. 484-493.

Blanchard, R.A., Myers, A.M. and Porter, M.M. (2010) 'Correspondence between self-reported and objective measures of driving exposure and patterns in older drivers', *Accident Analysis and Prevention*, 42(2), pp. 523-529.

Boufous, S., Finch, C., Hayen, A. and Williamson, A. (2008) 'The impact of environmental, vehicle and driver characteristics on injury severity in older drivers hospitalized as a result of a traffic crash', *Journal of Safety Research*, 39(1), pp. 65-72.

Boyatzis, R.E. (1998) *'Transforming qualitative information: Thematic analysis and code development'*. Sage. London.

Braun, V. and Clarke, V. (2006) 'Using thematic analysis in psychology', *Qualitative Research in Psychology*, 3(2), pp. 77-101.

Brooks, J.O., Goodenough, R.R., Crisler, M.C., Klein, N.D., Alley, R.L., Koon, B.L., Logan Jr, W.C., Ogle, J.H., Tyrrell, R.A. and Wills, R.F. (2010) 'Simulator sickness during driving simulation studies', *Accident Analysis & Prevention*, 42(3), pp. 788-796.

Bruner, G.C., Hensel, P.J. and James, K.E. (2005). 'Marketing measure for consumer behaviour', *Proceedings of the 2nd International Conference on Green Communications and Networks 2012*

Bryden, K.J., Charlton, J.L., Oxley, J.A. and Lowndes, G.J. (2013) 'Self-reported wayfinding ability of older drivers', *Accident Analysis & Prevention*, 59(0), pp. 277-282.

Burkhard, M. and Koch, M. (2012) 'Evaluating Touchscreen Interfaces of Tablet Computers for Elderly People', *Mensch & Computer 2012,* Munich pp.53-59

Burnett, G. (1997) 'An assessment of moving map and symbol-based route guidance systems ', *Journal of Navigation*. ,in: Y. IANNOY (Ed.), Ergonomics and Safety of Intelligent Driver InterfacesLawrence Erlbaum Associates, Mahwah (1997), pp. 115–136

Burnett, G. (2000) ''Turn right at the traffic lights': The requirement for landmarks in vehicle navigation systems', *The Journal of Navigation*, 53(3), pp. 499-510.

Burnett, G. and Joyner, S. (1996) 'Route guidance systems: Getting it right from the driver's perspective', *Journal of Navigation*, 49(2), pp. 169-177.

Burnett, G. and Parkes, A. (1993) 'The benefits of 'Pre-Infomration' in route guidance systems degin for vehicle ', in Lovesey, E.J. (ed.) *Contemporary ergonomics*. Taylor and Francis

Burnett, G.E. (1998) ''Turn Right at the King's Head': Drivers' Requirements for Route Guidance Information'. Loughborough University of Technology, UK.

Burnett, G.E. (2000) 'Usable Vehicle Navigation Systems: Are we there yet? ', *Vehicle Electronic Systems*. 29-30 June European conference and exhibition pp. 3.1.1-3.1.11.

Burnett, G.E., Smith, D. and May, A.J. (2001) 'Supporting the navigation task: Characteristics of 'good' landmarks', *Proceedings of the Annual Conference of the Ergonomics Society*, pp. 441-446.

Burnett, P. and Lucas, S. (2010) 'Talking, walking, riding and driving: The mobilities of older adults', *Journal of Transport Geography*, 18(5), pp. 596-602.

Burns, P.C. (1998) 'Wayfinding erros while driving ', *Journal of Environmental Psychology*, 18(2), pp. 209-217.

Burns, P.C. (1999) 'Navigation and the mobility of older drivers', *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*, 54(1).

Byers, J.C., Bittner, A.C. and Hill, S.G. (1989) ‘Traditional and raw task load index (TLX) correlations: Are paired comparisons necessary? Advances in Industrial Ergonomics and Safety’. *Mital A. (Ed.) Taylor & Francis*, pp. 481–485.

Caird, J. (2004) ‘In-Vehicle Intelligent Transportation Systems: Safety and Mobility of Older Drivers’. *In Conference Proceedings 27: Transportation in an Aging Society: A Decade of Experience, Transportation Research Board of the National Academies*, Washington, D.C., pp. 236–255

Cairns, P. and Cox, A.L. (2008) 'Research methods for human-computer interaction'. Cambridge University Press.

Cantin, V., Lavallière, M., Simoneau, M. and Teasdale, N. (2009) 'Mental workload when driving in a simulator: Effects of age and driving complexity', *Accident Analysis and Prevention*, 41(4), pp. 763-771.

Charlton, J.L., Oxley, J., Fildes, B., Oxley, P. and Newstead, S. (2003) 'Self-regulatory behaviours of older drivers', *Annual proceedings / Association for the Advancement of Automotive Medicine. Association for the Advancement of Automotive Medicine*, 47, pp. 181-194.

Charmaz, K. (2006) ‘Constructing grounded theory: A practical guide through qualitative analysis’. Sage Publications Limited.

Chiang, D.P., Brooks, A.M. and Weir, D.H. (2004) 'On the highway measures of driver glance behavior with an example automobile navigation system', *Applied Ergonomics*, 35(3), pp. 215-223.

Chown, E., Kaplan, S. and Kortenkamp, D. (1995) 'Prototypes, location, and associative networks (PLAN): Towards a unified theory of cognitive mapping', *Cognitive Science*, 19(1), pp. 1-51.

Clarke, D.D., Ward, P., Bartle, C. and Truman, W. (2010) 'Older drivers' road traffic crashes in the UK', *Accident Analysis & Prevention*, 42(4), pp. 1018-1024.

Clarke, V. and Braun, V. (2013) ‘Successful qualitative research: A practical guide for beginners’. London. Sage.

Coluccia, E., Iosue, G. and Antonella Brandimonte, M. (2007) 'The relationship between map drawing and spatial orientation abilities: A study of gender differences', *Journal of Environmental Psychology*, 27(2), pp. 135-144.

Coluccia, E. and Louse, G. (2004) 'Gender differences in spatial orientation: A review', *Journal of Environmental Psychology*, 24(3), pp. 329-340.

Coren, S. (1994) 'Most comfortable listening level as a function of age', *Ergonomics*, 37(7), pp. 1269-1274.

Craik, F. and Salthouse, T.A. (2000) *The Handbook of Aging and Cognition* Second Edition edn. London Lawrence Erlbaum Associates

Creswell, J.W. and Clark, V.L.P. (2007) *Designing and conducting mixed methods research*. Wiley Online Library.

Cristea, M. and Delhomme, P. (2014) 'Comprehension and acceptability of on-board traffic information: Beliefs and driving behaviour', *Accident Analysis & Prevention*, 65(0), pp. 123-130.

Cutmore, T.R.H., Hine, T.J., Maberly, K.J., Langford, N.M. and Hawgood, G. (2000) 'Cognitive and gender factors influencing navigation in a virtual environment', *International Journal of Human-Computer Studies*, 53(2), pp. 223-249.

Daimon, T. and Kawashima, H. (1995) 'New viewpoints of evaluation of in-vehicle information system — applying methods in cognitive engineering', *JSAE Review*, 16(3), p. 318.

Daimon, T., Nishimura, M. and Kawashima, H. (2000) 'Study of drivers' behavioral characteristics for designing interfaces of in-vehicle navigation systems based on national and regional factors', *JSAE Review*, 21(3), pp. 379-384.

Dalton, P., Agarwal, P., Fraenkel, N., Baichoo, J. and Masry, A. (2013) 'Driving with navigational instructions: Investigating user behaviour and performance', *Accident Analysis & Prevention*, 50(0), pp. 298-303.

Davidse, R.J. (2006) 'Older Drivers and ADAS - Which System Improve Road Safety?', *IATSS Research*, 30(1), pp. 6-20.

Davidse, R.J., Hagenzieker, M.P., Van Wolffelaar, P.C. and Brouwer, W.H. (2009) 'Effects of in-car support on mental workload and driving performance of older drivers', *Human Factors*, 51(4), pp. 463-476.

Davis and Schmandt (1989) ‘The Back Seat Drivers: Real Time Spoken Driving Instructions’ in Reekie, D.H. M. And Tsai, J (ed), *Proccessedings of the IEEE Vehicle Navigation and Information Systems Conference.*

de Winter, J.C.F., de Groot, S., Mulder, M., Wieringa, P.A., Dankelman, J. and Mulder, J.A. (2009) 'Relationships between driving simulator performance and driving test results', *Ergonomics*, 52(2), pp. 137-153.

de Winter, J.C.F., van Leeuwen, P.M. and Happee, R. (2012) ‘Advantages and Disafvantages of Driving Simulators: A Discssion’ *Measuring Behavior 2012*. Utrecht.

