Vehicle ergonomics and older drivers

by

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Doctoral thesis submitted in part fulfilment of the requirement for the award of Doctor of Philosophy of Loughborough University

Abstract

There is a growing population of older people around the world and the population of older drivers is increasing in parallel. UK government figures in 2012 reported that there were more than 15 million people with a driving license aged over 60; more than 1 million of these were over 80. The aim of this thesis is to determine the requirements of older users for an improved driving experience leading to recommendations for the automotive industry.

Initially it was necessary to understand some of the key issues concerning the driving experiences of older drivers; therefore a questionnaire survey of drivers of all ages (n=903) was conducted supplemented by interviews with drivers aged ≥ 65 years (n=15). Areas covered included: musculoskeletal symptoms, the vehicle seat, driving performance and driving behaviour. Respondents reported that they were dissatisfied with adjusting specific seat features, for example the head rest height and distance from the head; females reported more difficulty than males. Reaching and pulling the boot door down to close was difficult for 12% of older females. Older males and females also reported more difficulties with parallel parking and driving on a foggy day than younger drivers ($p<0.01$). Nearly half of the sample (47%) reported that other drivers' lights restrict their vision when driving at night.

An in depth study was conducted to compare participants' own vehicle (familiar) and a test vehicle (unfamiliar) to understand how design of the vehicle cab impacts on posture, comfort, health and wellbeing in older drivers (n=47, ≥50 years). The study involved functional performance assessments, seat set-up process evaluation (observations and postural analysis), ergonomics and emotional design based evaluations of car seat controls. Many issues were identified related to the seat controls such as operating, accessing, reaching and finding, particularly for the head rest height and lumbar support adjustments. Approximately 40% of the participants had difficulty turning their head and body around to adjust the head rest height, and the majority of these were over 80.

This led to a series of workshops (including a participatory design exercise) with 18 participants (4 groups, ≥ 65 years).The aim was to explore the optimum positioning and operation of controls for older drivers. This research has provided foundational data and makes design recommendations for the automotive industry with a focus on making seat controls more inclusive (operation, location, type, size, colour and materials) and meet the requirements of older drivers.

Acknowledgements

I would like to thank Dr Diane Gyi and Professor Neil Mansfield for their expert discussions and guidance throughout this project. Their support and encouragement gave me confidence, always felt grateful to work with them.

I would like to acknowledge the EPSRC DTG Fund and Nissan Motor Co. Ltd for funding this research.

Special thanks to organisations and institutes such as; University of Third Age, PROBUS (Retired professionals), ROSPA, IAM, IED, IEHF, AGE UK and Loughborough Design School staff for enabling me to get in touch with volunteers to take part in my research.

I would like to thank all my participants who spared their valuable time to be involved in my research.

Also would like to thank Alun Owen, very grateful for his statistical guidance during this research.

I also would like to thank the Design school staff and colleagues in LDS 1.23 for providing fun and friendly atmosphere!

Finally, to my family for their endless support, I would like to thank my mum Mehribani, my sisters Ayfer and Burcu and my brother in law Baki.

This thesis is dedicated to my grandparents Huseyin Ocak and Sultan Ocak.

Publications

KARALI, S., GYI, D.E. and MANSFIELD, N.J., 2014. Better vehicle design for all, S. SHARPLES and S. SHORROCK, eds. In: *Contemporary Ergonomics and Human Factors 2014*, 7-10 April 2014, CRC Press: Taylor & Francis, pp. 413-416.

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Chapter 1- Introduction

1.1- Background to research

Vehicle design and performance are constantly developing; becoming smarter and more sophisticated. With the aid of technology vehicles are now equipped with many features; for example, technologies to assist the user with specific driving tasks, e.g. parking. Some contemporary vehicles incorporate intelligent parking assist systems that enable vehicles to park themselves, and some are fitted with parking sensors to assist the driver during parking (Bradley et al., 2008). These vehicles may also incorporate many features that provide feedback to users, e.g. blind spot alert and parking sensors/cameras.

On the other hand the automotive industry is facing new challenges and economic limitations (Bhise, 2012); one such challenge is determining the needs of older drivers. There is a growing population of older people around the world, mainly in developed countries (Meyer, 2009) and as a result, the population of older drivers is showing a parallel increase (IAM, 2012). Although some automotive manufacturers such as Ford have focused some of their research on older users where they created a 'third age suit' in the 90s in order to understand the issues in this age group, the needs and expectations of this population and many cars on the street do not fully address the needs of people with age-related disabilities (Herriotts et al., 2005).

Driving is an important activity for many older people in order to maintain their daily activities and keep their independence in tasks such as shopping, attending the doctors' surgery, visiting friends etc. (Musselwhite and Haddad, 2008). On the other hand, all vehicles are claiming to provide a positive driving experience, but do they really meet the requirements of users of all ages? Older drivers want to drive vehicles that demonstrate they are active, which clearly indicates that older drivers are not keen on driving cars that specifically designed for them e.g. cars with swivel seats. Many also hold the view that the driving package of most cars is designed to satisfy the needs of 95% of the able-bodied male driver population (Nicolle, 1995).

This PhD was part funded by EPSRC and an automotive client; the latter were kept informed and helped direct progression of this research.

1.2- Aim and objectives

The aim of the research presented in this thesis is to determine the requirements of older users for an improved driving experience. The following research objectives were identified:

Objective 1: To identify key issues with the driving experiences of older compared with younger drivers.

Objective 2: To understand how design of the vehicle cab impacts on posture, comfort, health and wellbeing in older drivers.

Objective 3: To explore design solutions to specific age-related challenges and to make design recommendations for the automotive industry.

1.3- Methodology

A detailed review of the literature was conducted in order to understand the key issues and identify gaps in knowledge for further exploration (Objective 1). Additionally, a questionnaire survey supplemented by interview was developed to understand the driving experience of older people, which then allowed a comparison of findings with the literature (Objective 1). As a result an in-depth audit study was undertaken capturing the postures of older drivers together with reasons for their choices. It also explored what influences the postures adopted in cars and factors that affect comfort, health and wellbeing (Objective 2). Finally workshops were conducted in order to understand specific design requirements and explore design solutions. The findings are presented in this thesis which will include recommendations for the automotive industry and overall conclusions (Objective 3).

1.4- Structure of the thesis

The thesis is structured as follows. **Chapter 2** presents a review of the literature, including: effects of ageing on the body; older drivers, car seat design and posture. **Chapter 3** presents the literature relevant to the research methods and methodology, including: research paradigm; research strategy; mixed methods; survey studies and experimental studies. **Chapter 4** reports on the questionnaire survey and interviews conducted to identify key issues with driving experiences of older compared with younger drivers. **Chapter 5** reports on an in-depth audit through capturing postures adopted by older drivers together with reasons for their choices. **Chapter 6** will describe workshops conducted with older drivers in order to explore design solutions to specific age-related challenges. **Chapter 7** presents the findings of the research as a whole together with recommendations for the automotive industry. Figure 1 illustrates the structure of this report and how the different chapters relate to each other.

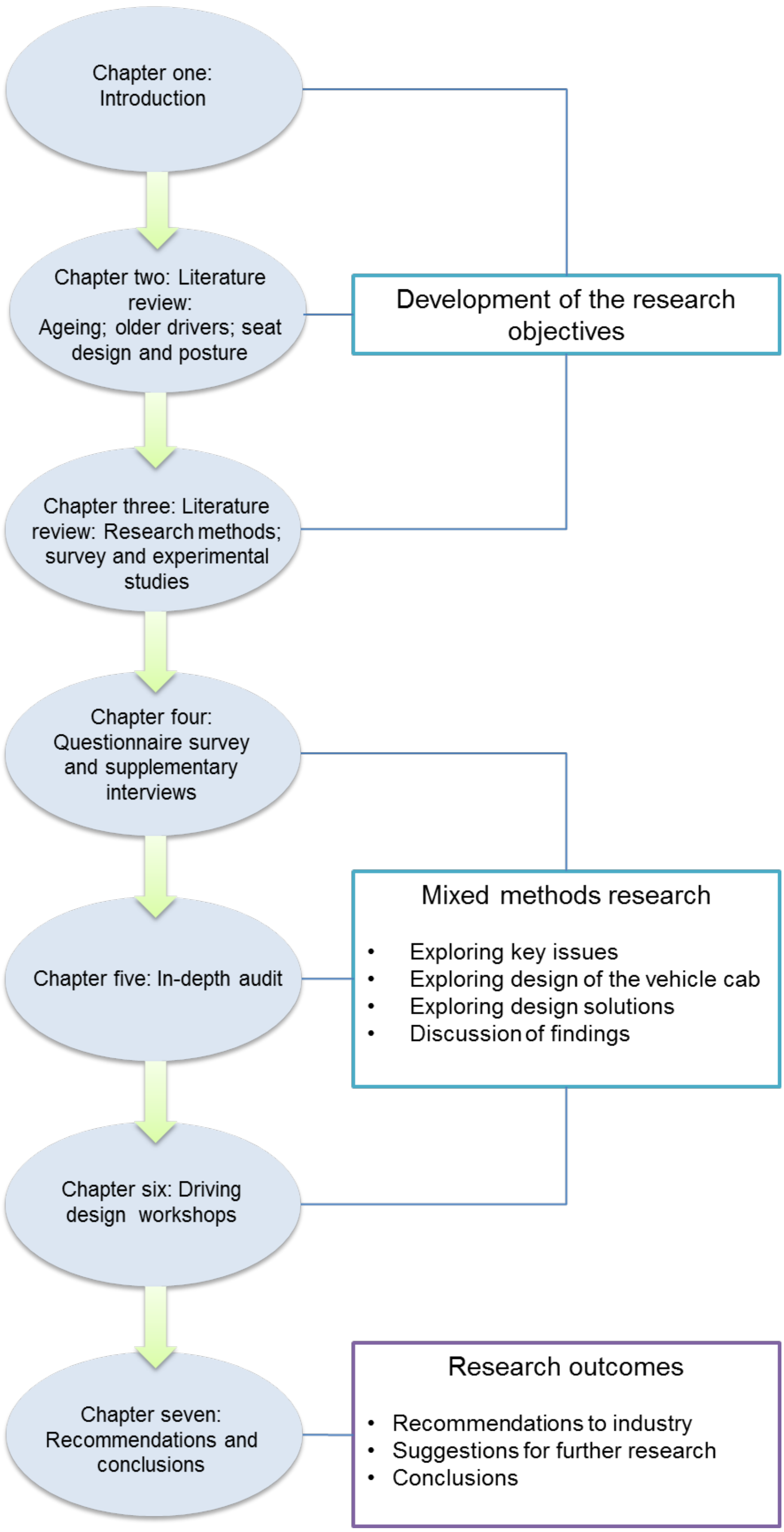

Figure 1: General structure of the thesis

Chapter 2- Literature review: ageing and older drivers

The literature review spreads into two chapters. This first chapter specifically focuses on the effects of ageing, older drivers, seat design and posture. The second chapter (Chapter 3) mainly reviews the data collection tools and methods related to older drivers. The objectives of this chapter were to:

- Understand the ageing process as well as the key issues associated with older drivers;
- Identify and discuss the current issues/gaps in the literature related to these.

A detailed literature review has been carried out to understand the previous research relevant to the topic. Relevant information was selected from journals, reports, conference proceedings and books. Topics included: general effects of ageing on the body; ageing and biological changes; ageing and anthropometric changes; decline in motor skills; sensory decline; older drivers and vehicle ergonomics; cognitive factors and older drivers; driving workload and older drivers; seating and posture for older drivers; and ingress/egress.

In order to collect the relevant information, various databases and library resources have been used. Some examples include Science Direct, Ergonomics Abstracts and Medline. The search strategy involved keywords such as: older driver; senior driver; ageing driver; ageing*; aging*; ageing AND vision; ageing AND vehicle AND ergonomic; vehicle OR automotive ergonomic*; driving posture; older driver posture*.

Other search strategies involved inclusion of references lists from specific papers relevant to the research topic. Abstracts from relevant papers were reviewed for their relevance to the topic; specific papers were excluded due to inconsistency in relevancy of the information to the topic (e.g. older drivers, crashes and injuries), other excluded information is based on quality (e.g. number/age of participants, duration of study, method of analysis, etc.). In addition, the quality of the methodological approaches used for the studies were also considered, for example papers that did not involve triangulation of their results (e.g. mixed methods) and only relied on a single method. Also some papers were excluded due to lack of detailed information on the outcomes of their results/findings in order to understand the reasons behind these.

2.1- Ageing demographics

The proportion of older people is increasing around the world, especially in developed countries (Meyer 2009). This increase is linked to a reduction in birth rates, progress in the health sector, availability of treatment for various age-related disease and improvements in the quality of life of people (Panno 2005). Compared to the mid-nineteenth century, health standards are enormously developed (Partridge 2010), for example at the beginning of the twentieth century the average life expectancy for a North American was 45 years and a more recent estimation is eighty years (Panno 2005). According to Oeppen and Vaupel (2002), in the USA average life expectancy has had a steady increase of 2.5 years for every ten years over the last 150 years and will further increase.

It is appropriate to provide some figures relating the ageing population among some of the developed countries around the world. Based on the figures provided by Office for National Statistics (2013), in the UK over the past twenty-five years the number of adults over 65 grew by 20% to 10.3 million and again over the same period those under 16 years old fell from 21% to 19%. Additionally, the number of people aged 85 and over increased more than 50% to 1.4 million in the UK (UK National Statistics, 2013).

In Europe, the percentage of people aged over 65 is expected to rise from 16% in 2010 to 29.3% in 2060. The European population aged over 80 is set to rise significantly. In 1960 it was just 1.4%, in 2010 this figure reached 4.1% It is estimated that in Europe the population aged over 80 will increase to 11.5% by 2060 (Creighton, 2014).

In the United States, there was a population of 12 million people aged 65 and older in the 1960s. This increased to 36 million by 2002 representing a threefold increase in this age group; there has been a corresponding eightfold increase in the age group of 85 and older (Meyer 2005). The fastest growing ageing population is in Japan, where the number of people aged 65 and older has increased over time from 15 million in

1990 to 29 million in 2010 (Tamiya et al. 2011). This is the highest proportion in the world and it is estimated that by 2050 40% of Japan's population will be 65 years and older.

In 2020 drivers aged 65 and older will represent 16.2% of the whole driving population in the USA. In the UK there is an increase in the number of older people with drivers' licences who currently drive. According to January 2012 figures of DVLA: there are more than 15 million drivers aged over 60; more than 1 million are aged over 80 (IAM, 2012). Also this demographic information indicates that the automotive industry is facing a new target population. Additionally, the BBC has reported that there are 191 people aged 100 years and over still driving vehicles and more than 4 million drivers over 70 (BBC, 2013).

2.2- Effects of ageing on the body

Throughout the ageing process a person may experience specific changes on their body; these include physical, cognitive, sensory and biological changes. This section provides an overview of these changes.

2.2.1- Terminology (young and old)

It is necessary to consider the diversity in what is defined as young and what is defined as old. For example in the US a middle aged person falls into the category of 40 to 65 years of age. Old age is considered as 65 to 75 years of age, very old age is categorised as 75 to 85 years of age and a person over age 85 is categorised as old-old (Shephard, 1997; Kroemer, 2006). According to Fisk et al. (2009) there is not a definite answer to categorise between young and old. For example when presenting data or a graph, older adults are represented as over age 50 or over 65. Kirkwood (1999) pointed out that age related changes in a person show different characteristics from one to another. Although the general ageing process is similar, specific features can vary, for example if a person has grey hair, this does not indicate that another person of a similar age will go grey. Shephard (1997) explains that the rate at which people age varies individually; compared to a 70 year-old, a 90 year old could remain more active.

2.2.2- Biological changes effects of ageing

There are many theories into the biology of ageing, some examples are (adapted from Panno, 2005):

- Error Catastrophe Theory: was first introduced half century ago (1960s) and based on the idea that over time there is a tragic amount of error build-up causing death of a cell and possibly the whole organism.
- Rate-of-Living Theory: this theory is not primarily concerned with underlying processes of ageing, in fact it supports the idea that the faster or harder an individual lives, their life span is more likely to be reduced. It is important to argue that this theory contradicts with the fact that in order to improve their health and to stay fit, most people do exercises and train their body, therefore the acceptance of this theory can be argued.
- Telomere: this is a basic DNA sequence repeated several times, it is found at the edge of each chromosome. Telomeres are necessary for the chromosomes to conduct appropriate repetitions in order to divide cells. If Telomere damage occurs, the implication is that they become progressively shorter thus weakening the main DNA strand.
- These theories have been around for 40 years and even today many believe the mechanisms of ageing process are not clearly understood (Panno, 2005). Biological factors relating to the process of ageing are not the primary concern of this research and are therefore not considered in detail.

2.2.3- Effect of ageing on posture and physical strength

With ageing, changes are apparent on the skin, as a result it wrinkles and sags due to loss of fat in the hypodermis. Age spots also appear, generally in colours such as light brown and black, and are associated with build-up of melanin (Jenkins et al. 2012). With regard to the effect of ageing changes on posture, Roaf (1997 pp.62) explains this as:

> '*Inevitably with age the intervertebral discs become thinner and the vertebrae more osteoporotic. Some shortening of the trunk and forward bending also always occurs. In joints of the limbs there is thinning and loss of elasticity of articular cartilage and reflexes are less brisk.'*

The musculoskeletal system is the combined operation of the skeleton and skeletal muscles (Ward et al. 2005), providing support and movement for the body (Silverthorn, 1998). As age increases, bones become more brittle and fractures can occur easily (Herlihy, 2007); this indicates that older people are more fragile compared to younger. For example, there is an increase with the inner and outer diameter of the long bones and a reduction in the overall bone mass occurs, which can lead to age-related osteoporosis (Kroemer, 2006). Bonnick (2006) has reported in his review that compared to females, males have 10% to 12% higher peak bone mass and greater size of bone. For both genders there is a variation in the age bone loss begins between skeletal areas; it is certain that bone loss is common for both genders after age of 50.

A decline in muscle strength is also known although authors contradict in this area regarding what age this decline starts. Metter et al. (1999) indicates that muscular strength is at its maximum between ages 20-35 and shows a small decline until the age of 50, after this age it shows a rapid decline. There is wide research in this area; some literature has been compared in terms of their methods, duration, sample size and age as shown in Table 1.

Table 1: Decline in muscle mass and strength

Author(s)	Main aim	Method	Sample	Outcome
Goodpaster et al. (2006)	To investigate the changes in muscle mass and strength of older people	Longitudinal study (duration 3 years)	(n =1880, participants aged between 70-79 years)	A rapid decline in muscle strength for both genders. Males lost double the amount of strength capacity compared to females each year: for white male 3.42% and black male 4.12% loss; for white female 2.65% and black female 2.97% loss.
Dohetry, (2001)	The influence of ageing on skeletal muscle mass and strength	Literature review (cross-sectional and longitudinal studies)	Search strategy or number of papers reviewed not indicated	Reduction in muscle strength after 30 years of age (10-15% every 10 years). The rate of force loss accelerates after age of 60 years.
Hurley, (1995)	Exploring the effect of age and gender on muscular strength	Literature review (cross-sectional and longitudinal studies)	Search strategy or number of papers reviewed not indicated	Cross-sectional studies indicate 35-45% decline between ages 50-80 years. Longitudinal studies show a higher rate of loss with age.
Hortobagyi et al. (1995)	Influence of ageing on three expressions of muscle strength (isometric, concentric, and eccentric)	Cross-sectional study	(60 males, age range 18-80 years and 30 females age range 20-74 years)	The results revealed that with the isometric and concentric forces a decline of 30N per decade and only 9N per decade reduction in eccentric strength.

In terms of the grip strength, Pheasant and Haslegrave (2006) explained that hand and wrist strength varies between individuals. A study conducted by Dhara et al. (2011) with a total number of 286 subjects (51-90 years of age) in India revealed that males have significantly higher grip strength than females. As the age increases, grip strength shows a decline. People living in rural and urban areas were also examined and a significant difference was identified in grip strength for both groups ($p<0.05$). Participants living in rural areas had greater grip strength than those living in urban areas for both male and female. This may have specific reasons such as differences in amount of physical activity conducted.

2.2.4- Motor skills

Age related changes in motor skills are associated with physical and cognitive functioning. For instance, with increasing age movement is affected by the erosion and damage to mechanisms such as tendons and tissues which connect the bones to the muscles, leading to symptoms such as pain (Whitbourne, 2002). The decline in the flexibility of tendons and ligaments causes the joints to function in a slower motion (Herlihy, 2007). Eby and Molnar (2012) and Fisk et al. (2009) listed the outcome of these changes as: decline in response time; loss of flexibility; reduction in the ability to carry out continuous movements; inconsistency in movement; weakness in muscle and stiffness in joints.

2.2.5- Anthropometric changes with ageing

As individuals grow older they experience anthropometric changes on their body e.g. a decline in stature and height related dimensions. According to Scanlon (1999) this decline varies from an inch or more per decade due to thinning of the vertebrae. Figure 2 shows the height of the adult civilian population of Great Britain and the United States plotted against age, a steady decline in the stature can be seen (Pheasant and Haslegrave, 2006). But this study is not simply showing a case of shrinking; it is a cross-sectional study and includes factors such as changes in diet and healthcare during the early 20th century. In order to gain a better understanding of changes on stature, some literature has been compared as shown in Table 2.

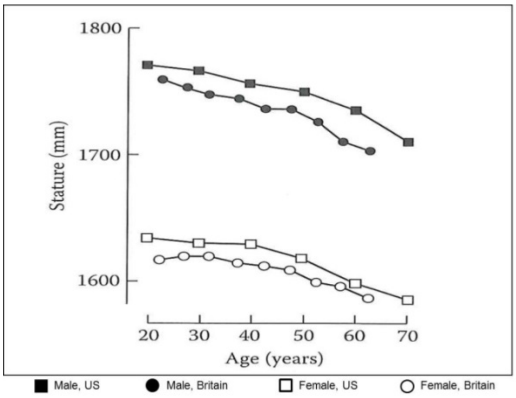

Figure 2: Decline in stature: American population vs. British population (adapted from Pheasant and Haslegrave, 2006)

Table 2: Decline in stature with age

Author(s)	Main aim	Method	Sample	Outcome
Sorkin et al., (1999)	Determining the height loss in relation to ageing and gender	Longitudinal study (Measuring height of males nine times during 15 years and females 5 times during the period of 9 years).	Total sample = 2084 (male and female aged 17-94)	The rate of decrease in height was greater for women than for men. The height loss began from the age of 30 for both genders. It showed acceleration as the age increased. Between the ages 30-70, the average height loss was 3cm for male and 5cm for female. By the age of 80 this increased to 5cm for males and 8cm for females.
Perissinotto et al., (2001)	Anthropometric changes in older (comparing age and gender)	Cross-sectional and longitudinal study (obtaining anthropometric measurements over a year period).	Total sample = 3356 (stratified by age and gender, 65 year and over).	The anthropometric measurements revealed that, a reduction of 0.3cm was observed in stature every year, equivalent to 3cm per decade.
Krishan et al., (2008)	Hypothesis: is there a relation with the decline in stature related to physical activity?	Observational, farmers in Punjab state of North India.	Not provided	It has been observed that the height of farmers is decreasing. Over the past 20 years, farmers and their families stopped working in the fields by employing workers; therefore they are doing less physical activity. There could be a relationship between physical activity and reduction in stature.
Mindell, (2008)	Examining the difference between measured height and demi-span equivalent height (DEH) of older people.	Cross-sectional study (height, weight and demi-span measurements were obtained according to the HSE standards).	Total sample = 3346 (1098 male and 1303 female aged 65 and over)	DEH measurements were higher than the height measurements within the 70-74 years age group for men and all age groups for women. For both genders, no significant difference was found in mean DEH and the measured height.

Throughout the life time a person experiences changes in body weight; this usually shows a steady increase and then a decline with age showing variations for males and females. For males, the decline in body weight (Figure 3) usually starts at around age 50 and for females after the age of 60 (Pheasant and Haslegrave, 2006).

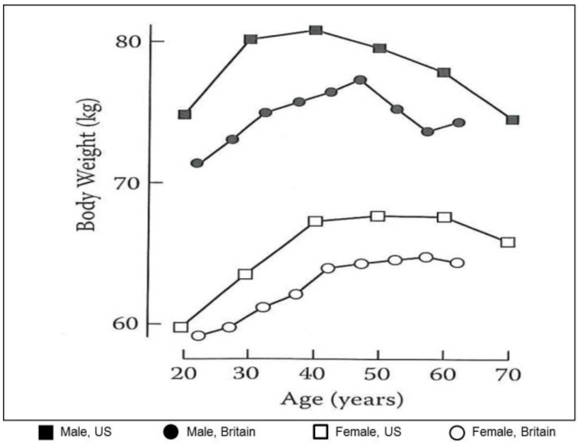

Figure 3: Change in body weight: American population vs. British population (adapted from Pheasant and Haslegrave, 2006)

2.3- Sensory decline with ageing

2.3.1- Hearing

With an increase in age, detection of the high frequency sounds reduces (Whitbourne, 2002; Panno, 2005). Estimations show that majority of people over the age of 50 experience some level of hearing decline (Giacomin, 2014). This decline in hearing capability involves many factors, (e.g. exposure to noise, genetic influences, and diet) and it is therefore difficult to know when normal hearing deterioration begins (Shaheen and Niemeier, 2001)

A review conducted by Harrington et al. (2000) reported that, a fall of up to 20dB can occur until the age of 80 for the 1 kHz tone. They also report that for a 90 year old to hear a sound of 4 kHz tone, it needs to be nearly the same level as the noise of a jet aircraft, clear evidence is not provided to support this information. Generally the reduction in hearing capacity is usually associated with constant damage to the hair cells in the organ of Corti, which enables the hearing function (Herlihy, 2007).

2.3.2- Haptics and Tactile Function

In a study conducted by Kenshalo (1986) on tactile threshold, the outcomes were interesting; it was based on comparing younger (n=27, ages 19-31) and older groups (n=21, ages 55 to 84) to cutaneous stimulation in two areas of the body; thenar eminence and foot sole. The study looked into six response types: tactile; vibration at

40 and 250Hz; increase/decrease in temperature and increase/decrease in noxious heat. The results showed that older group were less sensitive to tactile sensation and vibration, and their feet were also less sensitive to warm stimuli compared to younger people.

According to Fisk et al. (2009) haptics play a role in the fall incidents and unstable movements in older people compared to younger; and relates this to deterioration of vestibular cues associated to balance stability. For example due to loss/decline in kinaesthetic senses some older adults lose the capability to control body and movement unconsciously, causing serious fall incidents and postural instability.

2.3.3- Taste and smell

There is less reported research on taste and smell compared to other sensory systems such as vision and hearing. As a person reaches the age of 50, a gradual decline can start in taste and smell capabilities (Herlihy 2007). Age related taste loss is associated with changes in the function of the taste cell membranes. In terms of smell, as a person gets older, the olfactory capability reduces and this causes not only loss in sense of smell, it also becomes difficult for the person to distinguish between different smells (Boyce and Shone, 2006).

2.3.4- Vision

Age related visual decline is a broad area and there is a large body of literature, a brief description has been provided on the key points. Age related decline of vision generally starts around age 40 and increases with the age (Fisk et al. 2009; Meyer, 2009). With visual decline, identifying moving objects becomes difficult, night vision also reduces and close distance focusing is lost (Panno 2005). According to Freund & Smith (2011) and Mortimer & Fell (1989), flattening of the cornea and yellowing of the lens with increasing age plays part in decline in night vision. Less light enters the eye, and as part of this older people are more sensitive to bright sunlight and glare. For instance in relation to driving, Freund and Smith (2011) report that driving at dawn, dusk and night becomes more difficult for older drivers and according to Mortimer & Fell (1989) compared to younger, older drivers are more affected by the glare in night driving causing discomfort. Smith et al. (1993) provided a review of the literature on visual decline. They describe the causes of sensitivity to glare with increasing age and how the older eye requires longer time to recover from the glare. Also, the authors detail the reasons on why the amount of the light received to eye declines with age and the visual fields e.g. the angle of eye movements and target detection. These topics are out of the scope of this thesis.

2.4- Cognitive changes with ageing

Fisk et al. (2009) summarises the effect of age related cognitive decline; focusing on memory, attention, and spatial cognition. The specific areas of memory showing age-related changes are shown in Table 3:

Table 3: Effect of age related cognitive decline (Fisk et al., 2009)

Memory	Working memory	• Processes new information, it is the active memory of what is received and currently thought. It can store and manipulate information. It declines with increasing age.
	Semantic memory	• Acquired knowledge. Shows the least reduction with increasing age. But the capability to recall information can be slower and unreliable.
	Prospective memory	• Remembering to do something in the future. Age-related declines are less evident if people have strong cues available as reminders (e.g., take medication with dinner).
	Procedural memory	• The knowledge on how to do something. In terms of obtaining/learning a new procedure, compared to younger adults, older are slower and less successful.
Attention	Selective attention	• Selecting information in order to process it in detail, also to be able to divide attention between sources of information or switch between tasks. Older people perform less well than younger adults when required to coordinate multiple tasks, either by dividing attention or switching attention.
	Multiple task coordination	• Older adults are less successful than younger when coordinating multiple tasks for example dividing or switching attention.
Spatial cognition		• Spatial cognition declines with age, for example, maintenance and manipulation of visual images.

2.5- Research on older drivers

The aim of ergonomics (or human factors) is to design products, systems or processes in order to satisfy the capabilities of the users, rather than adapting the user to these (IEHF, 2013). The term ergonomics originates from Greek words *ergos* and *nomos* which mean *work* and *laws* (Bain et al. 1997). This section will describe the findings in literature based on the work carried out on older drivers, the key issues and the challenges faced by the automotive industry.

2.5.1- Inclusive design

It is important to indicate the relevance and importance of this work in relation to the area of inclusive design. The term inclusive design can be described as: *products or environments are designed that are flexible enough to be usable by people with no limitations as well as by people with functional limitations related to disabilities or due to circumstances* (Fisk et al. 2009, pp. 31). Inclusive design can play a big role in vehicle design and to address the challenges experienced by different groups of people such as older, disabled, children, obese and pregnant women etc. According to Woodcock (2012) some of the biggest challenges of day to day life are based on transport. Therefore, with the aid of inclusive design, identifying the needs/requirements of people with functional limitations such as older drivers may automatically meet some of the needs of other groups such as disabled users. On the other hand it will improve the quality of experience for people with no limitations.

2.5.2- Key issues with driving

A review on the general issues regarding the experiences of older drivers has been carried out. This section provides a review (Table 4) of the general issues experienced by older drivers. These are based on physical, cognitive, and sensory issues e.g. vision and environmental factors such as e.g. driving at night or road signs and technology related. The areas highlighted in this table may need further exploration in order to clarify if these issues still exist. Also it can be interesting to know if some of these issues are relevant to older drivers or common for both young and old.

Table 4: General issues identified in the literature on driving experiences of older drivers

Author(s)	Method	Sample	Facts	Relevant findings	Critique
Smith et al., (1993)	Literature review (descriptive data)		With increasing age, there is a decline in miles driven; most avoid driving at night; in bad weather; in rush hour traffic and avoid long trips.	Reduced visibility when driving at night; difficulty with turning head and body around when reversing; reaching for the seat belt; getting into and out of vehicle.	-Data used from the sources are very old. -It covers physical, environmental, safety, visual factors (broad source of information) related to older drivers and driving. -Lack of information on interaction with in-vehicle features, posture, comfort etc.
Bradley et al., (2008)	Focus groups, questionnaires, simulation and on-road tests	Drivers aged 50 and over (n=230)		Difficulty in turning head and body around when parking; reduced field of view in modern vehicles; unintentional speeding; getting less feedback regarding the speed in newer and quieter vehicles e.g. less engine noise.	-Large sample size and good proportion between age and gender distribution. -Methods used provides good source for triangulation. - Reasons behind the issues identified have been explained clearly. - Good quality of data since the target group was involved in the design process. -Involved mixed methods
Musselwhite and Haddad, (2008)	Interview based study	Sample size = 57	Older drivers tend to want technologies which would improve feedback; they do not prefer autonomous technologies that take over part of the driving task.	Difficulty with identifying road signs; maintaining a constant speed; tiredness and fatigue; parking and reversing; longer reaction times in carrying out specific tasks; glare from the sun; other drivers' lights when driving at night.	-It has small sample size. -No comparison between genders. -Proportion of females (37%) is lower than males (63%). -It only involves qualitative data. -Some issues identified are not described in detail, e.g. tiredness and fatigue, longer reaction times.
Bhise, (2012)	Descriptive			Older drivers can experience difficulties with tasks that demand high physical activity such as: lifting the boot; folding seats; loading and unloading heavy objects. Due to arthritis the following tasks are also difficult for older drivers: unlatching seat belts; operating door handles; pulling hand brakes and turning head to use side view mirrors.	-It is descriptive information. -Describes the effect ageing on interaction with vehicle features. -It mainly focuses on design related aspects. -No sample data provided.
Middleton et al., (2005)	Driving simulation based study (comparing younger drivers with older)	Sample size = 20		As the number of sources and complexity increases, the reaction and movement time shows a parallel increase; problems with making right turn; longer decision times.	-Sample size is too small. -Equal distribution between age and gender.

2.6- Cognitive factors

Various methods are used to assess the cognitive abilities of older drivers regarding their driving performance, although there is not a specific way to determine an individual’s suitability to drive; in the UK when the driver turns 70, the DVLA will send them a form to renew their licence for three years. The driver needs to declare on this form that they are still fit and able to drive safely (Rica, 2013). Other research methods include driving simulations and performance based on road studies (Carr and Ott 2010). Research shows that as cognitive ability reduces, the amount of driving is restricted. This is more common in females; men are less likely to give up driving (Freund and Szinovacz 2002; Ross et al. 2009).

A decline in cognitive functioning can bring safety risks for the driver and to the passengers. A study was conducted in the UK by Bunce et al. (2012) investigating inconsistency and age in driving. It compared younger (mean age: 21 and n=24) and older drivers (mean age: 71 and n=21) through a driving simulator based study. This study revealed that older drivers had greater inconsistency with driving at high speeds (70mph) in a motorway situation. They also had difficulty maintaining a constant speed such as following the vehicle in front. Keeping the vehicle within the lane also showed greater inconsistency compared to younger drivers in urban and motorway conditions. Generally all driving conditions showed higher mental demand for all driving situations.

There are other levels of cognitive impairment, including Alzheimer’s disease (AD) and dementia. However, these are age related chronic diseases and not considered as part of general ageing process. A study based on older drivers with AD and Parkinson’s disease (PD) whereby participants were given a performance based road test showed the following; AD participants had more errors compared to PD’s during the approach to do a lane change, pulling over on a curb and making a turn across oncoming traffic (Grace et al. 2005). This was a two phase study based simulation and on road tests, and in both experiments it was observed that for AD participants the difficulty was in carrying out the turns in traffic.

2.7- Driving workload

Driving workload is caused by the combination of a range of driving and non-driving tasks; Bhise (2012) describes these below:

- Driving tasks: these can be divided into two categories, primary controls and safety-related driving controls and displays. Primary controls include operation of steering and pedals during monitoring the roadway. Safety-related controls and displays include the operation of controls such as defrosting the windshield. Also responding to the demands from the roadway is part of the driving tasks, for example, curves and merges.
- Non-driving tasks: these include the operation of secondary controls such as climate controls, entertainment devices or reading displays. It involves activities such as looking at billboards/pedestrians and reading maps or talking with other passengers.

Kim and Son (2011) conducted an on-road assessment of driving workload in Korea (5 tasks) with older drivers (n=40) including operation of indicators, reading the speedometer and setting the climate control temperature. Compared to younger groups (aged 20-29), older people (aged 60-69) experienced a higher driving work load. On average older drivers took 3.9s longer to complete the tasks and the largest increase was changing the radio station which took 8.35s longer. Participants were given a specific car for the study (not their own car); this may have some effect on their performance. More realistic results could have been obtained by allowing participants to conduct the study with their own vehicle which they had experience with. Then more robust data on driving workload; time taken to operate the controls and age related decline in reactions could then have been obtained, and to avoid bias.

2.8- Car display design (visual)

Kim et al. (2011) investigated the usability of a car dashboard display comparing older and younger drivers (n=32) based on 6 different dashboard designs (high/low clutter; high/low contrast; use of colour). The results showed that contrast in the sizes of text and reduced clutter improved driving performance and that too many colour elements reduced performance. They also identified that low clutter designs are best for the dashboard making recommendations to reserve maximum size contrast for the central panel and use colour for background fills as well as the elements. For such studies, involving the users (older drivers) in the design phase can lead to the identification of the specific needs and the requirements can be set by the designers (Bradley et al. 2008). Participants may have selected the most appropriate dashboard within the options provided in Kim et al. (2011) study, but it is important to understand that this may not completely answer their demand. The dashboards involved in this study were graphical designs, the study could have been improved if dashboard displays also had analogue designs, and a comparison between analogue/digital displays could have been conducted.

2.9- Seat design, posture and controls for older users

The design of the seat and its features play an important role for the user comfort. However, there is a lack of research regarding seat design and posture solutions specifically for older drivers. This is noticeable from the figures of a survey conducted by Herriotts (2005); it was found that 6% of older drivers reported using additional items such as a bead mat to help them obtain a comfortable driving posture. 24.9% of older drivers also reported using a seat cushion compared to 2.1% of younger drivers ($p<0.001$). Shaheen and Niemier (2001) suggest that when designing seats for older driver the following should be considered:

- The seat cushion should be flat and rigid for users to be able to move into a desired position when seated.
- Seat surfaces should be designed to minimise friction, this will then enable users to swivel easier during entry and exiting the vehicle.

It can be understood that the suggestion of Shaheen and Niemier (2001) is more concerned with getting in and out of the vehicle and in order to do this the seat should be rigid and flat with less friction.

A study conducted by Kyung and Nussbaum (2009) with 38 participants (younger = 20 years and over compared with older = 60 years and over) aiming to explore driving postures adopted by older drivers compared to younger. The study was based on an adjustable driving rig based on a simulated driving condition. It was found that older drivers had a smaller angle in the right elbow and the left hip in sedans. In SUVs six joint angles were smaller; this revealed that older drivers adopted a posture close to the steering wheel. This seems interesting information but it may need a further analysis/study to understand the type of postures they selected. Also there is not clear information about if this was common for both males and females.