Dennis, M. (1997) 'The description of routes: A cognitive approach to the production of spatial doscource ', *Current Psychology of Cognition* 16, pp. 409-458.

Diana, M. and Pronello, C. (2010) 'Traveler segmentation strategy with nominal variables through correspondence analysis', *Transport Policy*, 17(3), pp. 183-190.

Dickerson, A.E., Molnar, L.J., Eby, D.W., Adler, G., Bédard, M., Berg-Weger, M., Classen, S., Foley, D., Horowitz, A., Kerschner, H., Page, O., Silverstein, N.M., Staplin, L. and Trujillo, L. (2007) 'Transportation and aging: A research agenda for advancing safe mobility', *Gerontologist*, 47(5), pp. 578-590.

Dicks, L., Burnett, G. and Joyner, S. (1995) *Proceedings of the Ergonomics Society’s 1995 Annual Conference*. London Taylor and Francis

Dingus, T.A., Hulse, M.C., Antin, J.F. and Wierwille, W.W. (1989) 'Attentional demand requirements of an automobile moving-map navigation system', *Transportation Research Part A: General*, 23(4), pp. 301-315.

Dingus, T.A., Hulse, M.C., Mollenhauer, M.A., Fleischman, R.N., McGehee, D.V. and Manakkal, N. (1997) 'Effects of age, system experience, and navigation technique on driving with an advanced traveler information system', *Human Factors*, 39(2), pp. 177-199.

Domeyer, J.E., Cassavaugh, N.D. and Backs, R.W. (2013) 'The use of adaptation to reduce simulator sickness in driving assessment and research', *Accident Analysis & Prevention*, 53(0), pp. 127-132.

Eby, D.W. and Molnar, L.J. (2001) 'In-vehicle route guidance preferences of driving tourists', *ITS Journal*, 6(3), pp. 261-279.

Eby, D.W. and Molnar, L.J. (2009) 'Older adult safety and mobility: Issues and research needs', *Public Works Management and Policy*, 13(4), pp. 288-300.

Edwards, J.D., Bart, E., O'Connor, M.L. and Cissell, G. (2010) 'Ten years down the road: Predictors of driving cessation', *Gerontologist*, 50(3), pp. 393-399.

Edwards, J.D., Lunsman, M., Perkins, M., Rebok, G.W. and Roth, D.L. (2009) 'Driving cessation and health trajectories in older adults', *Journals of Gerontology - Series A Biological Sciences and Medical Sciences*, 64(12), pp. 1290-1295.

Edwards, J.D., Ross, L.A., Ackerman, M.L., Small, B.J., Ball, K.K., Bradley, S. and Dodson, J.E. (2008) 'Longitudinal predictors of driving cessation among older adults from the ACTIVE clinical trial', *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*, 63(1), pp. P6-P12.

Eisses, S. (2011) ‘ITS Action Plan 3.4 - Safety and comfort of the vulnerable road user’:91 Commission, E.

Fairclough, SH, Ashby, MC, Ross, T, Parkes, AM (1991) Effects of Handsfree Telephone Use on Driving Behaviour. In *Road Transport Informatics (RTI)/Intelligent Vehicle-Highway Systems (IVMS)*, Proceedings of the 24th ISATA International Symposium on Automotive Technology and Automation, Florence, Italy, 20-24 May, pp.403-409

Fastenmeier, W., Haller, R. and Lerner, G. (1994) 'First World Congress on Applications of Transport Telematics and Intelligent Vehicle Highway Systems'. Boston. Artech House

Field, A. (2009) 'Discovering statistics using SPSS' . London. Sage Publications Limited.

Fofanova, J. and Vollrath, M. (2011) 'Distraction while driving: The case of older drivers', *Transportation Research Part F: Traffic Psychology and Behaviour*, 14(6), pp. 638-648.

Fonda, S.J., Wallace, R.B. and Herzog, A.R. (2001) 'Changes in driving patterns and worsening depressive symptoms among older adults', *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*, 56(6).

Forlizzi, J., Barley, W.C. and Seder, T. (2010) 'Where should i turn: moving from individual to collaborative navigation strategies to inform the interaction design of future navigation systems'., *Proceedings of the 28th international conference on Human factors in computing systems'*. ACM.

Fred D, D. (1993) 'User acceptance of information technology: system characteristics, user perceptions and behavioral impacts', *International Journal of Man-Machine Studies*, 38(3), pp. 475-487.

Frith, H. and Gleeson, K. (2004) 'Clothing and Embodiment: Men Managing Body Image and Appearance', *Psychology of Men & Masculinity*, 5(1), p. 40.

Gardezi, F., Wilson, K.G., Man-Son-Hing, M., Marshall, S.C., Molnar, F.J., Dobbs, B.M. and Tuokko, H.A. (2006) 'Qualitative research on older drivers', *Clinical Gerontologist*, 30(1), pp. 5-22.

Gelau, C., Sirek, J. and Dahmen-Zimmer, K. (2011) 'Effects of time pressure on left-turn decisions of elderly drivers in a fixed-base driving simulator', *Transportation Research Part F: Traffic Psychology and Behaviour*, 14(1), pp. 76-86.

Glaser, B.G. (1965) 'The Constant Comparative Method of Qualitative Analysis', *Social Problems*, 12(4), pp. 436-445.

Glaser, B.G. (1999) 'The future of grounded theory', *Qualitative Health Research*, 9(6), pp. 836-845.

Glaser, B.G. (2001) 'The grounded theory perspective: Conceptualization contrasted with description'. Mill Valley: Sociology Press.

Glaser, B.G. (2002) 'Constructivist grounded theory?', *Forum Qualitative Sozialforschung*, 3(3).

Glaser, B.G. and Holton, J. (2004) 'Remodeling Grounded Theory'. Forum Qualitative Sozialforschung / Forum: Qualitative Social Research,

Godley, S.T., Triggs, T.J. and Fildes, B.N. (2002) 'Driving simulator validation for speed research', *Accident Analysis & Prevention*, 34(5), pp. 589-600.

Goodman, J., Brewster, S.A. and Gray, P. (2005) 'How can we best use landmarks to support older people in navigation?', *Behaviour and Information Technology*, 24(1), pp. 3-20.

Goodman, J., Gray, P., Khammampad, K. and Brewster, S. 3160 (2004) 'Using landmarks to support older people in navigation'. *Computer Scinece 3160* pp. 38-48.

Green, P. (1993) ‘Measures and Methods used to assess the safety and usability of driver information systems’ *Final Report Transportation Research Institute (UMTRI)*

Green, P. and George, K. (1995) ‘When should auditory guidance systems tell drivers to turn?’, Proceedings of the 39th Annual Meeting of the Human Factors and Ergonomics Society, 2, pp.1072-1076

Green, P., Hoekstra, E. and Willimasm, M. (1993) 'On-the-Road Tests of Driver Interfaces: Examiniation of a Route Guidance System and a Car Phone'. *Final Report Transportation Research Institute (UMTRI)*

Gstalter, H. and Fastenmeier, W. (1991) 'Safety Impacts of In-Car Navaigtion Systems Munchen' (DRIVE I V1017 BERTIE, Deliverable 69). Munich, Germany: Bayerische Motorenwerke AG

Guest, G., MacQueen, K.M. and Namey, E.E. (2011) 'Applied thematic analysis'. London Sage.

Guo, A.W., Brake, J.F., Edwards, S.J., Blythe, P.T. and Fairchild, R.G. (2010) 'The application of in-vehicle systems for elderly drivers', *European Transport Research Review*, pp. 1-10.

Guo, W., Blythe, P.T., Edwards, S., Pavkova, K. and Brennan, D. (2013) 'Effect of intelligent speed adaptation technology on older drivers’ driving performance'. *IET Intelligent Transport Systems* 2013, 7(4), 1-8.

Hakamies-Blomqvist, L., Raitanen, T. and O'Neill, D. (2002) 'Driver ageing does not cause higher accident rates per km', *Transportation Research Part F: Traffic Psychology and Behaviour*, 5(4), pp. 271-274.

Hakamies-Blomqvist, L., Sirén, A., Davidse, R.J. and Statens väg- och, t. (2004) 'Older drivers : a review'. [Linköping, Sweden]: Swedish National Road and Transport Research Institute.