Another study conducted by Kyung and Nussbaum (2010) involved different vehicle types and a rig in a lab environment with various types of driver seats. This study focuses more on exploration of user comfort and suggests that seat cushion should be soft to provide more comfort to the user. This is the opposite of the suggestion by Shaheen and Niemer (2011) previously discussed. Participants were asked to rate the comfort; at the same time with the use of pressure maps their pressure measures were obtained. It was found that:

- Some pressure measures showed different pressure loadings between younger and older drivers as a result of their postural differences.
- They suggested that in order to increase the user comfort the average pressure on the right buttock should be greater compared to left buttock.
- In order to improve the seat comfort, the cushion area contacting the buttock should have softer material.

Erol et al. (2014) looked into seat comfort in different perspective to the common methods used in the field. The authors carried out a study to find out if visual design of the seats had an impact on perceived comfort. In total 18 participants took part in the study (50% male, 50% female), two seat bucks were used in a static lab condition. Both seats were covered with two different seat covers: the "*streetwise accessories*" (black seat) and "*ultimate speed*" (grey seat), both seat covers had the same material and thickness. The seats were also identical in terms of their shape, stiffness, tilt angle and physical structure. Participants were asked to sit on the seats for one minute and rate their perceived comfort. This was carried out in two conditions, initially; seats were covered with white cotton sheets to design of both seats. The second stage was carried out without covering the seats, giving the opportunity for participants to see their actual design. It was identified that the design of the seat covers had a significant effect on the perception of initial comfort. Interestingly, participants indicated through their comments that elements such as the seat pattern and stich had an influence on their feelings which in return influenced their perceived comfort. Based on these findings the authors hypothesise that the visual design and aesthetics affected the initial experience of comfort and physical shape. The outcome of this study is interesting and it shows that when designing seats, automotive manufacturers should not only focus on the features of the seat but also incorporate aesthetics and visual design in order to increase the satisfaction of the users.

In-depth research is required in this area in order to determine comfortable postures. As mentioned in previous section 'general effects of ageing on the body' older people experience changes in body shape and measurements. Taking these into account the seat design should focus on the changes in posture and look for ways to support the body in a comfortable position. Gyi (2012) suggests that more data is needed to focus on dynamic and functional anthropometric measurements in vehicle design to accommodate specific needs of older drivers. Some examples include postures for reversing; postures for operation of seat adjustment controls; opening car boots; reach to seat belts and reach to adjust mirrors.

In order to benefit the people who suffer decline in intervertebral disk spacing in the spine, there is a need for better seat design and the location of primary controls should be closer to aid the user with such decline (Thompson, 1995). Based on the ergonomic review conducted by Haigh (1993) on the process of aging and the challenges for design, the author has suggested some design guidelines for better designed controls due to the decline in hand function as people age:

- Size: user should be able to grip it with one hand; e.g. not so tiny and hidden or not very large.
- Shape: should be easy to hold
- Texture: the user should be able to grip it without slip.

In addition, the authors McCauley-Bush (2012), Kroemer (2001), Guastello (2006) and Vink (2004) provided detailed guidelines on the design of controls through consideration of ergonomics principles. Most of these principles may also be relevant in the design and development of car seat controls. Although these suggestions are important, these are not specifically related to seat or vehicle primary controls, they are generic guidelines for control design with little detailed information. For instance Williams et al. (2011) conducted a study to explore user-centred design and evaluation of electrically operated seat adjustment controls in luxury vehicles (Sport Utility Vehicle's) but did not look into age and gender. It is important to state that the use of manual controls is still common in most vehicles or on some aspect of these vehicles and so there is a need for detailed information.

2.10- Model for comfort

It is also necessary to define comfort and discomfort and provide an overview of current thinking. Comfort models can be useful and are discussed in the context of the proposed research in order to provide a unifying framework for discussion of the various aspects in a systematic way.

In a special issue published by Vink and Hallbeck (2012), ten papers were explored that contribute to knowledge in relation to product comfort and associated models. Specific elements of these models are then combined into a new model which links comfort parameters to products. The author points out that the ten papers define comfort as “comfort is seen as pleasant state or relaxed feeling of a human being in reaction to its environment” and “discomfort is seen as an unpleasant state of the human body in reaction to its physical environment”, but each has specific contributions to new knowledge in the field of comfort. Based on the outcomes of these papers, the author proposed a new model which mainly involves elements from the models of Moes (2005) and De Looze et al. (2003). This new model is described below (key to Figure 4) and shown in Figure 4.

- *The interaction (I) with an environment is caused by the contact (could also be a non-physical contact).*
- *This can result in internal human body effects (H), such as tactile sensations, body posture change and muscle activation.*
- *The perceived effects (P) are influenced by the human body effects, but also by expectations (E).*
- *These are interpreted as comfortable (C) or you feel nothing (N) or it can lead to feelings of discomfort (D).*
- *There is not one form of comfort or discomfort experience, but it can vary from almost uncomfortable to extremely comfortable and from no discomfort to extremely high discomfort. It could even be that both comfort and discomfort are experienced simultaneously* (adapted from Vink and Hallbeck 2012, pp.275).

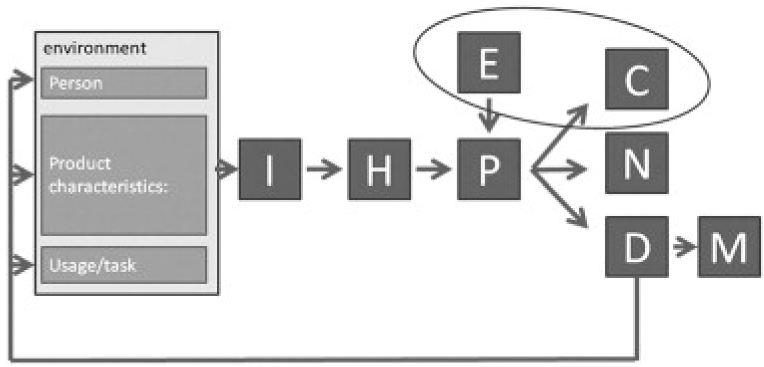

Figure 4: The new proposed comfort model (Vink and Hallbeck 2012)

2.11- Head movement restrictions

The field of view/vision is the extent to which *the driver can see 360 degrees around the vehicle in terms of up and down (vertical or elevation) angles and left and right (horizontal or azimuth) angles of the driver's line of sight to different objects outside the vehicle* (Bhise 2012, pp.105).

Turning the head and body around during driving is one of the common issues experienced by all drivers and it's a problem for older drivers; this also has an impact on the useful field of view. A study was conducted by Isler et al. (1997), in order to analyse the age related effects of restricted head movements on the useful field of view of drivers. Eighty participants, four groups of 20 (10 males, 10 females), aged under 30 (young), 40-59 (middle aged), 60-69 (older) and over 70s (oldest) participated in tests in order to measure the maximum head movements. Their maximum head movements were measured in degrees using a head turning measurements device developed by the research team. This device was formed of a cycle helmet with a stylus pointer attached at the centre, extending parallel to the line of vision (pointed directly ahead). Arrow shaped equipment was then hung to the stylus using a cord allowing a reading to be taken with the aid of a shoulder harness. Two specific measurements were taken; these were maximum head rotation to the left and to the right. Figure 5 shows that as the age increases, the maximum head movement decreases. There is 27 degrees of maximum head movement difference between the younger and oldest participants.

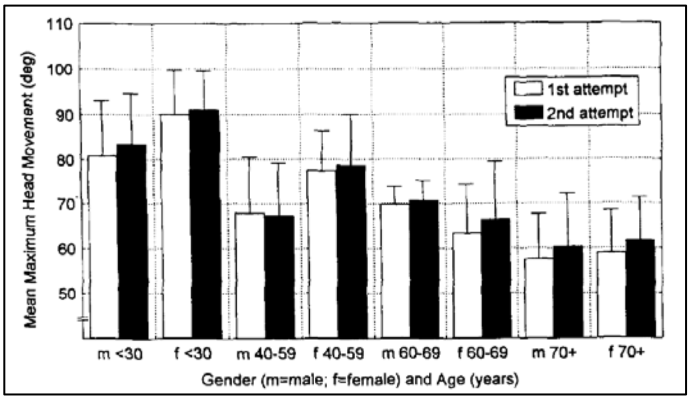

Figure 5: Mean maximum head movements (adpated from Isler et al. 1997)

This study reveals that the head movement capabilities of older drivers need closer attention. Exploring the speed of the head movement to a specific target would be useful.

2.12- Ingress/egress

Ingress and egress is a technical term used in ergonomics referring to getting in and out of a vehicle. The information related to ingress and egress has been identified as one of the major issues experienced by older drivers.

A study was conducted by Dellinger et al. (2008) through data analysis of the injuries admitted to emergency departments in USA (2001-2003). It was identified that there were 37,000 injuries per year in the USA among older drivers during getting in and out of their vehicles. 43% of these were falls related to the vehicles themselves. The analysis also revealed that the risk of falls increased with age. Most of the fall incidents occurred during egress.

A questionnaire study conducted by Herriotts et al. (2005) with more than 1000 drivers supports that most difficulty is experienced with getting out of the vehicle. The study compared older (aged 60-79, n=1013) vs. younger drivers (aged 20-59, n=97) in the UK. 32.2% of older drivers reported difficulty with getting out of the vehicle and 25.5% indicated difficulty with getting in the vehicle within the older age group (aged over 60). A follow up question was sent out to all of the respondents covering all ages (n=602) to identify which parts of the car were causing difficulty during entering and exiting, the main findings are shown in Figure 6:

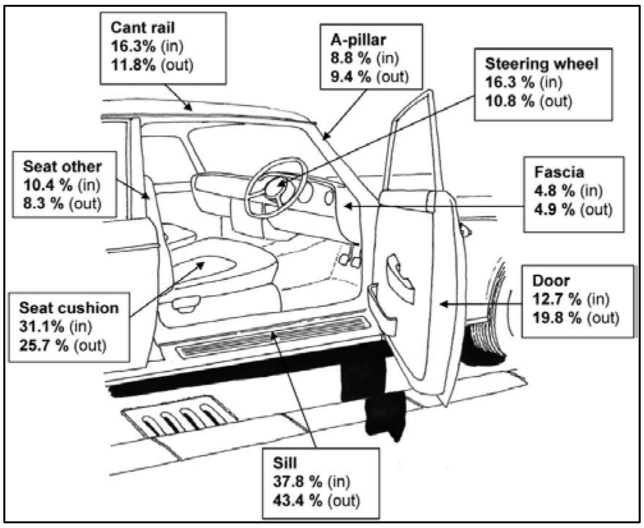

Figure 6: Car features causing difficulty entry and exit (adapted from Herriotts, 2005)

Although a questionnaire survey is a good way of understanding general issues, it may not be the best way to gain in-depth information. Observational studies may help to understand in more detail the experiences of people during entry/exit from vehicles.

2.13- Crash risk for older drivers

In a study carried out by Welsh et al. (2006), using UK in-depth crash injury data (CCIS) and injury outcomes for older passenger car occupants was analysed. Once the research team had explored the National accident data in the UK, they identified that older drivers are less likely to be involved in a car accident compared to younger drivers; this is also backed by Dahmen-Zimmer et al. (2014). However, in the case of an accident older drivers are more likely to lose their life or experience permanent injuries compared to younger drivers. Through the analysis of National accident data in the UK, Welsh et al. (2006) reported the injury severity by driver age group. For the frontal crashes, the KSI (killed or seriously injured) rate increases with age, but this is also similar for younger groups. One important result shows that when they analysed the data for the struck-side impacts, older people are at higher risk of death and serious injury. The risk of death increases with age as shown in Figure 7.

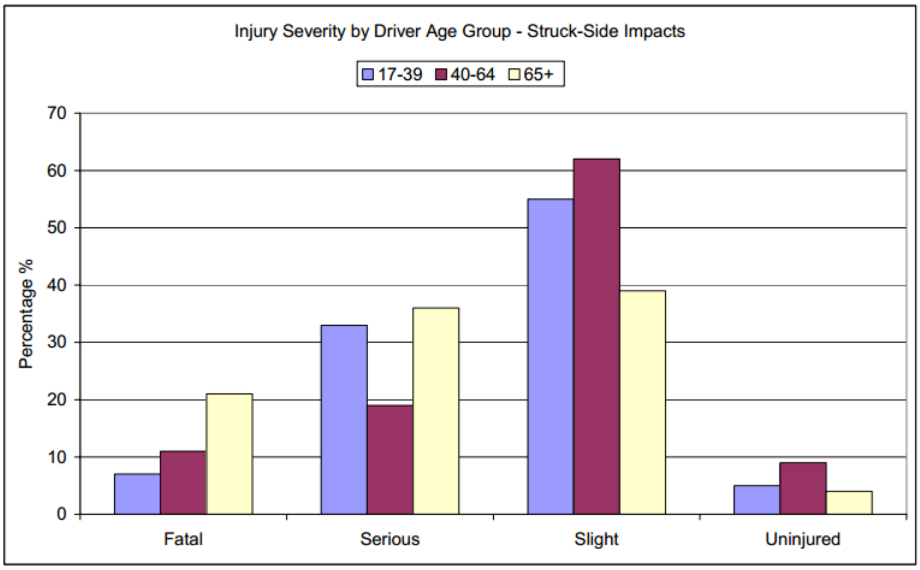

Figure 7: Injury severity by Driver Age Group (struck-side impacts)- adapted from Welsh et al. (2006)

One of the cases when struck-side impacts may occur is in intersections when making a left turn (right turn in the UK) and this may be minimised/solved through designing assistive systems to the driver.

A broad study was carried out by Dahmen-Zimmer (2014), focusing on exploring the challenges with making a left turn (right turn in the UK) at intersections for older drivers. The study involved comparison of accident statistics, observations, simulator based experiments which then lead to development and evaluation of a left-turn assistance. The process started with identification of types of manoeuvres which lead to accidents in intersections, this was made through the analysis of accidental data. A comparison was then made using the results obtained through a field observational study conducted at specific intersections using multiple video cameras, combined with time codes. By comparing both data, significant differences were identified between older and younger drivers. The accidental data on manoeuvring intersections showed that:

- Entering and crossing at intersections showed high risk for older drivers
- Passing by the intersections showed higher risk for younger drivers, especially due to tailgating
- Turning left at intersections were especially high risk for older drivers
- Loss of control, especially in rural areas: higher risk for younger drivers.

The following conclusions were made through the field observations:

- The accepted time gaps were estimated through speed reductions and stops at intersections. As a result, older drivers took longer time to manage the task due to their reduced functional capabilities.
- Particularly intersections with a curve or with construction work had a negative impact on older drivers.
- The intersections with more visible guidelines reduced the risk for both younger and older.

The research team then conducted a simulator based experiment with 17 younger drivers (average age 37) and 18 older drivers (average age 67). The experiment scenario was set in three types of intersections (standard, asymmetric and combined) with various guidelines. These guidelines were with or without traffic lights, yield signs and stop signs. The measurements of temporal and spatial parameters for all courses and subjects were obtained in order to determine the position of simulated car in every situation, the speed and time-to-collision at each intersection.

Similar to field observations, more visible guidelines were also used in simulator environment; this caused a positive effect on the traffic safety for drivers. Additionally, older drivers used different strategies to minimise the difficulty of making a left turn by using their experience and other strategies to balance their psycho-motor skills such as taking longer time. These strategies were used in order to avoid challenging situations or conditions for bad driving or situations with lack of predictability. Briefly the methods in this study revealed that turning left intersections is a difficult task for the older drivers.

The research group then worked in collaboration with the Engineering Psychology Group at the University of Regensburg and developed an assistive system for turning left on intersections. The methodology involved comparison of younger (n=20, average age 26) and older drivers (n=21, average age 68). The aim was to test the system as a result of the findings in previous experiments carried out in this study. It was also a simulator based experiment. The data of subjects were compared on the effect of time pressure and the speed limit on driving manoeuvres at different scenario setting. The assistant system is shown in Figure 8.

	System status: active	Time-to-collison sufficient for maneuver	Time-to-collison only marginally sufficient	Time-to-collision to small for maneuver
Time-to-collision	No vehicle	> 5 Sek.	2-5 Sek.	<2 Sek.
Symbol indicating the feasability of turning left				
Suggested maneuver:	Turning left	Turning left	Stop or finish the maneuver	Stop

Figure 8: Left-turn assistant - prototype informs the drivers based on the condition of the intersection to make a left-turn, Dahmen-Zimmer (2014)

The findings revealed that the time pressure setting has increased the realistic impression of the driving experience in the simulator. With the incorporation of the Left-turn-assistant the manoeuvring of younger and older drivers has become more similar and balanced out. The main outcome of the study is that, through the field study and both simulator studies it has been noticed that Left-turn-assistant has shown a signal for better traffic safety for older driver. But the research admits that there is no clear sign of what exactly makes manoeuvring left turn at intersections difficult for older people. This shows that approaches have shown that the experience of older drivers can be improved with similar approaches making intersections less challenging for older people.

It is important to make a comment that this study involves many approaches and experiments but it does not reveal more specific/detailed findings about older drivers. Considering the amount of experiments carried out it is expected that more concrete information could have been gathered. For instance, before developing the prototype for Left-turn assistance, the research team could have interviewed the participants about their experiences with intersections before making a left turn. Also it would have been more beneficial to include them in the design process of the prototype to get their opinion and their expectations in Left-turn assistance. But overall, the study shows a signal that difficulty in making a Left-turn can be minimised with design solution for older drivers.

2.14- Previous research: RICA

As well as reporting the issues of older drivers, it is also important to talk about the work of organisations such as RICA. This is an organisation which carries out consumer research for older drivers and disabled people (mobility and home & technology). The organisation provides a wealth of information on vehicle requirements for older and disabled users and families with disabled children. This includes practical information based on research with older and disabled people regarding transport & mobility aids such as: motoring, public transport, scooters, powered wheelchairs, walking aids etc. For example, the organisation has gathered a huge data of vehicle dimensions and categorised these depending on individual's needs. Depending on these needs the users can use the website to search for suitable cars by bringing the results of recommended brands/types of vehicles to suit these needs. In addition, RICA provides suggestions and recommendations to help users meet their needs to improve safety, ingress/egress, assistive products e.g. car controls. Some examples have been summarised in Table 5.

Table 5: Recommendations and suggestions for older and disabled users based on research carried out by RICA (RICA, 2014)

Services	Technologies and products	Recommendations	Description
In-car safety technology	Passive information systems	• Satellite navigation • Night vision • Blind spot detection	Information on cars environment
	Semi-autonomous driver assistance systems	• Parking assist • Emergency brake assist • Drowsiness detections and control	Provides assistance to the user by taking certain level of control over the brakes or steering wheel.
	Autonomous vehicle control and safety systems	• Autonomous emergency braking (AEB) • Electric stability control (ESC)	Takes over the control to minimise risk/accident.
	Parking systems	• Parking technology	Provides audio or visual feedback to the use if the vehicle is too close to another vehicle Takes the control of the steering wheel and parks autonomously.
Getting in/out of the vehicle	Suggestions and techniques	• Vehicles with high and wide door openings • Swivelling the body around and putting both legs out (egress). • Sit on the seat first and then bring legs in afterwards (ingress).	These techniques and accessories provide assistance during ingress/egress to the user.
	Adaptations and accessories	• Swivel seats • Hand bars to hold on during egress	
Car controls	Adaptable accessories	• Assistive devices for improving primary controls e.g. steering, controlling speed, changing gear, operating hand brake etc.	Variety of options of car adaptation products to suit the needs/abilities of the user.

2.15- Summary

Specific issues were identified related to driving experiences of older drivers, including: physical, visual, cognitive and environmental. This means the automotive industry needs to focus on specific areas associated with older users, especially on the physical issues with driving and interacting with the vehicle. There is clear and consistent evidence that there is an age-related reduction in physical abilities and which affects driving tasks, for example ingress/egress, reversing, seat comfort and posture for older drivers. Objective 1 of this research is partially addressed through this literature review; in order to fully address this objective the areas identified requires more focus and further research should be carried out by comparing older with younger drivers based on the issues/topics identified through literature.

Chapter 3- Literature review: research methods

This chapter will talk about the research methodology; explore various methods and data collection tools that may be potentially used in the research.

3.1- Research Paradigm

This section will describe examples of the main research paradigms which are also relevant to this research project. Walliman (2006) and Robson (2011) describe each paradigm as:

- Positivism: this paradigm relies on obtaining facts through experiencing a situation or through observations by exploring theories in an unbiased way.
- Post-positivism: as positivism, this paradigm also relies on quantitative data; it targets the truth but considers any one study may not achieve this.
- Interpretivism/Constructivism: it relies on qualitative information; the subjective meanings play an important part in social actions.

The research paradigms have been described in a generic way, but it is understood that the first two rely on obtaining quantitative information where the third targets qualitative facts.

3.2- Research Strategy

To identify the type of study or data to be collected for this research, it is necessary to adopt a good research strategy. There are three types of strategies available; these are known as fixed designs, flexible designs and mixed methods as described in Figure 9.

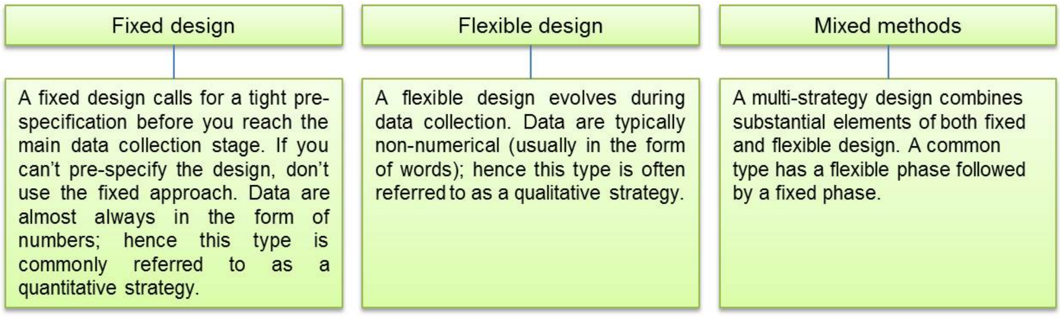

Figure 9: Research strategy (Robson, 2011 p.74-75)

The strategy adopted for this research will be based on the principle of mixed methods, combination of qualitative and quantitative data. Fink (2008) describes qualitative and quantitative data as:

- Quantitative methods are based on numerical and statistical representations
- Qualitative methods rely on opinions, behaviours and experiences of the participants to be investigated

The validity of research refers to what extent the findings of the research are based on truth (Walliman 2006). In order to validate the findings of this research, the triangulation process will be adopted. The triangulation process is defined as the systematic comparison of findings on the same research topic generated by different research methods (Bloor and Wood, 2006 p.170).

By adapting the research strategy as mixed methods, this improves the validity of findings, because it is the combination of both qualitative and quantitative data, which is part of triangulation process (Robson 2002). For example, if a questionnaire survey is conducted and it provided quantitative data, an interview based study can also be conducted to collect qualitative data, comparing the findings in both improves the validity of research.

3.3- Survey studies

Research methods which are relevant to this research project are now described. These are based on qualitative and quantitative data collection techniques such as literature review, surveys, focus groups and case studies.

3.3.1- Interviews

Types of interviews are shown in Figure 10:

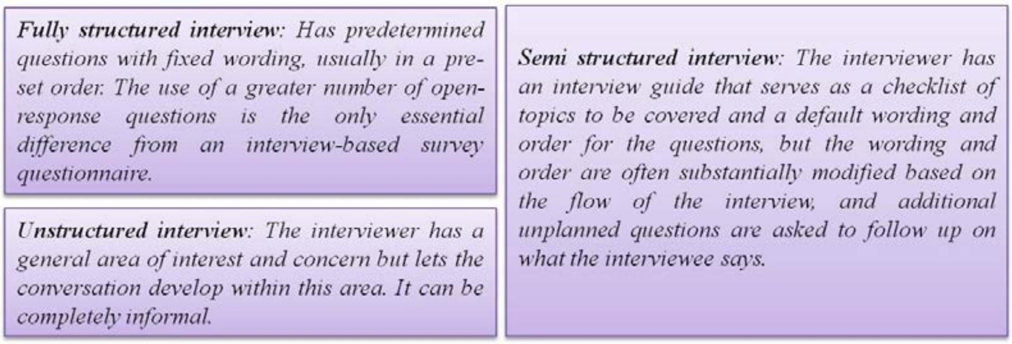

Figure 10: Types of interview (Robson, 2011)

As explained in Figure 10, it is reasonable to use any one of the three interview types depending on the study; for example if a questionnaire survey is being conducted then it can also be used as a fully structured interview tool to collect data. For example the unstructured interview can be useful for focus group studies. The semi-structured interview can be useful for focus group studies.

3.3.2- Focus groups

Focus groups are based on group interviews, and generally focus on a specific topic or area aiming to gain an in-depth understanding of the issue/situation. Participants involved in forming this group are mainly the people who have experience in the area that is being researched and share their opinions and experiences. One of the disadvantages is sometimes difficult to form a group discussion session (Grix, 2010). Liamputtong (2011) describes some key features of focus group interviews:

- Form of informal discussion is carried out with a group of selected individuals about a specific topic.
- With involvement of relatively small number of participants in-depth discussions can be carried out.
- The researcher acts as a moderator and introduces the topic and helps participants to discuss it. Sometimes there can be more than one operator in one focus group session.

3.3.3- Questionnaire surveys

There are some advantages and disadvantages of conducting surveys; Robson (2011) gives some examples:

Advantages

- They provide a relatively simple and straightforward approach to the study of attitudes, values, beliefs and motives.
- It is a basic method to the study of attitudes, values, beliefs and, motives.
- Useful for collecting generalizable data from any human population.
- Great level of data standardisation.

Disadvantages

- Sometimes the data is affected due to the individual characteristics of the participants, for example; knowledge, experience and memory.
- Some participants will generally report incorrect information regarding their beliefs or attitudes etc. This is likely to cause bias in the data.

Generally the principle of a survey is to get opinions from a wide range of audience on a particular topic and this makes them one of the widely used data collection methods.

3.4- Methods used in automotive industry

There are various evaluation and data collection tools in the field which are used in studies/research on drivers. Bhise (2012) provides examples (Table 6) of these tools which can be potentially used during the experimental study of the proposed research. Many have been used in other driver related research:

Table 6: Types of methods used for vehicle evaluation- adapted from Bhise (2012)

Type	Description	Examples
Observational methods	Direct/indirect observations of participants during their product usages. Observations can be made directly or recorded with a video camera to be played at a later time. (Qualitative)	The following can be recorded by the observer: • Duration of different type of events • Number of attempts made to perform an operation • Number and sequence of controls used • Number of glances made etc.

Communication methods	Information from the user by asking their impressions or experiences with the product. This could be carried out in a form of personal interview. (Qualitative)	For example, questions can focus on the during and after usage of the product: • Impressions about the product e.g. usability • Using a nominal scale to categorise the product e.g. comfortable or uncomfortable; liked or disliked. • Rating the product on scales e.g. workload ratings, difficulty ratings.
Experimental	It enables the investigator to control the study, for example selecting a vehicle design or a test condition. (Quantitative)	Explores the relationship between the response variable and independent variables may be evaluated e.g., • Operating forces • Type of display • Type of control
Vehicle user interviews	Conducting individual or group interviews with drivers e.g. focus group sessions. (Quantitative)	These could focus on issues experienced, any concerns in relation to various vehicle features for example.
Rating on interval scales	These are form of interval scales which can be used for ergonomic evaluations. (Quantitative)	Examples include; characteristics of controls, visual and tactile features of materials e.g., • Instrument panels • Door trim • Seat areas • Steering wheel
Driving simulator studies	These are mainly focusing on evaluation of issues related to driver work-load with operation of various devices. (Qualitative and quantitative)	With the aid of simulator tests the following three methods can be used: • Observation • Communication • Experimentation
Field studies and drive tests	Method relies on actual driving conditions which can be performed on test tracks; public roads and various driving/traffic conditions. (Qualitative)	Examples include; evaluation of seat comfort; driver workload; experimenting controls and display etc.
Task analysis	A main task is divided into subtasks/stages in order to analyse the demands placed on the user in performing each step and compare against the capabilities and limitations of the users. (Qualitative)	With this possible user problems and errors can be revealed during the use of a product.

3.5- Sampling Techniques

There are various sampling techniques in the field which are used in both qualitative and quantitative studies. This section describes various techniques which may be useful when selecting appropriate sample for future studies of this research. According to Robson (2011) samples can be put into two main categories: probability and non-probability samples. The possibility of involving anyone in the sample can be determined by probability (probability sampling). Any plan where this is not possible refers to ‘non-probability sampling’. The table 7 shows various types of sample designs and describes their purposes - adapted from Owen (1996) and Robson (2011).

Table 7: Sample design techniques from Owen (1996) and Robson (2011)

Type	Description
Simple random sampling	It is simply based on random selection of subjects for the sample from a population list. With this each subject gets equal chance of being selected, there is a good advantage of getting representative sample of the population.
Systematic sampling	Some areas of this sampling are common to random sampling. Once a decision is made on the sample size, each subject in a sampling frame/list is given a number. For instance if the sample size is 50 and the sampling frame is 2000, then every 40^{th} person is included in to the sample i.e. 2000/50 = 40. In theory it may sound simple way of creating sample but it has specific statistical characteristics.
Stratified sampling	A stratified sampling technique is used, whereby the population is divided into various subgroups/strata. Once the strata are determined, a simple random sample is taken from each stratum individually. With this approach the characteristics of the population are more likely to be reproduced.
Quota sampling	This is very similar to stratified sampling techniques, instead of choosing a simple random sample from each strata, any accessible subject is included. But it needs to come from the sub-groups defined earlier. It is not common to use the term strata within this sampling technique; therefore the term sub-group is preferred.
Purposive sampling	The selection process in purposive sampling is based on the researcher’s decision as to characteristics or interest. In this sampling technique the researcher builds a sample based on the specific needs in a research. For instance, the researcher adopts grounded theory approach during the initial sampling stage, and then through the analysis of the results the sample can be extended in ways guided by their emerging theory.
Cluster sampling	The population is divided into a number clusters. Individuals are distributed into clusters based on their specific characteristics. A random selection is used to choose each cluster. It is more widely used when the population covers an area that can be divided by regions, e.g. dividing an area to be studied into a number of streets, or by using simple random sampling. This involves each subject in the clusters identified.
Judgemental sampling	It is slightly similar to quota sampling, but does not involve sub-groups. Participants are included in the study in a way that they are thought to be representative of the population.
Convenience sampling	This involves participants that are easy to find or available for the study. It is one of the most widely used and least reliable types of sampling technique.
Snowballing sampling	The researcher targets individuals from the population of interest. Once the individual is participated, they are then used to inform other individuals from the target population, and this rolls on.

3.6- Assessment tools for older drivers

In order to understand the effects of ageing on functional capabilities which may result in difficulties with carrying out specific driving tasks it was important to look at tools to assess the functional capabilities of older people. A research carried out by Eby et al. (2006) provides very detailed information on a large number of assessment tools which can be used to assess functional capabilities of older drivers. The authors provided the details of assessment tools focusing on cognition, driving, health, motor, perception and psychosocial. All these tools are tested and used in the field. Some of these tools can be used in the future in order to understand the ageing patterns and to compare data; some of the potential tools are described in Table 8 which may be selected for the current research.

Table 8: Specific assessment tools in literature used to assess older drivers- adapted from Eby et al. (2006)

Author	Type	Assessment	Method
Haymes and Chen, (2004)	Pelli-Robson Contrast sensitivity	Contrast sensitivity	Assessment of how well large faint objects are seen. Conducted through standardised conditions. Uniformly large letters which fade out towards the bottom, subject reads as many as possible from 1 metre distance. The score is the faintest triplet that for which 2 of the 3 letters are correctly identified.
Charlton *et al*., (2002)	Clock reading test	Upper body flexibility and range of motion	Conducted under standardised conditions by measuring the ability of a driver to look over their shoulder. The researcher stands 3m behind the driver, clock hands set to 3.00 or 9.00. The score is pass/fail.
Smith *et al*., (2000)	9-hole peg test	Hand coordination and dexterity	The task requires subjects to place the pegs into the peg board one at a time and then remove them. It is conducted with dominant and non-dominant hand and the score is the time taken to complete the tasks.
Charlton *et al*., (2002)	Arm reach test	Shoulder flexibility	Subject remains seated facing the researcher, is then asked to raise his/her right arm and then down again. Same process is carried out with left arm. The score is pass or fail, if their elbow is below their shoulder height then it is a fail.
Marottoli *et al*., (1994)	Rapid pace walk	Coordination; strength; and lower body stiffness	Participants are instructed to walk along the side of a tape measure (10 feet long, placed on the floor) to the end, and walk back as quick as they can. This process is then timed.
Freund *et al.*, (2005)	Clock drawing test	Visuospatial skills and cognitive functioning	It is carried out under standardised conditions. Participants are verbally instructed to draw a clock, labelled with numbers and the time needs to show 11:10. Instructions are repeated to the participant upon request.
Marottolli and Richardson, (1998)	Confidence scale	Assessing confidence on specific driving tasks	Self-rated confidence has a scale, 0 (not confident at all) to 10 (completely confident). The driver rates his/her self on their experience with 10 driving conditions. These include driving at night; bad weather; parallel parking.

3.7- Posture analysis

A comfortable seating position does not only depend on the seat comfort, it also depends on the seating position and the posture adopted by the driver. Porter & Gyi (1998) carried out a study to explore the optimum posture for driver comfort. Part of the study involved obtaining measurements of driving position of each subject as they adopted their comfortable driving positions in a simulator environment. Measurements were carried out semi-depressing the accelerator, hands placed on the steering wheel and looking ahead. By using joint markers on the anatomical landmarks through clothing, angles were measured. These anatomical landmarks included:

- Neck inclination
- Trunk-thigh angle
- Arm flexion
- Elbow angle
- Knee angle
- Ankle angle

By obtaining ranges of posture angles, Porter & Gyi (1998) compared their findings with those of Rebiffe (1969) and Grandjean (1980). Each one of them has provided minimum and maximum angle values to indicate the comfort zone for the driver (Table 9).

Table 9: Recommended comfortable posture angles (Literature)

	Ranges of postures (recommended)		
	Rebiffe (1969)	**Grandjean (1980)**	**Porter & Gyi (1998)**
Trunk-thigh angle	(95-120)	100-120	(90-115)
Arm flexion	(10-45)	(20-40)	(19-75)
Elbow angle	(80-120)	(-)	(86-164)
Knee angle	(95-135)	(110-130)	(99-138)
Ankle angle	(90-110)	(90-110)	(81-105)

By using similar approach it can be useful to understand how older drivers adopt their driving positions by measuring their postures. The data can then be compared with these suggested comfortable postures to see if the postures adopted by older driver fall into the comfort zone.

The method used by Porter & Gyi (1998) is simple and reliable for obtaining posture measurements. This method would be useful to understand how older drivers adopt their driving position and can be compared with those in the literature. However, it should be noted that in this study all of the participants were under 65 (n=55).

3.8- Simulation/empathy suits

This section will provide brief description of previous research carried out on older drivers and how these lead to design of some tools such as the 'Third Age Suit'. Hitchcock et al. (2001) described the origins of the Third Age Suit in the paper 'Third age usability and safety – an ergonomics contribution to design'. With increase in the ageing population one of the challenges of the new millennium was to meet the needs of older people through inclusive design.

Within the commercial industry, designers had to meet project deadlines with short budget and steep financial targets. By taking these factors into account some organisations such as Ford decided to meet the needs of this future market (ageing population). For instance the company approached human factors specialists at ICE Ergonomics at Loughborough University to work with them. After carrying out a detailed review and by taking into account of physiological, visual and cognitive changes of ageing process and its effect on older drivers, a suit that simulated the effects of ageing was developed as part of the project. This brought many advantages to engineers at Ford; they used the suit as a design tool and helped them to gain more realistic understanding of the effects of ageing and the experiences of older drivers. In order to reduce the forward movement of the torso and shoulders webbing was used. Specially designed gloves have two functions: one is to reduce joint mobility and other is to reduce tactile sensitivity. The movement of elbows, fingers, knees, and ankles were restricted using joint restrictors. Specially designed glass generated a reduced vision; this involved reduced acuity, high sensitivity to glare and yellowing of visual perception (Hitchcock et al., 2001).

According to Ford the suit has assisted the users to identify specific problems and apply design solution which improved the (Ford motor company, 2011):

- Visibility and size of the dashboard controls and their operation.
- More head room was provided to the vehicles for ease of entry/exit.

- Improved H-point to swivel during entry and exit.
- Location of the hazard warning switch was improved.

The design and use of simulation suit developed by Hitchcock et al. (2001) is becoming a widely used tool in order to experience the difficulties of older people in their daily life. For example some architects also uses it to simulate old age in order to design better living environments for them (BBC, 2004).

3.9- Summary

This chapter has reviewed the methodological approaches for the research on vehicle design and older drivers. The following conclusions are made:

- There are three types of research strategies available: qualitative, quantitative and mixed methods. Particularly, mixed methods can be a good source of triangulation process in order to improve the validity of findings.
- Relevant research methods were reviewed for their suitability for the current research, each one has its own advantage depending on the depth of information required. These include interviews, questionnaire surveys and focus groups etc.
- Experimental (driver related) methods were reviewed based on their types and their way of use for data collection. Some elements from these may be useful and can be implemented depending on the direction of this research and based on their suitability.
- Based on type of the study and sample size, appropriate sampling methods can be adopted through the selection of sampling designs reviewed through this chapter, e.g. a convenience sampling would be suitable for pilot studies, it is quick, does not look for specific type of sample etc.
- Assessment tools have been reviewed for older drivers and could potentially be used to understand how ageing process could affect driving related tasks for older people. All these tools are already tested and used in the field for their reliability.