Hale, A.R., Stoop, J. and Hommels, J. (1990) ‘Human error models as predicitores of accident scenaarios for designers in road transport systems’. *Ergonomics*, 33, 1377-1388

Hannukainen, P. and Hölttä-Otto, K. (2006) ‘Identifying Customer Needs: Disabled Persons as Lead Users’ *ASME 2006 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*. American Society of Mechanical Engineers.

Hanson, T.R. and Hildebrand, E.D. (2011) 'Can rural older drivers meet their needs without a car? Stated adaptation responses from a GPS travel diary survey', *Transportation*, pp. 1-18.

Hart, S.G. and Staveland, L.E. 52 (1988) 'Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research'. pp. 139-183.

Harvey, C., Stanton, N.A., Pickering, C.A., McDonald, M. and Zheng, P. (2011a) 'Context of use as a factor in determining the usability of in-vehicle devices', *Theoretical Issues in Ergonomics Science*, 12(4), pp. 318-338.

Harvey, C., Stanton, N.A., Pickering, C.A., McDonald, M. and Zheng, P. (2011b) 'In-vehicle information systems to meet the needs of drivers', *International Journal of Human-Computer Interaction*, 27(6), pp. 505-522.

Harvey, C., Stanton, N.A., Pickering, C.A., McDonald, M. and Zheng, P. (2011c) 'A usability evaluation toolkit for In-Vehicle Information Systems (IVISs)', *Applied Ergonomics*, 42(4), pp. 563-574.

Hayutin, A.M. (2007) 'How Population Aging Differs Across Countries: A Briefing on Global Demographics'*.* Stanford Center on Longevity

Heath, H. and Cowley, S. (2004) 'Developing a grounded theory approach: a comparison of Glaser and Strauss', *International journal of nursing studies*, 41(2), pp. 141-150.

Henrie, R.L., Aron, R.H., Nelson, B.D. and Poole, D.A. (1997) 'Gender-related knowledge variations within geography', *Sex Roles*, 36(9-10), pp. 605-623.

Hölscher, C., Tenbrink, T. and Wiener, J.M. (2011) 'Would you follow your own route description? Cognitive strategies in urban route planning', *Cognition*, 121(2), pp. 228-247.

Horberry, T., Anderson, J., Regan, M.A., Triggs, T.J. and Brown, J. (2006) 'Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance', *Accident Analysis and Prevention*, 38(1), pp. 185-191.

Huang, C.-H., Chao, C.-W., Tsai, T. and Hung, M.-H. (2013) 'The Effects of Interface Design for Head-Up Display on Driver Behavior', *Life Science Journal*, 10(2).

Huang, Y.M. and Wang, J.Y.T. (2008) 'Modelling modal choices with discrete choice models: An application to the North Shore Busway', *Road and Transport Research*, 17(2), pp. 50-59.

Huebner, K.D., Porter, M.M. and Marshall, S.C. (2006) 'Validation of an electronic device for measuring driving exposure', *Traffic Injury Prevention*, 7(1), pp. 76-80.

Hutcherson, D.G. (1989) 'Self-monitoring of driving for the elderly: evidence for use of a driving diary.', *Physical & Occupational Therapy in Geriatrics*, 7, pp. 171-201.

Iachini, T., Iavarone, A., Senese, V.P., Ruotolo, F. and Ruggiero, G. (2009) 'Visuospatial Memory in Healthy Elderly, AD and MCI: A Review', *Current Aging Science*.

Iaria, G., Palermo, L., Committeri, G. and Barton, J.J.S. (2009) 'Age differences in the formation and use of cognitive maps', *Behavioural Brain Research*, 196(2), pp. 187-191.

Ishikawa, T., Fujiwara, H., Imai, O. and Okabe, A. (2008) 'Wayfinding with a GPS-based mobile navigation system: A comparison with maps and direct experience', *Journal of Environmental Psychology*, 28(1), pp. 74-82.

Jacob, R.J.K. and Karn, K.S. (2003) ‘Eye tracking in human-computer interaction and usability research: Ready to deliver the promises'. Ready to deliver the promises, In J. Hyönä, R. Radach, & H.Deubel (Eds.), The mind's eye: Cognitive and applied aspects of eye movementresearch (pp. 573-605). Amsterdam: Elsevier.

Jensen, B.S., Skov, M.B. and Thiruravichandran, N. (2010) ‘Studying Driver Attentiona and Behaviour for Three Confuqurations of GPS Navigationin RealTraffic Driving’. *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI'10)*.

Jones, M. and Alony, I. (2011) 'Guiding the use of Grounded Theory in Doctoral studies–an example from the Australian film industry'. International Journal of Doctoral Studies, 6 (N/A), 95-114.

Kaptein, N.A., Theeuwes, J. and van der Horst, R. (1996) 'Driving simulator validity: some considerations', *Transportation Research Record*, (1550), pp. 30-36.

Kennedy, R.S., Lane, N.E., Berbaum, K.S. and Lilienthal, M.G. (1993) 'Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness', *The international journal of aviation psychology*, 3(3), pp. 203-220.

Kim, M. and Son, J. (2011) 'On-road assessment of in-vehicle driving workload for older drivers: Design guidelines for intelligent vehicles', *International Journal of Automotive Technology*, 12(2), pp. 265-272.

Kim, S., Dey, A.K., Lee, J. and Forlizzi, J. (2011) 'Usability of car dashboard displays for elder drivers'. Proceedings of the 2011 Annual conference on Human factors in computing. Vancouver, 493-502.

Kim, S., Hong, J.-H., Li, K., Forlizzi, J. and Dey, A. (2012) 'Route guidance modality for elder driver navigation', *Pervasive Computing*, pp. 179-196.

Kitchin, R.M. (1994) 'Cognitive maps: What are they and why study them?', *Journal of environmental psychology*, 14(1), pp. 1-19.

Klippel, A., Tappe, H. and Habel, C. (2003) 'Pictorial representations of routes: Chunking route segments during comprehension', in *Spatial cognition III*. Springer, pp. 11-33.

Kostyniuk, L.P. and Molnar, L.J. (2008) 'Self-regulatory driving practices among older adults: Health, age and sex effects', *Accident Analysis and Prevention*, 40(4), pp. 1576-1580.

Kostyniuk, L.P., Molnar, L.J. and Eby, D.W. (2009) 'Safe mobility of older drivers: Concerns expressed by adult children', *Topics in Geriatric Rehabilitation*, 25(1), pp. 24-32.

Kostyniuk, L.P. and Shope, J.T. (2003) 'Driving and alternatives: Older drivers in Michigan', *Journal of Safety Research*, 34(4), pp. 407-414.

Kostyniuk, L.P., Streff, F.M. and Eby, D.W. (1997) 'The Older Driver and Navigation Assistance Systems' (UMTRI-97-47). Michigan: Institute, T.R.

Kozlowski, L.T. and Bryant, K.J. (1977) 'Sense of direction, spatial orientation, and cognitive maps', *Journal of Experimental Psychology: Human Perception and Performance*, 3(4), p. 590.

Krishnasamy, C., Unsworth, C. and Howie, L. (2011) 'The patterns of activity, and transport to activities among older adults in singapore', *Hong Kong Journal of Occupational Therapy*, 21(2), pp. 80-87.

Krosnick, J.A. (1991) 'Response strategies for coping with the cognitive demands of attitude measures in surveys', *Applied cognitive psychology*, 5(3), pp. 213-236.

Krueger, R.A. and Casey, M.A. (2009) 'Focus Groups: A Practical Guide for Applied Research'. SAGE Publications. Lonfon

Langford, J., Koppel, S., McCarthy, D. and Srinivasan, S. (2008) 'In defence of the 'low-mileage bias'', *Accident Analysis and Prevention*, 40(6), pp. 1996-1999.

Langford, J., Methorst, R. and Hakamies-Blomqvist, L. (2006) 'Older drivers do not have a high crash risk-A replication of low mileage bias', *Accident Analysis & Prevention*, 38(3), pp. 574-578.

Lansdown, T. (1997) 'Visual demand and the introduction of advanced driver information systems into road vehicles' Loughborough University, UK.

Lawton, C.A. (1994) 'Gender differences in way-finding strategies: Relationship to spatial ability and spatial anxiety', *Sex Roles*, 30(11), pp. 765-779.

Lee, H.C. (2003) 'The validity of driving simulator to measure on-road driving performance of older drivers ', *Journal of Transport Engineering in Australia*, 8(2), pp. 89-100.

Leshed, G., Velden, T., Rieger, O., Kot, B. and Sengers, P. (2008) 'In-car GPS navigation: Engagement with and disengagement from the environment', pp. 1675-1684.