Chapter 4: Questionnaire survey and interviews

4.1- Introduction

It has been identified from the literature that there are specific issues related to the driving experiences of older drivers, which are, physical, visual, and cognitive. Part of the focus of this research is to understand the driving experiences of older drivers. A questionnaire survey was therefore conducted to build on the literature and further address the following objective:

- To identify key issues with the driving experiences of older compared with younger drivers.

4.2- Research method

4.2.1- Survey design and rationale

Figure 11 summarises the questionnaire focus areas, these were selected based on the findings from the literature review; the survey was arranged in a logical sequence and divided into 7 sections.

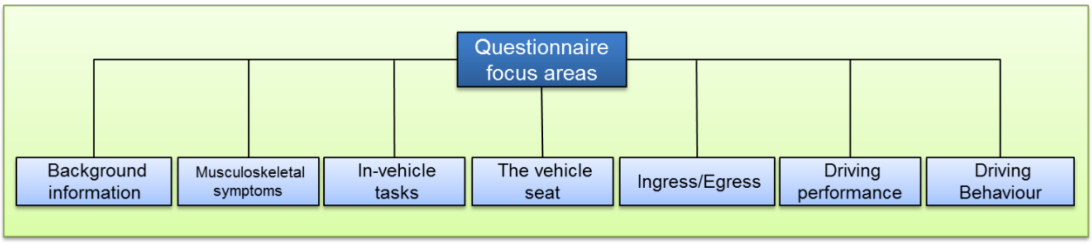

Figure 11: Questionnaire focus areas

The first section of the survey was used to obtain background information about participants, including: age; gender; employment status; make/model of their vehicle; annual mileage and average hours driven in a typical week and whether they drive as part of their job. Their name and date of birth is not reported for reasons of keeping anonymity.

Respondents were also asked about in-vehicle tasks specific to driving including operating pedals; signals and lights; mirrors and hand brake and on non-driving tasks including climate controls and entertainment devices such as operating the radio. It was important to have a section based on in-vehicle tasks because these are the primary tasks that the user is involved in their vehicle.

It was identified in the literature review that there was a gap in the research on the postures that older drivers adopt and seat design focusing on the requirements of this age group. A section of the survey focused specifically on the adjustability of the seat features and how users interact with them to set their driving positions. Also the literature review in Chapter 2 revealed that many older people experience physical limitations such as arthritis, and upper body flexibility which may impact on reach to the seat belt; pulling it across their body and fastening it. Similarly, with adjusting the head rest a lot of physical effort may be required turning the head and body around. Specific controls such as the seat lifter and seat recline can also be stiff and difficult to turn or grasp for a person with arthritis. Therefore it was important to include a section focusing on seat features.

It was identified from the literature that older drivers experience difficulties with ingress/egress, and lot of trip/fall incidents were reported among this population (study by Dellinger, 2008). A section of the survey was needed focusing on getting in and out of the vehicle including, opening the driver's door (from inside/outside) and getting into/out of the vehicle (Survey conducted by Herriotts, 2005). Additionally, a question was included to ask participants if they had ever fallen/tripped during entry/exiting the vehicle.

A section called 'driving performance' was included in the survey with the topics based on parking; reversing the vehicle; various weather and time conditions (e.g. driving in the dark); keeping a constant speed etc. These were the topics identified from the literature as being difficult for many older drivers. Ratings of 'driving performance' were obtained based on Owsley et al. (1999). Similarly, a section called 'driving behaviours' was also added and included topics focusing on physical, visual, and cognitive tasks related to driving e.g. 'I have difficulty turning my head and body around when reversing' or 'operating navigation systems distract me from driving'.

The NMQ (Nordic Musculoskeletal Questionnaire) was incorporated into the survey in order to assess the prevalence of musculoskeletal symptoms in participants.

Research was carried out on previous questionnaires relevant to the topic, these were checked and analysed in their structure and content. Elements from a survey conducted by Sang et al. (2009) were included into the survey with slight changes; this includes a simplified version of NMQ, and specific questions. Incorporating relevant questions from other questionnaires brings many advantages, for example:

- Questions are already piloted and tested for their reliability
- The results can be compared between both studies

The final questionnaire went through various stages during the design and development phase. Many factors were considered, e.g. questions had to be specific, short and easy to understand for older people. Rather than creating long questions, Likert scales were incorporated with specific statements and tick boxes. Comment sections were also included at the end of each section for participants to add extra comments. Generally some people do not want to give their personal details such as name, date of birth etc. These types of questions were excluded from the survey for example; tick boxes were used to indicate their age range (20-34, 35-49, 50-64, 65-79 and over 80s). However there was an option for participants to give their contact details for follow-up interviews or for clarification of any points.

The intended sample size for the survey was large (n=600+), it was therefore important to consider different data collection tools. The most suitable option was Survey Monkey, which was competitively priced, comes with full features for 1 year, and has the ability to send the survey link via e-mail to contacts and other organisations, and data can be exported to Excel or SPSS, which saves time. The survey was designed in two versions, a paper based and on-line version using Survey Monkey. The paper based version was developed initially due to the requirements of the older age group, for example, some older people don’t have access to the internet. Some participants may require assistance to fill in the survey, so the survey was either posted to them or taken directly to them. The data collected through the paper questionnaires was imported in to the online survey and downloaded to Excel and SPSS.

4.3. - Pilot study

A pilot study was conducted on the questionnaire survey; online and paper based versions focusing on the following points:

- To check the wording and structure of the questionnaire.
- To ensure that the responses were as anticipated.
- To capture the time taken to complete the survey.
- To develop a strategy for data analysis.

4.3.1- Participants

A convenience sample of drivers was obtained. This involves participants that are easy to find or available for the study (Owen 1998). It is a simple and quick method, commonly used in pilot studies. A total number of 22 participants took part in the pilot study and the majority were research students, and university staff.

4.3.2- Key points

Small typographical modifications were made to some of the questions to improve clarity. Other specific changes include:

- For the questions on mileage and weekly car usage in the section on 'about the vehicle you drive', structured options were included for participants to select from.
- On the question regarding current work status in the section on 'background information' more options were provided to accommodate different backgrounds.
- Some participants felt that they needed to provide further detail on the problems they experienced; therefore a 'comments' section was included at the end of each section in the survey.

The pilot study showed that the responses were as anticipated. The average time taken to complete a questionnaire was 10 minutes (range 6-16 minutes). With the online version, most participants took no longer than 10 minutes to complete. A copy of the final questionnaire can be found in Appendix 1

4.4- Data collection (Questionnaire survey)

Data collection was conducted over a 3 month period and completed on 30/09/12.Various organisations were approached for the survey and agreement was obtained for the distribution of questionnaire (data collection from e-mails, interviews and personal contacts). Figure 12 shows some examples of the places consulted; these include major motoring organisations, institutes and older people's organisations such as Age UK, University of Third Age (U3A), and The Royal Society for the Prevention of Accidents (ROSPA) and Institute of Advanced Motorists (IAM). For the on-line survey snowball sampling was used as a strategy to increase the responses.

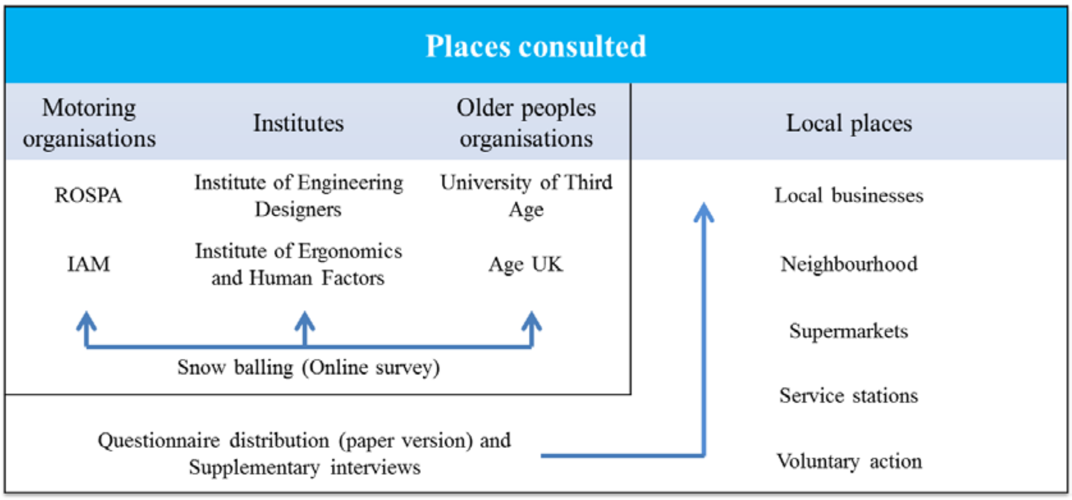

Figure 12: Places consulted for survey distribution

4.4.1- Sampling strategy

Various sampling techniques were reviewed and their suitability was assessed for this study in the previous chapter. These include: simple random sampling, systematic sampling, stratified sampling, quota sampling and convenience sampling. A stratified purposive sampling technique was used, whereby the population is divided into various subgroups/strata (Robson 2002). Once the strata are determined, a simple random sample was taken from each stratum individually. With this approach the characteristics of the population are more likely to be reproduced (Owen 1998).

For the questionnaire survey, the sample was arranged in a number of sub-groups focusing on age and gender (Figure 13). According to Owen (1998), there is a link between sample size and the accuracy of the collected data, e.g. if the sample size is large, then the data is likely to be accurate. This author also points out that, sample size should focus on a reasonable number, taking time and budget into account. Therefore the proposed sample size for the questionnaire survey was 600; this was thought to be a reasonable number to gain a robust data set for statistical analysis.

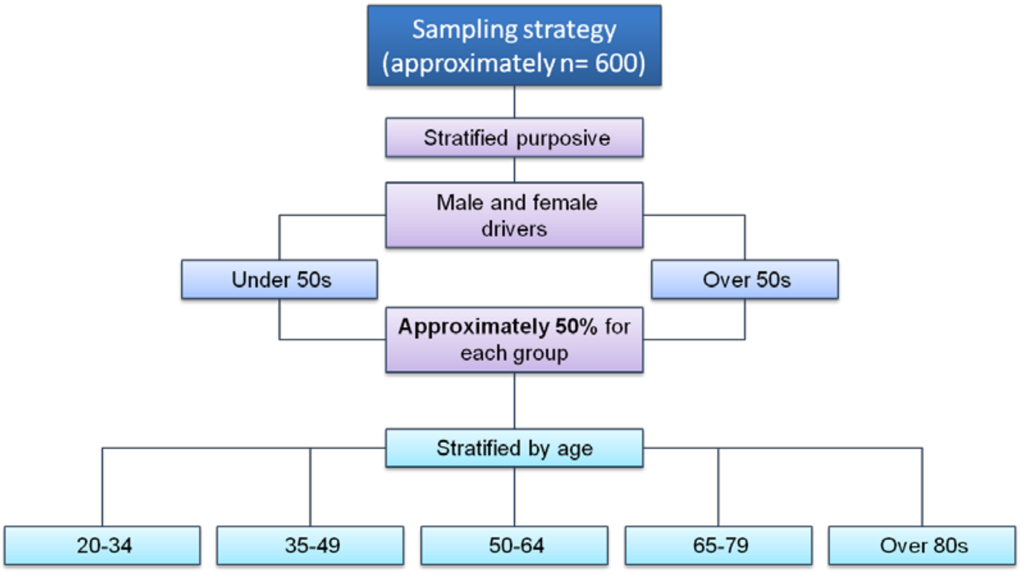

Figure 13: Sampling strategy (Stratified sampling)

As shown in Figure 13, for the purpose of the survey younger drivers were defined as under 50s and older drivers are as age 50 and over. The sample was divided into 5 sub-groups by age. This makes an approximate number of 120 responses for each group (60 male and 60 female).

4.5- Data analysis (Questionnaire survey)

Data from the questionnaire were analysed using SPSS and Excel, firstly to gain a general understanding focusing on the whole sample, and differences between age and gender were also explored. Statistical methods such as Chi-squared test, Mann-Whitney-U test and log linear analysis were used. The Chi-squared test was considered to evaluate specific questions such as getting in and out of the car in the section ‘accessing your vehicle’, to compare the collected data with an estimated population response and to validate if the collected data differs from the estimated data. Mann-Whitney-U test was used to evaluate the responses given to statements based in the section ‘driving behaviour’, e.g. comparing older with younger drivers based on their responses on navigation systems. Log linear analysis is explained in more detail in section 4.7.7 of this chapter.

4.6- Data collection (interviews)

Supplementary interviews (n=15) were also conducted with a further sample of drivers aged 65 years, using the questionnaire in a structured interview format. Interviews aimed at specifically obtaining qualitative data and to gain further understanding of some of the issues involved in the driving experiences of older drivers. This sample did not take part in the questionnaire survey; they only took part in the interview part of the study.

4.6.1- Sampling

The sample was identified using a stratified purposive sampling technique for the interviews.

4.6.2- Data analysis (interviews)

The analysis of the data was based on a thematic qualitative data analysis which was conducted manually by selecting top themes.

4.7- Results

This section will introduce the key findings focusing on the following areas: musculoskeletal symptoms, operation of in-vehicle controls, adjusting seat features, ingress/egress, accessing vehicle features, driving performance and driving behaviour. Data from the supplementary interviews are included to add more detail and explain some of the reasons behind the key findings.

4.7.1- Sample distribution

Initially, the target sample size for the survey was 600; this was thought to be a reasonable number in order gain a robust data set for statistical analysis; however, the survey achieved 50% more participants (n=903), and therefore, for the purpose of analysis, younger drivers were re-categorised as <65 and older drivers considered as ≥65, but the distribution of participants can also be viewed by age group (Table 10). Of the 903 people that took part; 53.5% were younger drivers (*n*= 483, <65) and

46.5% were older drivers (*n*= 420, ≥65). Drivers over 80 years represented 7.1% (*n*= 64) of the whole sample. 59% of participants were male and 41% were female.

Table 10: Age groups and response distribution (n=903)

Age category	Age	Male		Female		Total	
		n	%	*n*	%	*n*	%
Younger drivers (<65 years) 53.5%	20-34	70	7.8	66	7.3	**136**	**15.1**
	35-49	62	6.9	53	5.9	**115**	**12.7**
	50-64	144	15.9	88	9.7	**232**	**25.7**
Older drivers (≥65 years) 46.5%	65-79	216	23.9	140	15.5	**356**	**39.4**
	≥ 80	43	4.8	21	2.3	**64**	**7.1**
Total		**535**	**59.2**	**368**	**40.8**	**903**	**100**

4.7.2- Musculoskeletal symptoms

High levels of musculoskeletal symptoms were reported in the lower back (39.2%), knees (29.2%), neck (29.2%) and shoulders (29.1%), for the whole sample as shown in Figure 14. Younger drivers reported higher levels of musculoskeletal symptoms in the neck ($p<0.01$), shoulders ($p<0.05$) and middle back ($p<0.001$) compared to older drivers (Figure 15) for the 12 month period prevalence. Significantly more discomfort was reported by older drivers in the hips/thighs/buttocks and knees ($p<0.05$) compared to younger drivers. Compared to older, younger drivers reported their symptoms were related to their work, particularly for the neck ($p<0.001$), shoulders ($p<0.001$), wrist/hands ($p<0.001$), middle back ($p<0.001$), lower back ($p<0.001$), hips/thighs/buttocks ($p<0.01$) and ankles or feet ($p<0.01$) as shown in Figure 16. This shows the level of activity of younger is likely to be greater than the older drivers. Younger and older drivers were compared for their annual mileage and weekly driving hours and significant differences were found. Compared to younger drivers, older drivers reported lower mileage ($p<0.001$) and weekly driving hours ($p<0.001$), so symptoms may be related to driving exposure.

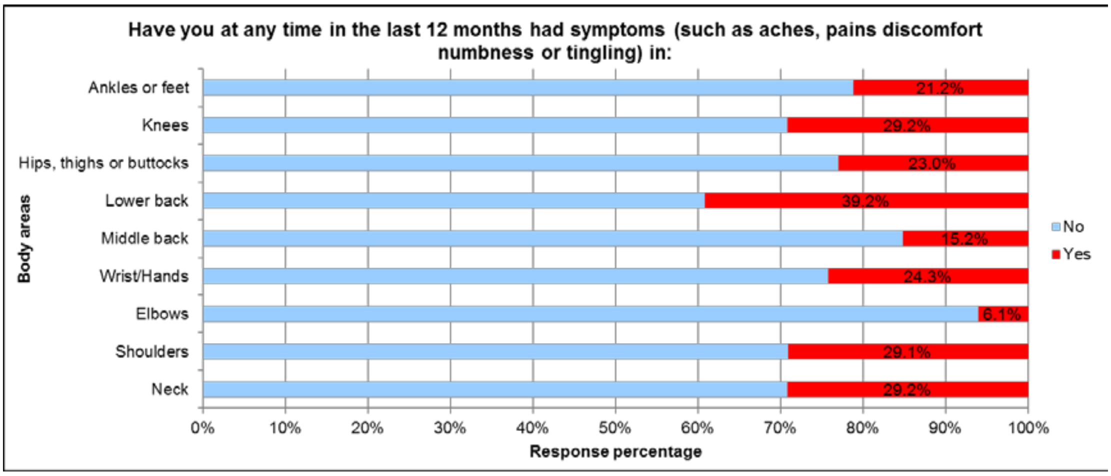

Figure 14: 12 month period prevalence (whole sample, n=903)

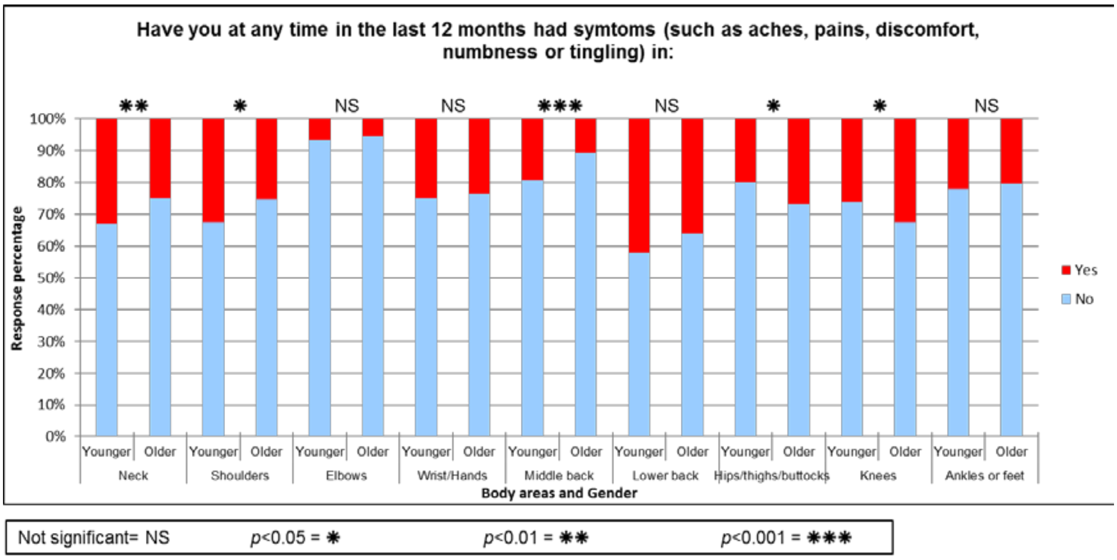

Figure 15: 12 month period prevalence (older vs. younger drivers, n=903)

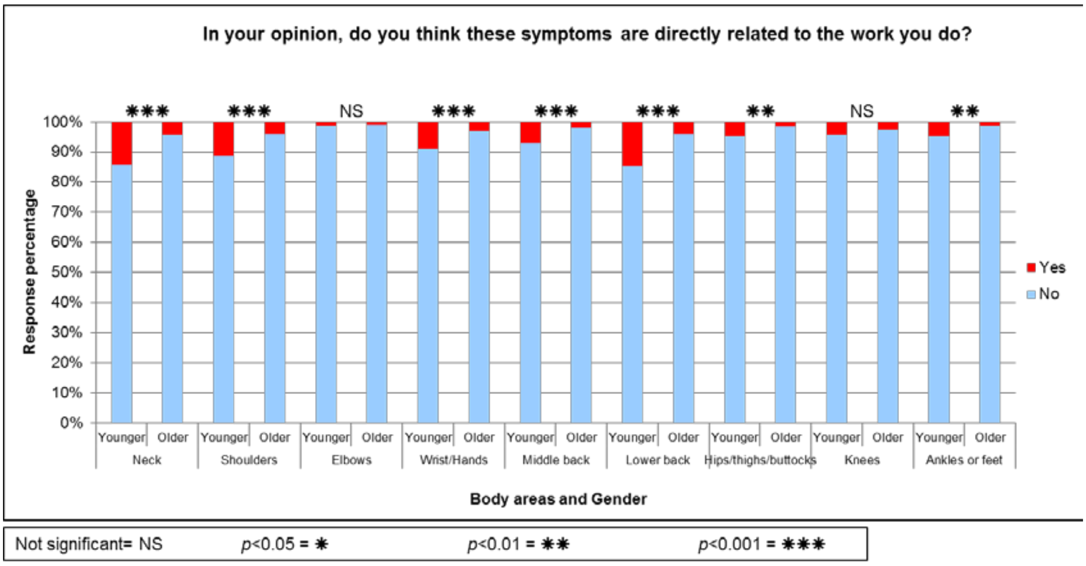

Figure 16: Activity related to work (older vs. younger drivers, n=903)

4.7.3- In-vehicle controls

The results shown in Table 11 are the distribution for the whole sample regarding the operation of in-vehicle controls.

Table 11: Do you have any other comments regarding the in-vehicle tasks?

Answer options	Difficult (%)		Easy (%)	Response count (*n*)
Pressing the horn	Greatest	7.5	92.5	894
Activating temperature controls		5.7	94.3	893
Adjusting the side view mirrors		4.3	95.7	897
Operating the radio		4.0	96.0	878
Deactivating the hand brake		3.3	96.7	883
Activating the hand brake		2.7	97.3	885
Activating the windscreen wipers		2.1	97.9	895
Pushing the clutch pedal		2.1	97.9	754
Adjusting the rear view mirror		1.5	98.5	892
Pushing the brake pedal		0.9	99.1	899
Activating the head lights		0.6	99.4	892
Pushing the accelerator pedal		0.6	99.4	898
Activating the indicator lights	Least	0.6	99.4	899

Key	
	Difficult = (Difficult + Very difficult)
	Easy = (OK + Easy + Very easy)

In general participants found it easy to operate most in-vehicle controls. Difficulties with pressing the horn were the most frequently reported problem with a total of 7.5% participants finding it difficult or very difficult. Age and gender were also compared for 'pressing the horn'. No significance was found with age but there were however differences in gender, 10.1% of females compared to 5.7% of males reported difficulty pressing the horn (p<0.01) as shown in figure 17.

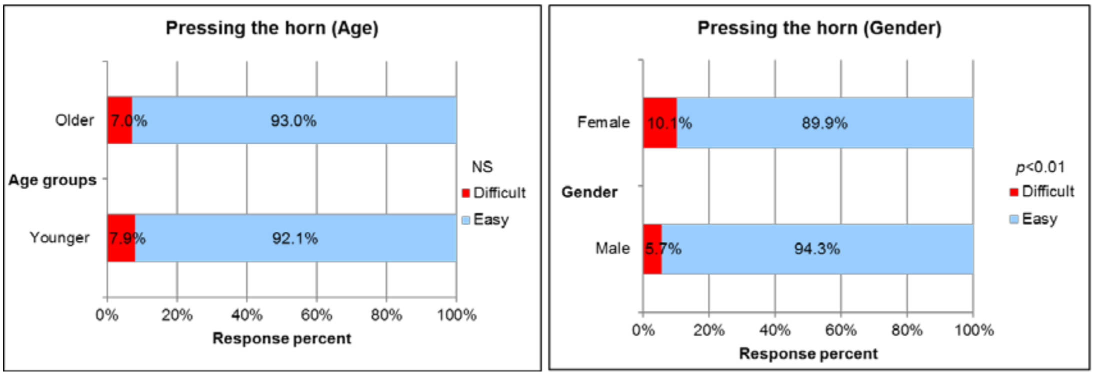

Figure 17: Pressing the horn (age and gender, n=903)

The supplementary interviews indicated that in emergency situations older drivers cannot always press the horn instantly; this is due to size of the control e.g. too small. The angle of the steering wheel and the location of the controls seem to have an effect, for example, if the horn button is located on the sides of the steering wheel (left or right) the driver cannot locate it as they are focusing on the road; this causes delay with finding the horn button.

4.7.4- Adjusting the seat features

The adjustability of vehicle seat features showed some interesting findings, shown in Table 12. 10.5% of respondents reported that they were dissatisfied with adjusting specific seat features, namely the head rest height, head rest distance from the head and setting the seat belt height. Females reported significantly more difficulty than males with adjusting the head rest height (p<0.001). Reasons given for this difficulty included reaching, accessing and operating the controls while seated.

Table 12: Please indicate how satisfied you are with adjusting the following features of the main car that you drive?

Answer options	Dissatisfied (%)		Satisfied (%)	Response count (*n*)
Setting the belt height	Greatest	10.5	89.5	754
Head rest (distance from the head)	↓	10.5	89.5	803
Head rest (height)		10.4	89.6	869
Lumbar support (in and out)		8.1	91.9	556
Lumbar support (up and down)		8.0	92.0	535
Setting the seat height		7.1	92.9	792
Backrest angle		5.8	94.2	885
Reaching for the seat belt		5.3	94.7	899
Moving the seat forwards and backwards		3.5	96.5	896
Fastening/unfastening the belt		2.8	97.2	898
Pulling it across your body	Least	2.3	97.7	899

Key	Dissatisfied = (Dissatisfied + Very dissatisfied) Satisfied = (OK + Satisfied + Very satisfied)

4.7.5- Getting in/out of the vehicle

Table 13 shows the results for accessing the vehicle; this includes opening the driver's door from inside/outside, getting in/out of the vehicle. The results indicate that 9.7% of participants reported being uncomfortable getting out of their vehicle and 6.9% with getting in to their vehicle. No age and gender differences were found.

Table 13: Please indicate how comfortable you are with getting in and out of your main vehicle?

Answer options	Uncomfortable (%)		Comfortable (%)
Getting out of your vehicle	Greatest	9.7	90.3
Getting into your vehicle	↓	6.9	93.1
Opening the driver's door from the inside		4.1	95.9
Opening the driver's door from the outside	Least	2.5	97.5

Key	Uncomfortable = (Uncomfortable + Very uncomfortable) Comfortable= (OK + Comfortable + Very comfortable)

Regarding the question based on fall/trip incidents, 94.1% reported never experiencing a fall/trip accident. However, this equates to 1 in 17 of the sample having had an accident. Surprisingly, 8.1% of younger drivers reported fall incidents compared to 3.3.% of older drivers ($p<0.01$). With gender, 7.9% of females reported experiencing a fall incident compared to 4.5% of males ($p<0.05$).

4.7.6- Accessing features of the vehicle

Participants were asked to indicate how they found accessing specific features of their vehicle. The results are shown in Table 14. With accessing specific vehicle features, the greatest number of difficulties reported were with the release button on the bonnet (18.5%), the release button in-vehicle (13.1%) and reaching and pulling the boot door down to close it (8.2%) for the whole sample.

Table 14: Please indicate how you find accessing the following features of the main vehicle that you drive?

Answer options	Difficult (%)		Easy (%)	Response count (n)
The release button on the bonnet	Greatest	18.5	81.5	871
The release button in-vehicle	↓	13.1	86.9	842
Reaching and pulling the boot door down to close	↓	8.2	91.8	874
Lifting the bonnet	↓	7.9	92.1	883
The control to open the boot	↓	4.0	96.0	834
Opening the fuel cap	Least	3.8	96.2	897

Key	
Key	Difficult = (Difficult + Very difficult) Easy = (OK + Easy + Very easy)

Age and gender were compared; females reported more difficulties operating the release button in-vehicle (Figure 18, $p<0.001$) and the release button on the bonnet (Figure 19, $p<0.001$). No significance was found with age.

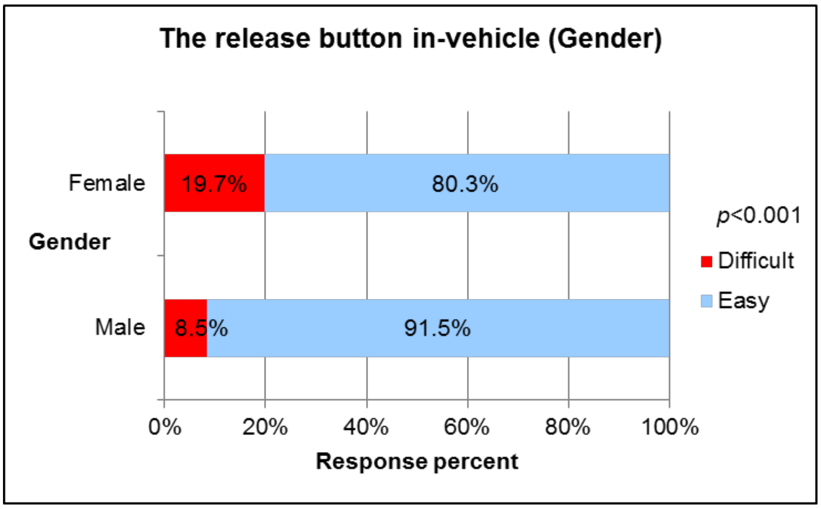

Figure 18: The release button in-vehicle (Gender)

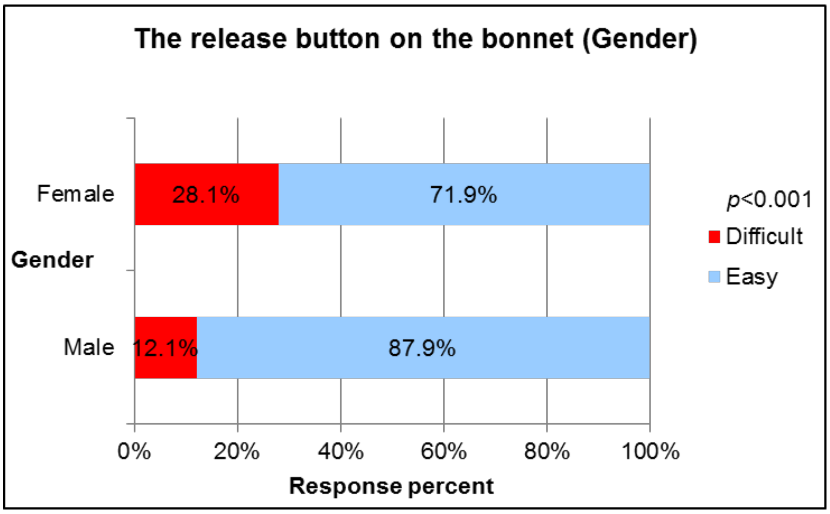

Figure 19: Operating the release button on the bonnet (n=903)

With reaching and pulling the boot door down to close 11.8% of older drivers reported difficulties (Figure 20, $p<0.001$) compared to 5.2% of younger drivers. In terms of gender, 13.6% of females compared to 4.5% of males reported difficulties (Figure 21, $p<0.001$). In order to investigate if this was linked particularly with older females a Binary logistic regression was conducted to explore any iteration between two groups (age and gender). The results were not significant and therefore this was not specifically related to older females. The results indicate that this difficulty was for older people and females generally. Older people reported reasons for this in the interviews as having less mobility and reduced reach and being shorter in stature.

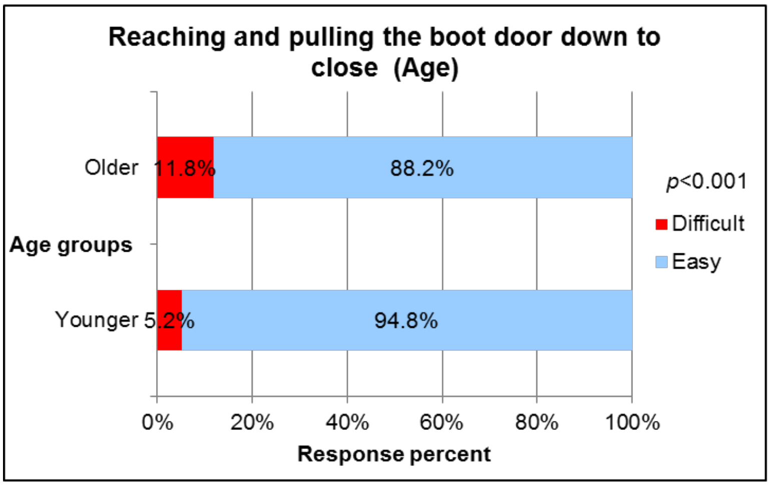

Figure 20: Reaching and pulling the boot door down to close (age, n=903)

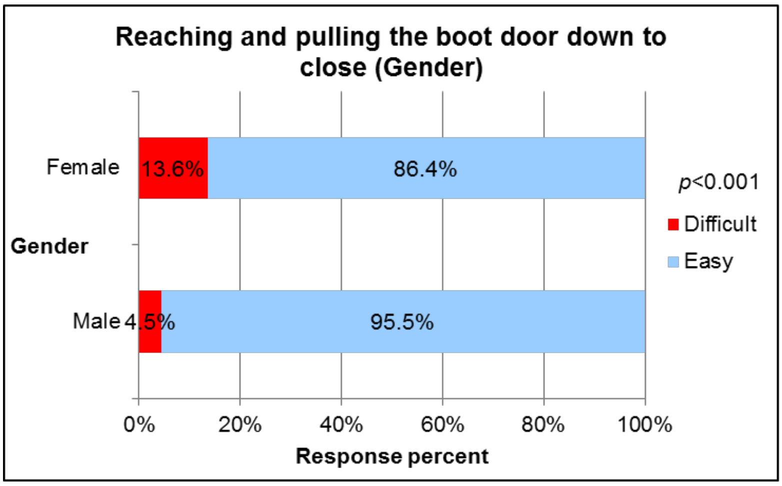

Figure 21: Reaching and pulling the boot door down to close (gender, n=903)

4.7.7- Driving performance

Participants were asked to indicate how they find carrying out specific driving tasks with the vehicle that they drive. Interestingly, 20.7% of the whole sample reported more difficulty driving on a foggy day, 14.4% with parallel parking between two cars and 9.3% reports difficulty driving in the dark as shown in Table 15. The supplementary interviews supported the fact that older drivers are less likely to drive at night. This is likely to be due to a decline in vision and their short travelling distances, e.g. shopping and visiting friends/family.

Table 15: Please indicate how you find carrying out the following driving tasks with the main vehicle that you drive?

Answer Options	Difficult (%)		Easy (%)
Driving on a foggy day	Greatest	20.7	79.3
Parallel parking between two cars at the side of a road		14.4	85.6
Driving in the dark		9.3	90.7
Reversing the vehicle		7.2	92.8
Driving in the rain		6.2	93.8
Driving on a sunny day		5.0	95.0
Driving in busy traffic		3.7	96.3
Parking in a marked space in a car park		3.4	96.6
Changing into another lane when driving on a dual carriageway		3.4	96.6
Making a right turn onto a main road		2.3	97.7
Keeping a constant speed		1.8	98.2
Keeping a safe distance from the car in front		1.3	98.7
Driving in day light	Least	0.7	99.3

Key	Difficult = (Difficult + Very difficult) Easy = (OK + Easy + Very easy)

Differences were found in age and gender. Again, it is not surprising that older drivers reported more difficulty ($p<0.01$) driving on a foggy day (25.3%) than younger drivers (16.8%, Figure 22). Also, 29.3% of females reported difficulty compared with 14.8% of males (Figure 23, $p<0.001$). Similarly, with parallel parking 16.9% of older drivers reported difficulty compared with 12.3% of younger drivers ($p<0.01$). By gender, 20.1% of females reported difficulty and 10.5% of males ($p<0.001$) for parallel parking.

Chi-squared analysis was carried out on both age and gender for driving on a foggy day and it showed significantly more difficulty was reported by older drivers ($p=0.01$) and females ($p=0.01$). This then motivated the question: is the reported difficulty more common for older females? Further analysis was necessary in order to see if this result was common for older females in the sample. This research question was investigated by combining the three categories variable: foggy day (difficult); age and gender.

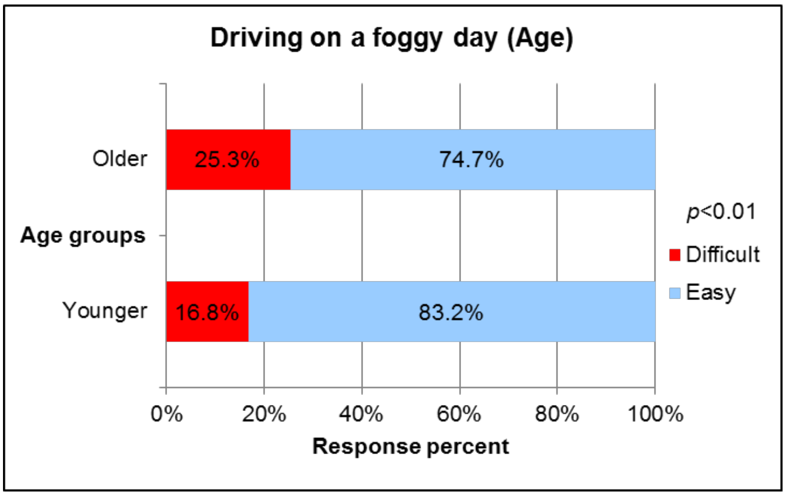

Figure 22: Driving on a foggy day (Age)

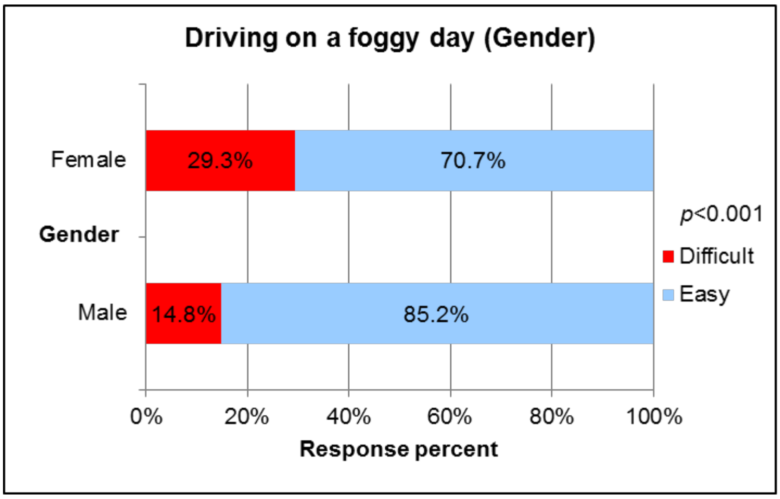

Figure 23: Driving on a foggy day (gender, n=903)

In order to investigate if there was an interaction between the variables age and gender, a Log linear analysis was carried out using SPSS. Log linear analysis looks into 3-way interactions in order to see whether there is significance and if the 3rd order interaction is significant. For instance, a Chi-squared test is a 2nd order interaction (2-way interaction) comparing two variables at a time, e.g. foggy day × foggy day; foggy day × gender, and age × gender. A log linear analysis compares 3 variables at once (3-way interaction), e.g. foggy day × age × gender. The K order effect table indicates that the 3-way interaction was not significant (p= 0.961, Table 16).