Lin, P.-C. and Chen, S.-I. (2013) 'The effects of gender differences on the usability of automotive on-board navigation systems – A comparison of 2D and 3D display', *Transportation Research Part F: Traffic Psychology and Behaviour*, 19(0), pp. 40-51.

Liu, I., Levy, R.M., Barton, J.J.S. and Iaria, G. (2011) 'Age and gender differences in various topographical orientation strategies', *Brain Research*, 1410(0), pp. 112-119.

Liu, Y.C. (2000) 'Effect of advanced traveler information system displays on younger and older drivers' performance', *Displays*, 21(4), pp. 161-168.

Liu, Y.C. (2001) 'Comparative study of the effects of auditory, visual and multimodality displays on drivers' performance in advanced traveler information systems', *Ergonomics*, 44(4), pp. 425-442.

Llaneras, R., Lerner, N., Dingus, T. and Moyer, J. (2000) 'Attention Demand of IVIS Auditory Displays: An On-Road Study Under Freeway Environments', *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 44(20), pp. 3-238-3-241.

Lo, V.E.W., Green, P.A. and Franzblau, A. (2011) 'Where do people drive? Navigation system use by typical drivers and auto experts', *Journal of Navigation*, 64(2), pp. 357-373.

Lovelace, K.L., Hegarty, M. and Montello, D.R. (1999) 'Elements of good route directions in familiar and unfamiliar environments', in *Spatial information theory. Cognitive and computational foundations of geographic information science*. Springer, pp. 65-82.

Lozano, L.M., García-Cueto, E. and Muñiz, J. (2008) 'Effect of the number of response categories on the reliability and validity of rating scales', *Methodology: European Journal of Research Methods for the Behavioral and Social Sciences*, 4(2), pp. 73-79.

Lynch, K. (1960) 'The Image of the City' Twetny-fourth edn. The Technoology Press and Harrvard Univeristy Press. Cambridge, Massachusetts.

Mahmud, A.A., Mubin, O. and Shahid, S. (2009) 'User experience with in-car GPS navigation systems: Comparing the young and elderly drivers'. In *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services.*

Mallon, K. and Wood, J.M. (2004) 'Occupational therapy assessment of open-road driving performance: Validity of directed and self-directed navigational instructional components', *The American journal of occupational therapy*, 58(3), pp. 279-286.

Marottoli, R.A., de Leon, C.F.M., Glass, T.A., Williams, C.S., Cooney Jr, L.M. and Berkman, L.F. (2000) 'Consequences of driving cessation: decreased out-of-home activity levels', *The journals of gerontology. Series B, Psychological sciences and social sciences*, 55(6).

Marshall, S.C., Wilson, K.G., Molnar, F.J., Man-Son-Hing, M., Stiell, I. and Porter, M.M. (2007) 'Measurement of driving patterns of older adults using data logging devices with and without global positioning system capability', *Traffic Injury Prevention*, 8(3), pp. 260-266.

Martin, A.J., Marottoli, R. and O'Neill, D. (2009) 'Driving assessment for maintaining mobility and safety in drivers with dementia', *Cochrane Database of Systematic Reviews*, (1).

May, A., Ross, T. and Osman, Z. (2005) 'The design of next generation in-vehicle navigation systems for the older driver', *Interacting with Computers*, 17(6), pp. 643-659.

May, A.J. and Ross, T. (2006) 'Presence and quality of navigational landmarks: Effect on driver performance and implications for design', *Human Factors*, 48(2), pp. 346-361.

May, A.J., Ross, T. and Bayer, S.H. (2003) 'Driver's information requirements when navigating in an urban environment', *Journal of Navigation*, 56(1), pp. 89-100.

McCrum-Gardner, E. (2008) 'Which is the correct statistical test to use?', *British Journal of Oral and Maxillofacial Surgery*, 46(1), pp. 38-41.

Metz, D. (2003) 'Transport policy for an ageing population', *Transport Reviews*, 23(4), pp. 375-386.

Metz, D.H. (2000) 'Mobility of older people and their quality of life', *Transport Policy*, 7(2), pp. 149-152.

Mezuk, B. and Rebok, G.W. (2008) 'Social integration and social support among older adults following driving cessation', *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*, 63(5).

Michon, J.A. (1985) 'A critical view of driver behaviour models'. In L. Evans &R.S. Schwing (Eds.), Human behaviour and traffic safety. New York: Plenum Press

Michon, P.-E. and Denis, M. (2001) 'When and why are visual landmarks used in giving directions?', in *Spatial information theory*. Springer, pp. 292-305.

Moldenhauer, D. and McCrickard, S. (2003) 'Effect of Information Modality on Geographic Cognition in Car Navigation Systems'. Center for HCI and Department of Computer Science, Virginia Tech

Moore, G.E. (1965) 'Cramming more components onto integrated circuits'. *Electronics Magazine* Vol. 38, No. 8

Morgan, D.L. (1993) 'Successful Focus Groups' First edn. London Sage.

Morgan, D.L. (1996) 'Focus groups', *Annual review of sociology*, pp. 129-152.

Mourant, R.R., Tsai, F.J., Al-Shihabi, T. and Jaeger, B.K. (2001) 'Measuring divided-attention capability of young and older drivers'. Transportation Reserach Part F: Traffic Psychology and Behaviour, 10(6), pp. 40-45

Musselwhite, C. and Haddad, H. (2010) 'Exploring older drivers’ perceptions of driving', *European Journal of Ageing*, 7(3), pp. 181-188.

Mynatt, E. and Rogers, W. (2001) 'Developing technology to support the functional independence of older adults', *Ageing International*, 27(1), pp. 24-41.

Nielson, J. (1993) 'Usability Enginnering' (1 vols). Boston: Academic Press.

Noel, E., Nonnecke, B. and Trick, L. (2005) A comprehensive learnability evaluation method for in-car navigation devices. SAE International

Nothegger, C., Winter, S. and Raubal, M. (2004) 'Selection of salient features for route directions', *Spatial Cognition and Computation*, 4(2), pp. 113-136.

Obata, T., Daimon, T. and Kawashima, H. (1993). A cognitive study of in-vehicle naviagtion systems: aplying verbal protocal analysis to usability evaluation. In proceedings of Vehicle Navigation and Information Systems Conference, pp. 232-237

OECD (2001) 'Ageing and Transport Mobility Needs and Safety Issues (Complete Edition - ISBN 9264196668)', *SourceOECD Transport*, 2001, pp. I-125.

Office for National Statistics (2011) 'Ageing fastest increase in the 'oldest' old'. Available at: http://www.statistics.gov.uk/cci/nugget.asp?id=949 (Accessed: March 2011).

Owsley, C. (1999) 'Transportation in an Aging Society'. Maryland. Transportation Research Board

Owsley, C. and McGwin, G. (2010) 'Vision and driving', *Vision Research*, 50(23), pp. 2348-2361.

Owsley, C., McGwin, G. and Searcey, K. (2013) 'A population-based examination of the visual and ophthalmological characteristics of licensed drivers aged 70 and older', *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 68(5), pp. 567-573.

Oxley, J., Charlton, J., Scully, J. and Koppel, S. (2010) 'Older female drivers: An emerging transport safety and mobility issue in Australia', *Accident Analysis and Prevention*, 42(2), pp. 515-522.

Pak, R., Czaja, S.J., Sharit, J., Rogers, W.A. and Fisk, A.D. (2008) 'The role of spatial abilities and age in performance in an auditory computer navigation task', *Computers in Human Behavior*, 24(6), pp. 3045-3051.

Park, D.C. and Schwarz, N. (2000) 'Cognitve Ageing A Primer' Philadelphia Taylor & Francis

Park, P. and Cha, D. (1998) 'Comparison of subjective mental workload assessment techniques for the evaluation of in-vehicle navigation system usability' 5th World Congress on Intelligent Transport Systems. Seoul, Korea.

Parker, D., McDonald, L., Rabbitt, P. and Sutcliffe, P. (2000) 'Elderly drivers and their accidents: The Aging Driver Questionnaire', *Accident Analysis and Prevention*, 32(6), pp. 751-759.

Parker, D., McDonald, L., Rabbitt, P. and Sutcliffe, P. (2001) ‘Confidence and the older driver’. *Ageing and Society, 21(2),* pp.169-182

Parkes, A.M. (1991) 'Data capture techniques for RTI usablility evaluiation', *Advanced telematics in road transport - the DRIVE conference*. Amsterdam: Elsevier Science Publishers

Parkes, A.M. and Martell, A. (1990) 'A usability analysis of a PC based route planning system ', in Lovesy, E.J. (ed.) *Contemporary ergonomics* London: Taylor and Francis, pp. 50-55.