Table 16: K order effect table

K-Way and Higher-Order Effects		
	K	Sig.
K-way and higher order effects	1	0.000
	2	0.000
	3	0.961

The 3rd order effect foggy day × age × gender was not significant (p = 0.961) so there is no evidence that the effect of Age group on foggy day is different for males and females. Equally, there is no evidence that the effect of gender on foggy day is different for younger and older drivers (Figure 24). As age increases, the difficulty driving on a foggy day increases for both males and females, with females reporting slightly more difficulty. The results obtained through Log linear analysis can be interpreted that older drivers are experiencing more difficulty compared to younger drivers; it is not specifically older females that have difficulty. A binary logistic regression was also conducted to compare the results with the ones obtained in Log linear analysis, this analysis gave similar results (p = 0.961).

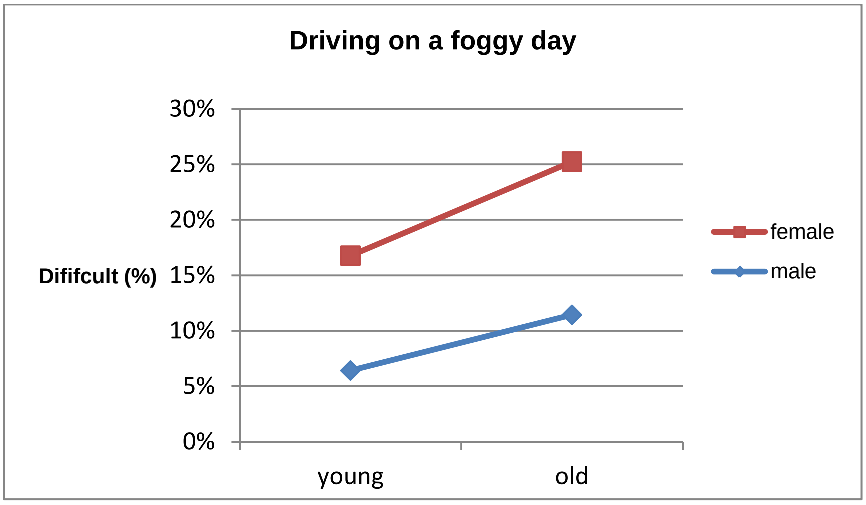

Figure 24: Driving on a foggy day (age vs. gender)

4.7.8- Driving behaviours

Half of all respondents (46.7%) reported that other drivers' lights restricted their vision when driving at night (Table 17); more females (53.3%) than males (42.5%) reported this (p<0.001). No age difference was found regarding this, which may be because older drivers are less likely to drive at night. Older drivers (31.7%) reported more difficulties than younger drivers (18.4%) with turning their head and body around during reversing (p<0.001). Similarly, older drivers reported their reactions were slower than they used to be (e.g. braking in an emergency situations) compared to younger drivers (p<0.01). Older drivers (19.5%) reported being less distracted operating navigation systems compared to younger drivers (25.5%) but no significance was found. Reasons for this may include that older drivers are more experienced, they know the routes, and they tend to travel shorter distances; therefore they may be less likely to use these technologies compared to younger drivers. The most commonly used entertainment system is the radio among older drivers.

Table 17: To what extend do you agree with the following statements in relation to your driving experience?

Answer Options	Agree (%)		Neither agree or Disagree (%)	Disagree (%)
Other drivers' lights restrict my vision when driving at night	Highest	46.7	19.0	34.2
I have difficulty turning my head and body around when reversing		24.5	14.2	61.4
Operating entertainment systems distract me from driving (e.g. playing radio)		23.7	38.0	38.3
Operating navigation systems distract me from driving (e.g. looking at sat-navigation)		22.9	29.5	47.6
I feel more safe driving below the speed limit		22.8	20.3	56.9
I worry about having an accident		17.8	25.7	56.5
My reactions are slower than they used to be (e.g. braking in an emergency situation)		15.6	23.1	61.2
I sometimes cannot judge my speed		10.4	17.6	72.0
I have difficulty judging the speed of oncoming vehicles		10.0	12.3	77.7
I sometimes have difficulty with identifying and reading road signs		9.9	10.3	79.8
I sometimes cannot hear the horns of other vehicles/sirens from emergency vehicles		8.6	8.1	83.3
I sometimes have trouble judging the distance from the vehicle in front		5.2	10.7	84.1
My speedometer is hard to read during the day time		4.9	6.8	88.4
My speedometer is hard to read driving at night time		3.1	7.8	89.1
I sometimes push the wrong pedal	Lowest	2.4	3.7	93.9

Key	Agree = (Agree + Strongly agree) Disagree= (Disagree + Strongly disagree)

4.8- Discussion

This survey was conducted to identify the key issues with driving experiences of older compared to younger drivers and compare and evaluate the findings with the literature. The survey has provided a large data set. Interestingly, it has been identified that most of the issues found in the literature published 20 years ago still exist today. Many issues are also common for both older and younger drivers as identified by Nicolle (1995) and Smith et al. (1993).

High levels of musculoskeletal symptoms were reported in the lower back, knees, neck, shoulders and elbows by the whole sample. Some similarities were found with the study of musculoskeletal symptoms in pharmaceutical sales representatives conducted by Sang et al. (2009) for example the lower back, neck and shoulders were most frequently reported areas. However, in the current study significantly more discomfort was reported by older drivers in the hips/thighs/buttocks and knees compared to younger drivers. The study conducted by Porter & Gyi (2002) identified that musculoskeletal symptoms reported in the large joints such as hips, ankles and elbows was found to be higher with older ages. In the current study no significance was found for ankles and elbows between younger and older for the prevelance of 12 months. Also, although not significant, there was a trend for older drivers to report less lower back discomfort compared to younger drivers. This was also reported by Porter et al. (1992) and was due to the specification of the car, particularly more luxury cars with more adjustable features. The author reported that there was a positive correlation with the price of the car and the drivers age. For the current study, younger drivers reported higher levels of musculoskeletal symptoms in the neck, shoulders and middle back, than older drivers. In order to understand the reasons for these symptoms, the annual mileage and weekly driving hours were compared for both younger and older drivers. Older drivers reported lower annual mileage and weekly driving hours. These results may be related to the driving exposure. It was also revealed that the level of activity of younger drivers was greater than for older drivers (e.g. work); these results may be related to the reduced symptoms for the older drivers.

Based on the seat features and their adjustability, the top four features that the whole sample were dissatisfied with were: setting the seat belt height; head rest (distance from the head); head rest (height) and lumbar support adjustments. Analysis of the results showed significant differences by gender but not with age, whereby generally females reported more difficulty. It is important to point out that all these seat features require certain amount of reach, turning the body around during seated position and carrying out certain amount of operation to set them to desired position. Therefore, the location and the reach distance of these adjustments could have an impact on this response and it is a design related issue which requires more focus.

An interesting finding from the survey was associated with accessing specific vehicle features, such as the release button on the bonnet and the release button in-vehicle. No significant differences were found with age, but there were significant differences between males and females. This may be related to the experience of the users with these controls and how often they use them. Supplementary interviews also investigated whether the person was the main driver or not and the majority of these interviewees reported (particlularly females) that they never used these features. This is only accessed when they take their vehicle for servicing.

Reaching and pulling the boot door down to close was also reported as difficult task by the respondents, age and gender differences were found. There is much literature showing that with the effect of ageing on the body there is a reduction in the stature (Sorkin et al., 1999; Perissinotto et al., 2001; Krishan et al., 2008; Mindell, 2008; Pheasant and Haslegrave, 2006) and in addition generally females are shorter than males making these reach tasks more difficult. This is clearly a design related issue that may need more focus to include the needs of older drivers and females.

The responses from the survey showed that the most uncomfortable task related to ingress/egress was getting out of the vehicle (9.5% of whole sample). This was similar to a questionnaire survey conducted by Herriotts et al. (2005) comparing younger to older drivers whereby difficulty with getting out of the vehicle was reported by 32.2% of the older drivers. In general getting into a vehicle was considered an easier task than getting out of the vehicle. It is worrying that 6% of the sample had experienced a fall incident during ingress/egress, but this was mainly with egress. However in the current study fall incidents were more common with younger drivers ($p<0.01$), the main explanation was that younger drivers reported rushing to get out of the car. Dellinger et al. (2008) conducted a study analysing the injuries admitted to emergency departments in USA (2001-2003), wherby 43% of these injuries were falls related to ingress/egress to vehicles, but it was mainly associated with older drivers.

Considering that older people are more fragile, they may need to attend hospitals to get treated after any fall incident, as a result number of admitting to hospitals may be higher for older people compared to younger.

Data based on the driving performance showed similarities with the literature, such as difficulty with driving in bad weather, e.g. foggy day and driving at night (Musselwhite and Haddad, 2008). This was observed for the whole sample but, particularly older drivers. Smith et al. (1993) reported that older drivers avoid driving in bad weather and night time. Also, the supplementary interviews from the current study found that older drivers were less likely to drive at night. As with the current study, parking and reversing the vehicle were also reported as one of the most difficult tasks to perform by older drivers compared to younger as identified by studies conducted by Bradley et al., 2008; Musselwhite and Haddad, 2008. Some of the reasons for this was due to decline in physical capabilities such as difficulty turning body around, variation of visibility/field of view in contemporary vehicles. The authors also indicate that older drivers also experience difficulty keeping a constant speed, but the findings of the current study showed that only 1.8% of the whole sample reported this and there was no relationship with age.

An important safety related finding of this study was related to driving behaviour, for example nearly half of the total sample reported other drivers' lights restrict their vision when driving at night. This is a common issue for drivers of all ages with 47% reporting problems. In addition, 25% of the whole sample, particularly older drivers reported difficulty turning their head and body around when reversing; this was also observed by Isler et al. (1997) in a study focused on the age related effects of restricted head movements on the useful field of view of older drivers. This indicates that as advocated by Gyi (2012) more data is needed to focus on dynamic and functional anthropometric measurements in vehicle design to accommodate specific needs of older drivers, such as postures for reversing. Similarly, 21% of older drivers reported their reactions were slower than they used to be compared to 11% of younger, this was also identified by Middleton et al. (2005) and Musselwhite & Haddad (2008). The study conducted by Middleton et al. (2005) has identified that compared to younger group; drivers aged 65 and over had significantly longer decision times when carrying out specific driving tasks based on a simulation study. In the study conducted by Musselwhite & Haddad (2008) participants reported this during the interviews. Regarding the navigation and entertainment systems, older drivers reported having less distraction when using these sytems. Reasons for this may include that older drivers are more experienced and they know the routes, they also travel short distances and are less likely to use these technologies.

Questions based on operation of in vehicle controls indicate that in general most participants found it easy to operate most in-vehicle controls. The greatest difficulty reported was with pressing the horn (7.5% of the whole sample). No significance was found with age but there were however differences in gender; 10.1% of females compared to 5.7% of males found it difficult pressing the horn ($p<0.01$). Supplementary interviews indicate that in emergency situations older drivers cannot always press the horn instantly; this was mainly due to the small size of the horn. The angle of the steering wheel and the location of the controls also seem to have an effect, for example, if the horn button is located on both sides of the steering wheel the driver cannot locate it as they are focusing on the road; this causes delay with finding the horn button. A research conducted by Ryu et al. (2009) focusing on older drivers' interaction with in-vehicle controls reported that compared to younger older people took longer (slower reaction time) and with higher error rates in general during actual driving conditions. This study was looking at interaction of older drivers with the LCD display, cluster gauge and temperature controls/air conditioning in order to establish design guidelines for this age group by focusing on visibility and accessibility to these controls. Comparing this to current study (results with pressing the horn) in general there is a contradiction, no significance was found in age but there was with gender. However the issue related to the horn was not identified in the literature. Depending on the vehicle make/model it is possible that the horn controls are different sizes, forms and are located in different positions on or near the steering wheel. This needs further exploration in order to determine the requirement for ideal location, size and visibility of these controls in order to prevent the difficulties reported and which may be experienced in the future.

It is also necessary to point out the limitations with this study. Since this data was collected in the UK, some of the findings may have differences with other countries around the world. For instance, different locations around the world had different cultural, environmental and physical characteristics (anthropometric). Based on some of these factors this data may not represent whole population around the world. Another limitation is that, during the interviews with older drivers (aged 65 and over) particularly with over 70s it was observed that they were limiting their selves with expressing the difficulties they experienced. Although it was clearly explained to them the information they provide will be kept confidential, they had the worry that their licence might be taken away.

4.9- Conclusion

This study has provided data to understand the key issues experienced by drivers of all ages. Some issues are common for all ages, and some are age related. Also the issues identified with the controls (seat and bonnet release controls) can be further analysed in order to understand how people interact with them. Some of the problems identified in this study are similar to the ones identified in literature, this shows that some of these issues reported in the past still exist and needs to be addressed. It was also identified that driving at night (other drivers' lights) is not only experienced by older drivers but it was also common for the younger. In literature this is mainly reported as a difficulty experienced by older drivers only. It is important to highlight that based on the outcome of the questionnaire survey together with the current literature there are potential research opportunities to focus on issues related to physical and design related issues and vision e.g. effect of other drivers lights when driving at night. The physical and design related issues include:

- Difficulties with turning head and body around.
- Difficulties with vehicle features such as boot release button in-vehicle and on the bonnet.
- Reaching and pulling the boot door down to close.
- Difficulties with adjusting seat features such as head rest height adjustments (in/out and up/down).
- Difficulties with parking and reversing.

Throughout this research, quarterly meetings were held with the sponsors of this research (automotive client) to present and discuss the findings. Based on these discussions of the possible focus areas, the sponsors were very interested to explore physical/design related aspects within the vehicle cabin area e.g. specific features such as operation of seat controls. This was therefore selected as the main focus of the research in Study. The future direction of this research will focus in more detail on understanding how design of the vehicle cab impacts on posture, comfort, health and wellbeing in older drivers. This would enable a better understanding of the issues identified in this study. Therefore comparison between a familiar and unfamiliar vehicle in a study could provide detailed understanding of the issues identified in this study.

Chapter 5: In-depth audit

5.1- Introduction

The previous chapter reported on a questionnaire study that identified the key issues with the driving experience of older compared to younger drivers. The findings indicated that there were issues related to visual, cognitive, environmental and particularly physical factors with the driving experience of older drivers. As a result, there was a need for an in depth study to understand more about how design of the vehicle cab impacts on posture, comfort, health and wellbeing in older drivers (Objective 2). Therefore the following research questions were asked:

1. What are the main design-related 'influencing' factors e.g. the seat and ease of adjustment?
2. How do older drivers set up their seat (seat set-up process)?
3. How does the design of the vehicle cab influence, driving comfort, health and wellbeing of older drivers?
4. What postures do samples of older drivers adopt (in a familiar and unfamiliar car)?
5. Do age-related changes influence the postures adopted by older drivers?

5.2- Research method

5.2.1- Study design and rationale

After considering various methods and techniques it was decided to conduct an in-depth audit using participants own vehicle (familiar) and a test vehicle (unfamiliar). The make and model of the test vehicle used during the audit was Nissan Qashqai, an SUV type vehicle. The main reason for including two vehicles (familiar and unfamiliar) was to understand how people make decisions in different vehicles and to allow them to carry out evaluations by comparing two vehicles. A repeated measures design would then provide a clearer understanding of the problems experienced, preferences, and likes/dislikes about the vehicle cab area such as the seat and seat controls, as well as to identify any similarities/differences in both vehicles. Although this study was going to involve a wide range of data collection techniques it had to be conducted within a reasonable amount of time, between 1.5-2 hours per person.

Taking into account the potential physical limitations of older participants (particularly the oldest group: over 80s) the audit needed to be carried out in static vehicle conditions (non-driving). Involving the option of driving could have implications in terms of safety and the risk of having an accident, particularly with a vehicle which participants do not have experience of driving. The format of the in-depth audit and data collection tools are described below.

It is important to clarify that the whole process and the set-up process (i.e. how they set up their seat) was carried out in the familiar vehicle and then unfamiliar vehicle for each participant. The main reason is, participants already had experience with their own vehicle, and therefore it was appropriate to start the set-up process in the familiar vehicle. Then by the time they move to the unfamiliar vehicle, they had an idea of what to do for the set-up process. Since the aim of this research was to determine the design requirements for older drivers (retired, semi-retired and working) the age criteria of participants involved in this study was set as 50 years and over (please refer to section 5.4.1).

The audit involved participants from various locations in the UK and was conducted for convenience either at their home, the university or other suitable venue. It was often more convenient for participants to take part from their home since majority lived outside the town in different cities; more than half of the participants were over 65s. The data capturing tools selected/designed for the audit included elements from both qualitative and quantitative methods (mixed methods) in order to triangulate the outcomes of this study; these are explained in further detail in section 5.2.3.

5.2.2- Ethical clearance

The ethical clearance form was completed and approval was obtained on 29 April 2013 from the Loughborough University committee. A detailed participant information sheet (Appendix 2) was also prepared for participants to read and understand the details of the study. After reading the information sheet an informed consent form was given to each participant for them to sign and agree to take part in the study (Appendix 3).

5.2.3- Procedure

This section describes the procedures carried out during the audit and the structure and format for each participant. Data collection sheets can be found in Appendix 4.

5.2.4- Demographic information

Initial part of the audit was designed to obtain background information about participants, including year of birth, gender, occupation, vehicle make/model, years of driving experience and annual mileage. Their full date of birth was not requested for reasons of keeping anonymity.

5.2.5- Self-rated confidence

The next section was based on a mini questionnaire concerned with self-rated confidence. Participants rate their confidence on a 10 point scale, 0 (not confident at all) to 10 (completely confident) depending on their experience with ten given driving conditions. These tasks include parallel parking, driving at night, making a right turn onto a main road, driving in busy traffic and reacting quickly. This questionnaire was adapted from Marottoli and Richardson (1998) rephrasing the wording to be suitable for the UK. Most of the driving tasks involved in this questionnaire were used in the questionnaire survey (Chapter 4).