Pauzié, A. (2003) 'Ageing population and ergonomics of innovative communicating technologies in driving', *Vieillissement de la population et ergonomie des innovations technologiques de communication dans la conduite automobile*, (81), pp. 203-212.

Peel, C., Baker, P., S. and Roth, D.L. (1995) 'Assessing mobility in older adults: The UAB Study of Aging Life-Space Assessment ', *Physical Therapy*, 85(10), pp. 1008-1019.

Petchenik, B.B. (1989) 'Vehicle Navigation and Information Systems' *Conference, 1989. Conference Record*. 11-13 Sept. 1989.

Pidgeon, N. and Henwood, K. (1997) 'Using grounded theory in psychological research'. In Hayes (Ed.), Doing qualitative analysis in psychology, Hove: Psychology Press.

Pielot, M., Henze, N. and Boll, S. (2009) 'Supporting map-based wayfinding with tactile cues', Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services.

Pison, G. (2009) 'Population ageing will be faster in the South than in the North', *Population and Societies*, (457), pp. 1-7.

Pohlmann, S. and Traenkle, U. (1994) 'Orientation in road traffic. Age-related differences using an invehicle navigation system and a conventional map', *Accident Analysis and Prevention*, 26(6), pp. 689-702.

Pyett, P.M. (2003) 'Validation of qualitative research in the “real world”', *Qualitative Health Research*, 13(8), pp. 1170-1179.

Rabbitt, P., Carmichael, A., Jones, S. and Holland, C.A. (1996) ‘When and why older drivers give up driving’*. AA Foundation for Road Safety research*

Ragland, D.R., Satariano, W.A. and MacLeod, K.E. (2004) 'Reasons given by older people for limitation or avoidance of driving', *Gerontologist*, 44(2), pp. 237-244.

Rakotonirainy, A. and Steinhardt, D. (2009) 'In-vehicle technology functional requirements for older drivers', *Proceedings of the 1st International Conference on Automotoive User Interfaces and Interactive Vehicular Applications. New York.* pp. 27-33.

Ranney, T.A. (1994) 'Models of driving behavior: A review of their evolution', *Accident Analysis & Prevention*, 26(6), pp. 733-750.

Richter, K.-F. and Duckham, M. (2008) 'Simplest instructions: Finding easy-to-describe routes for navigation', in *Geographic Information Science*. Springer, pp. 274-289.

Rockwell, T.H. (1988) ‘Spare visual capacity in driving-revisited: New empiricial resultsy for an old idea’ *Vision in Vehicles II. Second International Conference on Vision in Vehicles*.

Roger, M., Bonnardel, N. and Le Bigot, L. (2011) 'Landmarks' use in speech map navigation tasks', *Journal of Environmental Psychology*, 31(2), pp. 192-199.

Rosenbloom, S. (2007) 'Differences in perceptions of driving skills: Older drivers and adult children of older drivers in the United Kingdom'. *Journal of Tranport Geoegraphy* 18 pp.634-641

Rosenbloom, S. (2010) 'How adult children in the UK and the US view the driving cessation of their parents: Is a policy window opening?', *Journal of Transport Geography*, 18(5), pp. 634-641.

Ross, T., Midtland, K., Fuchs, M., Pauzie, A., Engert, A., Duncan, B., Vaughan, G., Vernet, M., Peters, H., Burnett, G. and May, A. (2008) ‘HARDIE Desgin

Guidlines Handbook: Human Factors Guidlines for Information' Presentation by ATT Systems.

Saad, F. (2004) 'Some critical issues when studying behavioural adaptations to new driver support systems.' *Cognition, Technology & Work 8.3* pp 175-181

Salthouse, T.A. and Siedlecki, K.L. (2007) 'Efficiency of route selection as a function of adult age', *Brain and Cognition*, 63(3), pp. 279-286.

Santos, J., Merat, N., Mouta, S., Brookhuis, K. and de Waard, D. (2005) 'The interaction between driving and in-vehicle information systems: Comparison of results from laboratory, simulator and real-world studies', *Transportation Research Part F: Traffic Psychology and Behaviour*, 8(2), pp. 135-146.

Schaller, R.R. (1997) 'Moore's law: past, present and future', *Spectrum, IEEE*, 34(6), pp. 52-59.

Schraggen, J.M.C. (1990) 'Strategy differences in map information for route following in unfamiliar cities; implications for in-car navigation'. Soesterberg, The Netherlands: B-1)., T.R.N.I.

Shaw, L., Polgar, J.M., Vrkljan, B. and Jacobson, J. (2010) 'Seniors' perceptions of vehicle safety risks and needs', *American Journal of Occupational Therapy*, 64(2), pp. 215-224.

Shechtman, O., Classen, S., Awadzi, K. and Mann, W. (2009) 'Comparison of driving errors between on-the-road and simulated driving assessment: A validation study', *Traffic Injury Prevention*, 10(4), pp. 379-385.

Silvis, J. and Niemeier, D. (2009) 'Social network and dwelling characteristics that influence ridesharing behavior of seniors'. *Transportation Research Record: Journal of the Transportation Research Board* 2118(1) 47-54

Siren, A. and Hakamies-Blomqvist, L. (2009) 'Mobility and well-being in old age', *Topics in Geriatric Rehabilitation*, 25(1), pp. 3-11.

Siren, A., Hakamies-Blomqvist, L. and Lindeman, M. (2004) 'Driving Cessation and Health in Older Women', *Journal of Applied Gerontology*, 23(1), pp. 58-69.

Siren, A. and Kjær, M.R. (2011) 'How is the older road users' perception of risk constructed?', *Transportation Research Part F: Traffic Psychology and Behaviour*, 14(3), pp. 222-228.

Sixsmith, J. and Sixsmith, A. (1993) 'Older people, driving and new technology', *Applied Ergonomics*, 24(1), pp. 40-43.

Smith, J.A. (2004) 'Reflecting on the development of interpretative phenomenological analysis and its contribution to qualitative research in psychology', *Qualitative Research in Psychology*, 1(1), pp. 39-54.

Song, W., Finch, A., Tanaka-Ishii, K., Yasuda, K. and Sumita, E. (2013) 'picoTrans: An intelligent icon-driven interface for cross-lingual communication', *ACM Transactions on Interactive Intelligent Systems (TIIS)*, 3(1), p. 5.

Spiers, H.J. and Maguire, E.A. (2008) 'The dynamic nature of cognition during wayfinding', *Journal of Environmental Psychology*, 28(3), pp. 232-249.

Srinivasan, R. (1999) 'Overview of some human factors design issues for in-vehicle navigation and route guidance systems', *Transportation Research Record*, (1694), pp. 20-26.

Staplin, L. and Hunt, L. (1999) ‘Driver programs’.*Transportation in an Aging Society*. Maryland Transportation Reseach Board

Stevens, A., Quimby, A., Board, A., Kersloot, T. and Burns, P. (2002) *Desgin Guidelines for Safety of In-Vehicle Infromation Systems*

Streeter, L.A. and Vitello, D. (1986) 'A Profile of Drivers' Map-Reading Abilities', *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 28(2), pp. 223-239.

Streff, F. and Wallace, R.R. (1993) '*Vehicle Navigation and Information Systems*' *Conference, 1993., Proceedings of the IEEE-IEE*. 12-15 Oct 1993.

Tison, J., Chaudhary, N. and Cosgrove, L. (2011) 'National phone survey on distracted driving attitudes and behaviors'. Washington, DC: National Highway Traffic Safety Administration

Tourangeau, R., Rips, L.J. and Rasinski, K. (2000) 'The psychology of survey response'. Cambridge University Press.

Turano, K.A., Munoz, B., Hassan, S.E., Duncan, D.D., Gower, E.W., Roche, K.B., Keay, L., Munro, C.A. and West, S.K. (2009) 'Poor sense of direction is associated with constricted driving space in older drivers', *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*, 64(3), pp. 348-355.

Underwood, G., Crundall, D. and Chapman, P. (2011) 'Driving simulator validation with hazard perception', *Transportation Research Part F: Traffic Psychology and Behaviour*, 14(6), pp. 435-446.

Urquhart, C., Lehmann, H. and Myers, M.D. (2010) 'Putting the ‘theory’back into grounded theory: guidelines for grounded theory studies in information systems', *Information systems journal*, 20(4), pp. 357-381.

Van Erp, J.B.F. and Van Veen, H.A.H.C. (2004) 'Vibrotactile in-vehicle navigation system', *Transportation Research Part F: Traffic Psychology and Behaviour*, 7(4-5), pp. 247-256.

Venkatesh, V. (2000) 'Determinants of perceived ease of use: Integrating control, intrinsic motivation, and emotion into the technology acceptance model', *Information systems research*, 11(4), pp. 342-365.

Verwey, W.B. (1993) 'Vehicle Navigation and Information Systems' *Conference., Proceedings of the IEEE-IEE*. 12-15 Oct 1993.

Voyer, D., Voyer, S. and Bryden, M.P. (1995) 'Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables', *Psychological Bulletin*, 117(2), pp. 250-270.

Vrkljan, B.H. and Polgar, J.M. (2007) 'Driving, navigation, and vehicular technology: Experiences of older drivers and their co-pilots', *Traffic Injury Prevention*, 8(4), pp. 403-410.

Wassink, I., van Dijk, B., Zwiers, J., Nijholt, A., Kuipers, J. and Brugman, A. (2006) 'In The Truman Show: Generating Dynamic Scenarios in a Driving Simulator', *Intelligent Systems, IEEE*, 21(5), pp. 28-32.

Waters, W. and Winter, S. (2013) 'A wayfinding aid to increase navigator independence', *Journal of Spatial Information Science*, (3), pp. 103-122.

Weathers, D., Sharma, S. and Niedrich, R.W. (2005) 'The impact of the number of scale points, dispositional factors, and the status quo decision heuristic on scale reliability and response accuracy', *Journal of Business Research*, 58(11), pp. 1516-1524.

Weng, L.-J. (2004) 'Impact of the number of response categories and anchor labels on coefficient alpha and test-retest reliability', *Educational and Psychological Measurement*, 64(6), pp. 956-972.

Wickens, C.D. (2008) 'Multiple resources and mental workload', *Human Factors*, 50(3), pp. 449-455.

Winsum, W., A. (1993) 'Selection of route in route navigation systems ', in Parkes, A. and Franzen, S. (eds.) *Driving Future Vehicles*. London CRC Press.

Wolf, J., Guensler, R., Washington, S. and Frank, L. (2001) 'Use of electronic travel diaries and vehicle instrumentation packages in the year', *Transportation Research Circular*, pp. 413-429.

Wood, E., Willoughby, T., Rushing, A., Bechtel, L. and Gilbert, J. (2005) 'Use of computer input devices by older adults', *Journal of Applied Gerontology*, 24(5), pp. 419-438.

Wood, J.M., Anstey, K.J., Lacherez, P.F., Kerr, G.K., Mallon, K. and Lord, S.R. (2009) 'The On-Road Difficulties of Older Drivers and Their Relationship with Self-Reported Motor Vehicle Crashes', *Journal of the American Geriatrics Society*, 57(11), pp. 2062-2069.

Wu, C.-F., Huang, W.-F. and Wu, T.-C. (2009) 'A Study on the Design of Voice Navigation of Car Navigation System', in Jacko, J. (ed.) *Human-Computer Interaction. Ambient, Ubiquitous and Intelligent Interaction*. Springer Berlin Heidelberg, pp. 141-150.

Xue, Q.-L., Fried, L.P., Glass, T.A., Laffan, A. and Chaves, P.H.M. (2008) 'Life-Space Constriction, Development of Frailty, and the Competing Risk of Mortality', *American Journal of Epidemiology*, 167(2), pp. 240-248.

Yamamoto, N. and DeGirolamo, G.J. (2012) 'Differential effects of aging on spatial learning through exploratory navigation and map reading', *Frontiers in Aging Neuroscience*, 4(JUN), pp. 1-7.

Yannis, G., Antoniou, C., Vardaki, S. and Kanellaidis, G. (2010) 'Older drivers' perception and acceptance of in-vehicle devices for traffic safety and traffic efficiency', *Journal of Transportation Engineering*, 136(5), pp. 472-479.

Zhan, J., Vrkljan, B., Porter, M.M. and Polgar, J. (2013) 'Older drivers' opinions of criteria that inform the cars they buy: A focus group study', *Accident Analysis & Prevention*. 61, pp. 281-287.

Zhang, L., Wang, B., Jia, H. and Dong, B. (2012) 'Study on the adaptabiliy of on-board naviagtion equipment for older people. Proceedings of the 12th COTA International Conference of Transportation Professionals, Beijing pp 1107-1114

Appendices

10.1 Appendix A: Ethical Consent and Disclaimer Form

School of Civil Engineering and Geosciences
Newcastle University
Cassie Building
Newcastle upon Tyne
NE1 7RU

Mr C Emmerson doctoral thesis study has been explained to my satisfaction and I have had the opportunity to ask questions. I understand that my participation is totally voluntary and I may withdraw from the study at any time. I choose whether or not to complete the questionnaire, travel diary and/or interview.

I understand that all information collected will be kept confidential by the researcher. No individual will ever be identified by name and any quotas used will be anonymous.

I also understand that I take full responsibility for the loaned in-vehicle navigation system and for my driving. Additionally, I am aware I will still be liable for any damages that will incur as a result of my own negligence under the Road Traffic Act. Furthermore, I understand that the loaning of the in-vehicle navigation system is for a two week period only.

Participant’s name (please print): ______________________________

Participant’s signature: __________________________ Date: _______

Researcher’s signature: _________________________ Date: _______

10.2 Appendix B: Preliminary Questionnaire

1. Approximately how many miles do you drive in a typical year?

   ☐ 0-2,000 ☐ 2,001- 5,000 ☐ 5,001- 10,000 ☐10,000+ ☐ Unsure

2. On average, how often do you drive?

☐ Occasionally (less than once a month)

☐ Sometimes (once or twice a month)

☐ Often (one to three times a week)

☐ Very often (four or more times a week)

☐ Daily (at least once a day every day of the week)

3. How often do you travel on an unfamiliar journey every month? (please circle one)

   0 1 to 3 4 to 6 6 +

4. Approximately what percentage of your annual mileage is spent on unfamiliar roads? ____________

5. When driving on your own in an unfamiliar area, how good are you at finding your way (please circle one)

Very good	Good	Slightly Good	Neither Good or Poor	Slightly Poor	Poor	Very Poor

About You

6. Age: ☐ 60-69 ☐ 70-79 ☐ 80-89 ☐ 90+

7. Gender: ☐ Male ☐ Female

8. Which of the following best describes your occupation?

☐ I'd prefer not to say ☐ Full time employment

☐ Part time employment ☐ Temporary employment

☐ Retired ☐ Student ☐ Not employed / seeking employment

9. Which of these best describes the location of your dwelling?

☐ City ☐ Town ☐ Suburban ☐ Village ☐ Rural

10.3 Appendix C: Driver Diary

Date: Mon / Tue / Wed / Thurs / Fri / Sat / Sun (please circle one)

From: To:

Approx. time left: Time arrived:

What is the purpose of your journey? (please tick one)

☐ Shopping, banking or for an errand ☐ See family/ friends

☐ Getting to an appointment (e.g. docs) ☐ Leisurely drive

☐ To go to a leisure activity (e.g. cinema) ☐ Going to work

☐ Other, please specify:

Have you made this journey before? Yes or No

If yes, is this a journey you make regularly? Yes or No

Did you undertake any pre-trip planning? Yes or No

If yes, what did you do? (tick all that apply)

☐Paper map, which one?________________ ☐ Navigation system

☐Online planner, which one?_____________ ☐ Visited websites

☐Other, please specify: _________________ ☐ Planned route from memory

What information were you trying to find out? (tick all that apply)

☐ What time to set off ☐ How long, in time, the journey would take

☐ Postcode of destination ☐ What the overall distance of the trip is

☐ Information on destination ☐ Points of interests near destination

☐ Contact number of destination ☐ Types of roads you would be driving on

☐ How to travel via a location ☐ To develop a mental map of the route

☐ Other, please specify:____

Did you change any of the settings on the navigation system? Yes or No

If yes, what did you do? (tick all that apply)

☐ Change to fastest route ☐ Change to most environmental friendly route

☐ Change to shortest route ☐ Changed to avoid motorways

☐ Other, please specify:

Number of passengers in the car:

Below is a list of several statements about your experience with the sat-nav on this journey. Please circle your response.

1. I relied on the in-vehicle navigation for this journey?

Strongly Agree	Agree	Slightly Agree	Neither Agree or Disagree	Slightly Disagree	Disagree	Strongly Disagree

2. The in-vehicle navigation systems affected my normal navigation performance?

Strongly Agree	Agree	Slightly Agree	Neither Agree or Disagree	Slightly Disagree	Disagree	Strongly Disagree

3. The in-vehicle navigation system was easy to use on this journey?

Strongly Agree	Agree	Slightly Agree	Neither Agree or Disagree	Slightly Disagree	Disagree	Strongly Disagree

4. The in-vehicle navigation system was effective on this journey?

Strongly Agree	Agree	Slightly Agree	Neither Agree or Disagree	Slightly Disagree	Disagree	Strongly Disagree

5. How did you rate the audio information provided?

Very Good	Good	Slightly good	Neither Good or Poor	Slightly Poor	Poor	Very Poor

6. How did you rate the visual information provided?

Very Good	Good	Slightly good	Neither Good or Poor	Slightly Poor	Poor	Very Poor

7. The in-vehicle navigation system made me confident while navigating this journey?

Strongly Agree	Agree	Slightly Agree	Neither Agree or Disagree	Slightly Disagree	Disagree	Strongly Disagree

If you found anything particular helpful or unsupportive from the audio or visual information please expand:

Diary entry:

10.4 Appendix D: Participant Information Pack

Introduction

Thank you for agreeing to take part in this research. This study is investigating how in-vehicle navigation systems (sat-navs) can be improved for the specific needs of older drivers. This investigation will loan you an in-vehicle navigation system for two weeks and we want you to keep a travel diary over this time.

Study outline

In your role as a participant you will be required to complete a short diary detailing your experiences in using the navigation system. For each diary entry, you will be required to answer a set of simple questions to highlight the context of your experience, and to write a short diary entry providing more details to your experience. The entry does not have to be long or complex but it should adequately convey your experience with the device.

In the travel diary, we would particularly like to find out about the types of interactions outlined below. Please read these pages and over the next two weeks whenever you encounter any of the issues outlined, while using the navigation system, simply record them in your diary.

1. How you found the information provided from the system

Please record your opinions of the information provided. This may include:

When listening to the audio instructions:

- Whether you could you understand the instructions delivered.
- Whether the instructions provided you with enough time to prepare and then perform the required manoeuvre.
- Was there any information you required that was not provided?

When looking at the display:

- Approximately how often you looked at the display.
- Whether you could gather information from the screen easily.
- What information did you want the display to show you?
- What information did you gather from the display and whether this was useful or not.

Whether you followed the route suggested by the system.

- How you used the audio and display information to complete the route.

2. Occasions where you made navigational errors because of the navigation system

If at any time you received route guidance information or instructions that you believed were wrong, inaccurate, unreliable or unusual please record this. For example, the navigation system may:

- Inform you of roundabouts or turnings that do not exist.
- Failed to inform you of upcoming objects like roundabouts.

- Any other forms of wrong, inaccurate, unreliable or unusual guidance information.

For each diary entry please also describe some additional information as to why you believed the guidance or information was wrong. This might include:

- You have superior knowledge of that route compared to the navigation system.
- You just knew that the system was mistaken.
- You observed road-signs that contradicted the system's instructions.
- You encountered a manoeuvre that was not indicated by the system.
- Any other reason.

What you did when you realised it was inaccurate.

- Followed the guidance instructions anyway.
- Only realised after the journey that it had been mistaken.
- Recalculated the route with the navigation system or through information from the roadside.
- Any other method.

3. Occasions when you made navigational errors that where your own fault.

Everybody makes mistakes when driving. If at any time you made a wrong turn or any form of navigational error when you choose not to follow the guidance from the navigation system, please record them. They may include:

- You felt you had superior knowledge of that route compared to the navigation system.
- You felt the navigation system was mistaken on its route choice.
- You observed environmental factors such as road signs that you felt were more reliable than the navigation systems.
- You missed important information from the navigation system.
- Incorrectly followed instructions from the navigation system.
- Misunderstanding or misinterpreting auditory or visual instructions.
- Any other navigational error for which you are to blame.

With the diary entry it would also be useful if you provided additional information to these errors.

- Why you felt you made the navigational error.
- Any safety implications of your navigational error.
- Any further information that you think might help put this user-experience in context.

4. Any user-experiences that you feel are worth nothing

The primary purpose of this diary study is to examine experiences of older drivers using an in-vehicle navigation system for the first time. With the aim to identify improvements to these systems for current and future needs of older adults. Therefore, we would also be keen to hear about:

- How useful the navigation system was on the journey.
- Whether the navigation system could be improved to help you navigate.

- Whether you felt the display assisted or hindered you.
- Whether you felt the audio information assisted or hindered you.
- Your level of faith/trust/confidence in the in-vehicle navigation system.

Completing diary entries

We would like you to complete a diary entry for each time you use the navigation system. Ideally you should complete the diary entry on the same day as you used the navigation system. That way the experiences are fresh in your mind. Of course, this is not always possible but we simply ask you to be as accurate as possible in completing your diary entry. Please use a separate dairy entry form for each journey. Finally, please state any other factors in your diary that you think may be relevant, no matter how trivial you think they may be. For example, this may include such things as:

- congestion
- mood
- tiredness
- strange behaviour from the system
- potential hazards
- visibility
- boredom
- problems with the vehicle
- unusual route choice
- stress
- surrounding noise

Personal information

During this study, you may reveal various forms of information concerning your attitudes and driving behaviour. We would like to assure you that the information you provide will remain anonymous and no information will be given to any other parties; so please complete the diary entries truthfully so that we receive reliable data.

Contact details

If you need any assistance or advice during this investigation then please feel free to contact Christopher Emmerson:

Telephone: 07672***** Email: christopher.emmerson@ncl.ac.uk**

10.5 Appendix E: Post- Investigation Interview Plan

Warm up

How did you find the IVNS over the two weeks?

Did you have any difficulties with using the IVNS?

Pre-trip planning (use travel diary information where appropriate)

Did your pre-trip planning change with access to the sat-nav?

You undertook a few journeys that you had not travelled before, why?

Did the access to the satnav influence your decision to travel?

Way-finding (use driver diary information where appropriate)

What were you experiences of following the route guidance information?

How did you find the visual screen?

- Did you place it in your field of view
- Could you adequately understand the information?

How did you find the audio information from the device?

- Could you adequately understand the information?

Opinions on satnav *(use driver diary information where appropriate)*

Do you think the use of satnav made any difference to your travelling behaviour?

Did you feel more confident before undertaking the journey with the satnav?

Did you feel more confident during the journey?

Overall, how did using the satnav make you feel?

- More confident, relaxed or stressed?

On reflection, is there anything else about the sat-nav that you found useful?

On reflection, is there anything else about the sat-nav that you found did not assist you?

What other information would like to be able to access from a satnav?

Over a longer term do you think access to a sat-nav would change your travel behaviour? (Focus on unknown locations)

10.6 Appendix F: Pre-Investigation Interview

Talk me through how you usual plan a journey?

Tell me how you plan a journey that you have never been on before?

Do you find anything challenging about planning a journey?

How do you navigate while you're driving?

Do you find anything challenging about navigating during a journey?

Have you found your navigational behaviour changing as you age?

What are the challenges of driving?

How integral is navigation to your driving?

Did you find navigation more challenging as you age?

10.7 Appendix G: Driving Simulator Questionnaire

Section 1: Driving habits and technology

1. How many year have you been driving? _________ years

2. Approximately how many miles do you drive in a typical year?

   ☐ 0-2,000 ☐ 2,001- 5,000 ☐ 5,001- 10,000 ☐10,000+

3. Please circle a number that how indicates how useful the following the navigational tool is

	Very Useful						Useless
Road numbers (e.g. follow A69)	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Place names (e.g. follow signs for Manchester)	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Junction numbers (e.g. exit at junction 12)	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Street/ road names (e.g. turn left into Green Street)	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Landmarks on the route (e.g. turn left at traffic lights, straight on under the bridge)	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Long distances follow the road for 3 miles)	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Short distances (e.g. turn right in 300 yards)	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Compass directions (e.g. head Northwards)	**7**	**6**	**5**	**4**	**3**	**2**	**1**

4. What percentage of your annual mileage is spent on unfamiliar roads? _____%

5. What percentage of your annual mileage is spent driving with no other passengers? ______%

6. When driving on your own in an unfamiliar area, how good are you at finding your way? (please circle)

Very	Good	Slightly	Neither Good or	Slightly	Bad	Very

Good		Good	Bad	Bad		Bad

7. I am confident with technology? (Please circle one)

Strongly Agree	Agree	Slightly Agree	Neither Agree or Disagree	Slightly Disagree	Disagree	Strongly Disagree

8. Have you avoided driving on an unfamiliar journey within the last six months?

☐ Yes ☐ No

Section 2: About You

9. Age: ☐ 60-65 ☐ 66-70 ☐ 71-75 ☐ 76-80 ☐80+

10. Gender: ☐ Male ☐ Female

11. Which of the following best describes your occupation?

☐ Full time employment ☐ Part time employment

☐ Temporary employment ☐ Volunteer

☐ Retired ☐ Not employed / seeking employment

☐ Other, please specify:

12. Which of these best describes the location of your dwelling?

☐ City ☐ Town ☐Suburbs ☐ Village ☐ Rural

10.8 Appendix H: Driving Simulator Questionnaire

1. How many years have you been driving? _________ years

2. Approximately how many miles do you drive in a typical year?

☐ 0-2,000 ☐ 2,001- 5,000 ☐ 5,001- 10,000 ☐10,000+

3. How often do you make an unfamiliar journey? (please circle)

2 or more times a week	About once a week	2-3 times a month	About once a month	About once every 2-6 months	About once a year	Never

13. Please circle a number that represents how you feel for each question below

How good are published maps in helping you find your way?	Very Good	Good	Slightly Good	Neither Good or Bad	Slightly Bad	Bad	Very Bad
How good are online maps in helping you find your way?	Very Good	Good	Slightly Good	Neither Good or Bad	Slightly Bad	Bad	Very Bad

4. Please circle a number that represents how you feel for each question below

How easy do you find it to locate a particular street name on a published map?	Very Easy	Easy	Slightly Easy	Neither Easy or Difficult	Slightly Difficult	Difficult	Very Difficult
How easy do you find it to plan a route using a road atlas?	Very Easy	Easy	Slightly Easy	Neither Easy or Difficult	Slightly Difficult	Difficult	Very Difficult
How easy do you find it to establish your current location using a published map?	Very Easy	Easy	Slightly Easy	Neither Easy or Difficult	Slightly Difficult	Difficult	Very Difficult
How easy do you find it to follow a route a map you have planning	Very Easy	Easy	Slightly Easy	Neither Easy or Difficult	Slightly Difficult	Difficult	Very Difficult

5. What experiences do you have of using a sat-nav whilst driving? (please circle one)

I own one and use it regularly	I own one but rarely use it	I own one but never use it	I have used one but do not own one	I have never used one

6. Have you avoided driving on an unfamiliar journey within the past 6 months? ☐ Yes ☐ No

If yes, why____

____

7. What percentage of your annual mileage is spent on unfamiliar roads? ______%

8. What percentage of your annual mileage is spent driving with no passengers? ______%

9. Which of the following best describes your occupation?

☐ Full time employment ☐ Part time employment

☐ Temporary employment ☐ Volunteer

☐ Retired ☐ Not employed / seeking employment

☐ Other, please specify:

10. Which of these best describes the location of your dwelling?

☐ City ☐ Town ☐Suburbs ☐ Village ☐ Rural

11. Age: ☐ 60-65 ☐ 66-70 ☐ 71-75 ☐ 76-80 ☐ 80+

12. Gender: ☐ Male ☐ Female

10.9 Appendix I: NASA-RTLX

SIX THEMES WHICH CONTRIBUTE TO THE DIFFICULTY OF THE DRIVING TASK

NB - Navigating is part of the overall task of driving

1. MENTAL DEMAND

This refers to any mental demands placed on you by driving (e.g. in planning, thinking, deciding, remembering, looking, and searching).

2. MENTAL EFFORT

This refers to how much concentration it took to complete the journey.

3. PHYSICAL DEMAND

This refers to any physical activity you have just experienced whilst driving (e.g. operating the car's controls).

4. TIME PRESSURE

This refers to how hurried or harassed you felt whilst driving (e.g. due to the presence of other vehicles, following the route guidance information, etc.).

5. DISTRACTION

This refers to the extent to which you felt distracted from driving.

6. STRESS LEVEL

This refers to how relaxed versus stressed you felt whilst driving (i.e. annoyed, frustrated, worried, and irritated).

Please place a line through each scale that represents how you feel for each factor in bold

Please place a line through each scale that represents how you feel for each factor in **bold**

Mental Demand	Low		High
Mental Effort	Low		High
Physical Demand	Low		High
Time Pressure	Low		High
Distraction	Low		High
Stress Level	Low		High

10.10 Appendix J: Driving Simulator Questionnaire

Map

	Strongly Agree						Strongly Disagree
The information was effective at navigating me	7	6	5	4	3	2	1
The information was easy to follow	7	6	5	4	3	2	1
The information made me confident on the journey	7	6	5	4	3	2	1
The information was not a distraction	7	6	5	4	3	2	1
the drive was a fair reflection of my usual performance	7	6	5	4	3	2	1

Other three scenarios

	Strongly Agree						Strongly Disagree
The information was effective at navigating me	7	6	5	4	3	2	1
The information was easy to follow	7	6	5	4	3	2	1
The information made me confident on the journey	7	6	5	4	3	2	1
The information was not a distraction	7	6	5	4	3	2	1
I thought the information was provided to me with enough time before each turning	7	6	5	4	3	2	1
I found the landmarks useful when navigating	7	6	5	4	3	2	1

10.11 Appendix K: Interview Structure

How did you find it when you planned a journey with the paper map and then drove that route?

What is your opinion on being navigated by landmarks?

What are your thoughts on the visual navigation screen?

How did you find the audio navigation information?

Do you think you would benefit from being navigated with landmarks?

10.12 Appendix L: Post- Investigation Questionnaire

1. Could you rank the method of information delivery you preferred during this trial (please number each one from best (1) to worst (4)).

Map ____________
Audio ____________
Visual Screen ____________
Audio and Visual Screen ____________

2. Please circle a number that represents how you feel for each question below

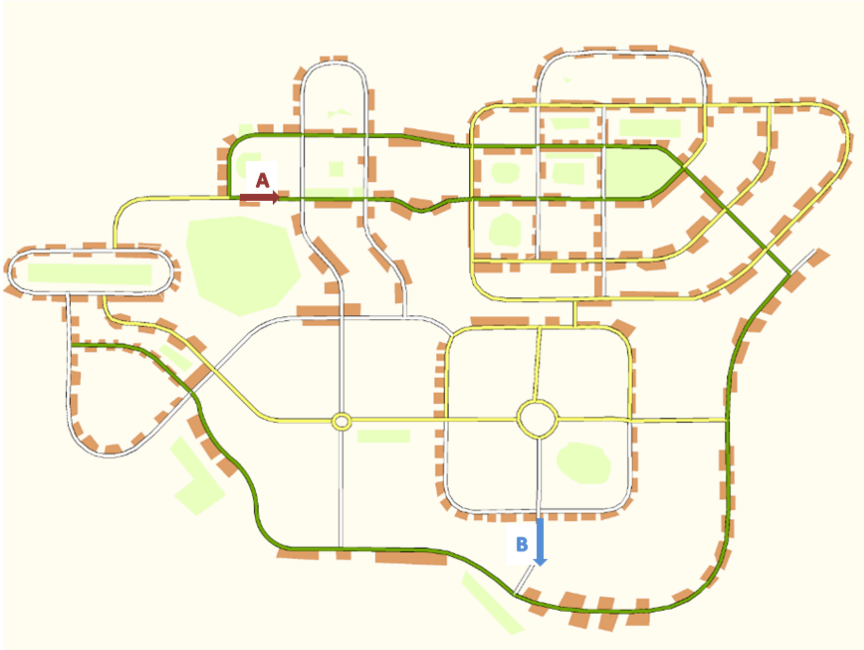
	Very Good	Good	Slightly Good	Neither Good or Bad	Slightly Bad	Bad	Very Bad
How did you rate the use of landmarks within the navigational information?	7	6	5	4	3	2	1
How did you rate the use of landmarks within the visual navigational information	7	6	5	4	3	2	1
How did you rate the use of landmarks within the audio information	7	6	5	4	3	2	1
How did you rate the use of landmarks within the visual screen	7	6	5	4	3	2	1

3. Please circle a number that represents how you feel for each question below

	Strongly Agree	Agree	Slightly agree	Neither Agree or Disagree	Slightly Disagree	Disagree	Strongly Disagree
Without help with car navigation I will start drive less	7	6	5	4	3	2	1
Without help with car navigation I will start to drive less to unfamiliar locations	7	6	5	4	3	2	1
I found the use of landmarks of benefit to my navigation	7	6	5	4	3	2	1
I would like to use a IVNS that used landmarks in my car	7	6	5	4	3	2	1
I would travel more to unfamiliar journeys if I was navigated by landmarks	7	6	5	4	3	2	1

10.13 Appendix M: Simulator Map

Please plan the most direct journey you can from the A to the B



Notes:

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