5.2.6- Seat set-up process

A video camera (GoPro Hero 3- wide angle) was used to record the seat set-up process for each participant in both vehicles starting with their own vehicle (the familiar vehicle) first. Using a wide angle camera mounted facing the driver on the windscreen easily captured the participant and the in-vehicle surroundings. Participants were initially given instructions (if needed, even in their own vehicle) on how to use the controls and asked to experience and familiarise themselves with the controls in both vehicles. They were then asked to get into the vehicle and set up their driving seat to be comfortable for driving. The seat positions were standardised for the set-up process in both vehicles; this was set to rear most and reclined position (approximately 110-150 degrees). Assistance were given by the researcher to participants who struggled or needed help during the set-up process in relation to finding and operation of specific controls.

Once the seat set-up process was complete, the video of each participant was played back to them using a laptop and they were asked to talk through each step they carried out together with their decisions. This form of observational technique was included in the study for two main purposes. It was thought to be easier for participants to watch their video and describe their actions straight away rather than trying to remember their actions. Additionally, through this sort of observation technique, both qualitative and quantitative data can be extracted. For example, the way participant interacted with specific vehicle features in vehicle cab and what are they struggling with; and the time they spent carrying out an action, gaining a better understanding of their experiences.

5.2.7- Posture analysis

Once participants completed the seat set-up process, their driving postures were captured in both vehicles and photographs were taken (please refer to appendix 4 for more detail). The following angles were measured - adapted from, Porter and Gyi (1998, pp.259):

- *Trunk-thigh angle: the angle between a line from the acromion to the greater trochanter and a line from the lateral condyle to the greater trochanter.*
- *Arm flexion: the angle between the vertical and a line from the acromion to the lateral epicondyle.*
- *Knee angle: the angle between a line from the greater trochanter to the lateral condyle and a line from the lateral malleolus and the lateral condyle.*
- *Ankle angle: the angle between a line from the lateral condyle to the lateral malleolus and a line parallel with the foot.*
- *Neck inclination: the angle between the vertical and a line from the 7th cervical vertebrae to the auditory canal.*
- *Elbow angle: the angle between a line from the acromion to the lateral epicondyle and a line from the ulnar styloid to the lateral epicondyle.*

This would then allow a comparison of the postures selected in both cars. The data was then compared with the recommendations from, Rebiffe (1969), Grandjean (1980) and Porter & Gyi (1998) shown in table 8 in chapter 3 (research methods).

5.2.8- Vehicle seat measurements

Participants were asked to get out of the vehicle without changing their set-up position. The following measurements were obtained from the seat and the seat controls as illustrated in Figure 25: seat position set by participants (seat height and fore/aft); seat fore/aft (minimum and maximum distance); seat height (minimum and maximum height); seat size (backrest length and cushion length). The aim was to obtain additional (quantitative) data to support the findings. The measurements can be found in Appendix 6.

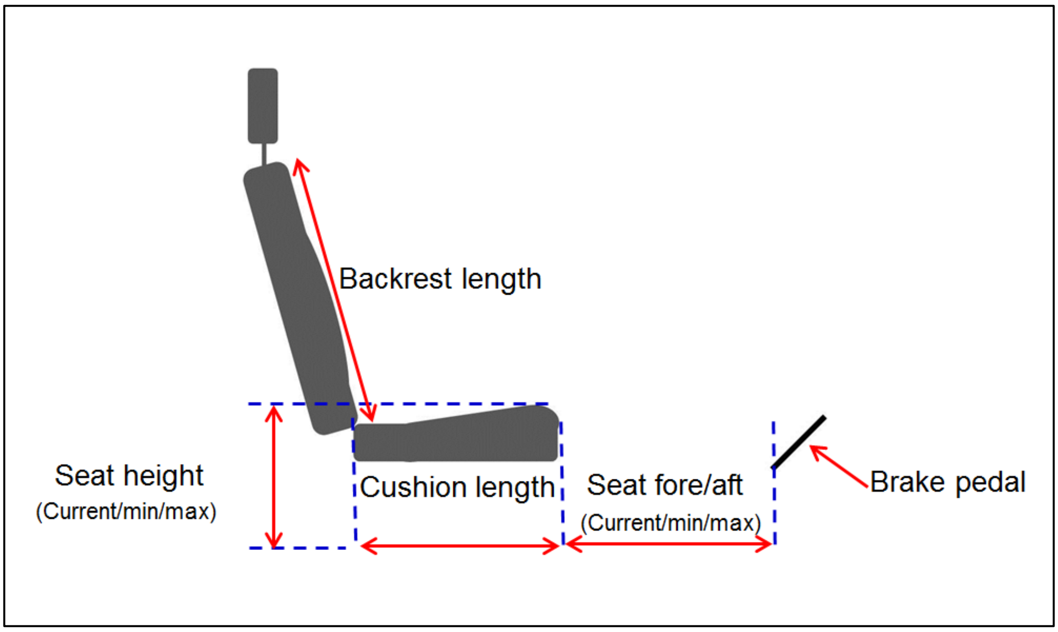

Figure 25: Measurement areas of the seat during the set-up process

Other measurements were also taken related to the location and spacing of the seat controls, for example the seat lifter and seat recline locations. It was necessary to find a reference point to measure the location of these controls and the pivot point of the seat was defined as the reference point illustrated (Figure 26). The distances of the lumbar support adjustments were measured to the edge of seat bolter as shown in Figure 27. The gap (distance) between the seat lifter and the door pocket was measured as shown in Figure 28. The same method was also used to measure the distance between the seat recliner and the door trim. Measurements are included in Appendix 7.

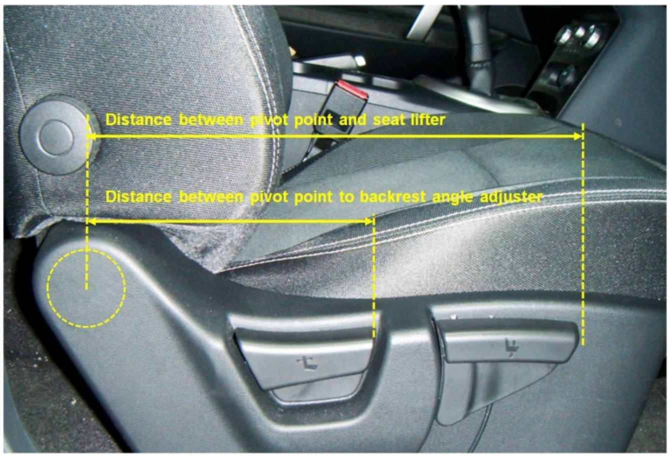

Figure 26: Measurement reference points for seat lifter and seat recliner

Figure 27: Measurement reference points for lumbar support adjustments

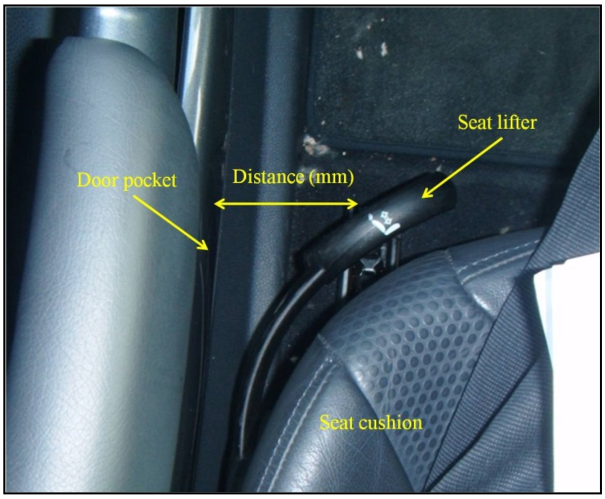

Figure 28: Measuring the gap between seat lifter and to door pocket

5.2.9- Ergonomics audit

Participants were asked to get back in the car in order to carry out an ergonomics audit (e.g. the seat and primary controls). The audit focused on evaluation of the seat controls based on their location; ease of operation and accessibility; as well as their needs and how they interacted with them.

5.2.10- Emotional design

A section based on emotional design was also developed; it was aimed to obtain information about how users perceive their seat controls in terms of pleasure and enjoyment. Each control was rated on the three categories: texture, shape and response. In order to evaluate the controls as accurately as possible in terms of these aspects, research was carried out on some of the tools used in emotional design. It was also important to determine the correct wording for the rating scales to be used during this evaluation (please refer to Section 5.3.2). Van Gorp and Adams (2012) provide a good insight to two different dimensions of emotions experienced by users. These are the combination of one's mental judgement (value) and their level of physiological stimulation (arousal). For instance, a person's experience is either good or bad or something between the two. The automatic unconscious brain perceives pleasant experiences as good and unpleasant as bad e.g. pain. Based on these examples the author adapted the theory of Russell (1980) in order to describe value judgments e.g. Unpleasant versus Pleasant, these elements were used in order to determine the evaluation of aspects of the seat controls concerned with emotional design.

5.2.11- Participant functional performance

The literature shows that there are many assessment instruments available in the field to assess the functional capabilities of older drivers. A review was conducted on appropriate assessment tools used to assess older drivers capabilities in Chapter 3 (section 3.6, Table 7). As a result, tools used as part of this study, were:

- Visual contrast sensitivity test (Hamilton Veale)
- Arm reach test (shoulder flexibility)
- Clock reading test (upper body flexibility)
- 9-hole peg test (hand co-ordination and dexterity)
- Self-rated confidence (10 point scale, 10 driving conditions)

The selection of the assessment tools were made based on the following reasons:

- It was necessary that the tests were suitable for a field based study in terms of set up process and the way they are conducted e.g. use within a short period of time and had to be easily understood and conducted by participants.
- Each test assesses different functional capabilities which are crucial to carry out specific driving tasks. For example, contrast would be very relevant for interacting with specific features in the cabin area, e.g. controls/displays. Therefore the contrast sensitivity test can be a very useful tool to gain understanding on this.
- Additionally, selected tools were also used in the literature and this would enable some of the results to be compared with the findings.

5.2.12- Anthropometric data

Anthropometric data was obtained for each participant; stature, sitting height, knee height, sitting hip width and popliteal length. The measurements were taken using a tape measure and anthropometer. For each body area, measurements were taken three times and the average value was recorded in order to improve accuracy. These measurements were compared with other data obtained from the participants during the audit and to understand the link (if any) between body size and their responses (measurements can be found in Appendix 5).

5.3- Pilot study

A pilot study was conducted for the in-depth audit focusing on the following areas:

- To standardise prompt questions
- To determine the time required to conduct the study
- To validate the data collection tools
- To ensure that the responses were as anticipated
- To ensure that appropriate rating scales were used

5.3.1- Participants

A convenience sample of drivers aged 22-64 years (3 males, 4 females) was obtained for the pilot study. All participants took part with their own vehicle (familiar) and a test vehicle. A Fiat Punto was provided to participants as a test vehicle (unfamiliar).

5.3.2- Key points

Modifications were made to some of the questions to improve clarity. Other specific changes include:

- The questions based on the 'ergonomics audit' were improved; various types of Likert scales were tested to ensure that the responses were as anticipated.
- Some respondents needed wider range options in the rating scales to describe their level of experience with the controls. The options on the rating scales were initially 3, then increased to 5 options.
- The sequence order of tasks and assessments for the audit were optimised to reduce the participant time needed to complete the study.

Another important improvement made during the pilot study was in the design of the measurement tools used. All these design modifications improved the accuracy of the measurements obtained and speeded up the process and saved more time. From problems identified during the pilot study, an extendable goniometer was developed. Initially a standard goniometer was used in the study to measure joint angles of participants in both vehicles and sticky dots were placed on anatomical landmarks. The standard goniometer had short arms and its end tips were not reaching the markers on the joints for accurate angle measurement. In order to solve this problem an extendable arm was designed and fitted on the standard goniometer. Two telescopic (magnetic) pickup tools were used as extendable arms. These were mounted on a bracket/mount which was created using CAD and cut with laser cutting technique, and then fitted on the standard goniometer (Figure 29). This then improved the accuracy of static driving posture and saved time on positioning it on the body (Figure 30).

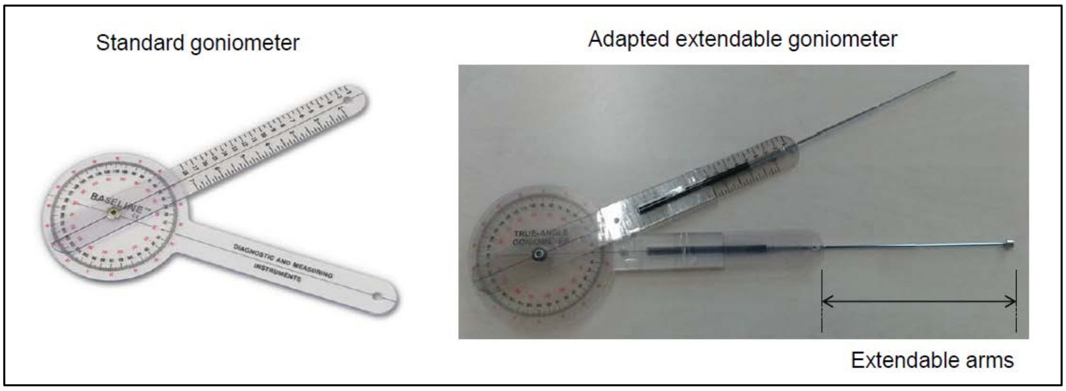

Figure 29: Extendable goniometer

Figure 30: Measuring static driving posture with extendable goniometer

A unique seat height measurement tool was also developed (Figures 31, 32 and 33). In order to capture the car seat height selected by participants, initially a standard ruler/tape was used. During the pilot study difficulties were experienced with obtaining these measurements accurately. Access to the seating area made it very difficult to position the measuring equipment. There was a need for a customised design and a unique seat height measuring tool was developed which was easier to position around the seat to obtain the measurement.

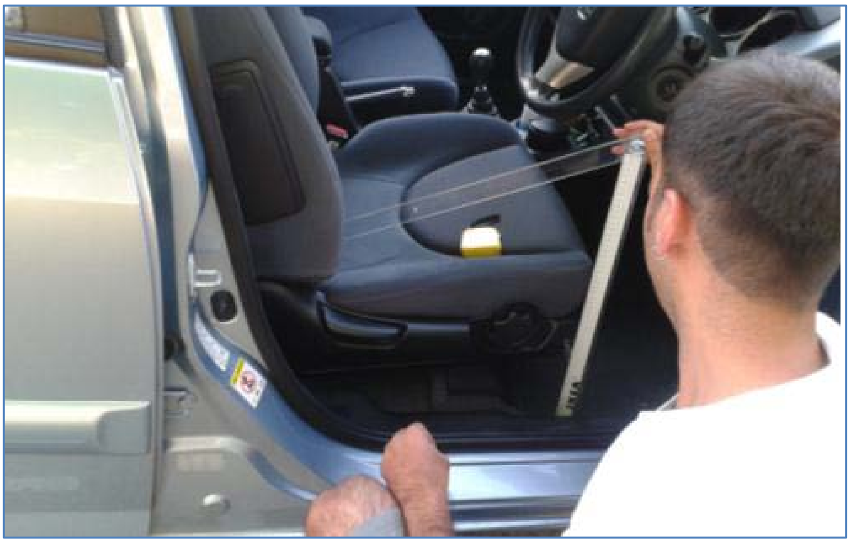

Figure 31: Seat height measurement tool positioned on the seat

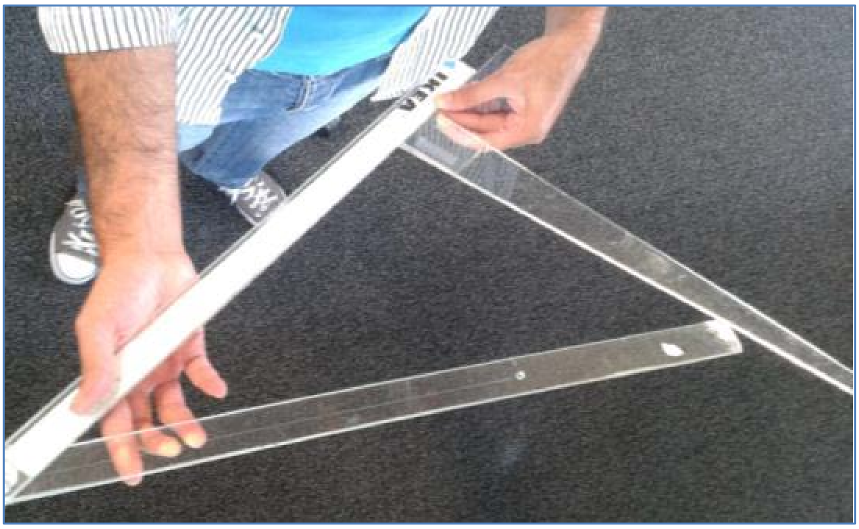

Figure 32: Seat height measurement tool checking the measurement value

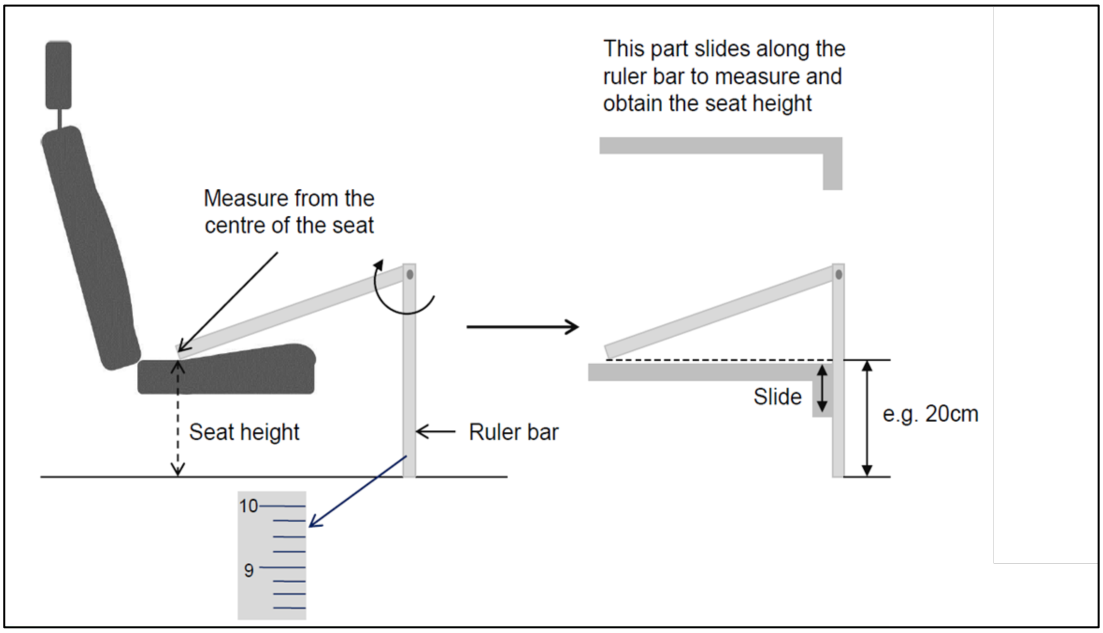

Figure 33: Seat height measurement tool operation method

Additionally a reference point marker was developed for measuring neck posture (Figure 34). In order to increase the accuracy of measurements obtained for neck inclination a c7 (cervical vertebrae) marker tool was developed- a ball shaped point marker with a flat base. It was modelled using 3D CAD software and printed with rapid prototyping technique. This was placed on the c7 of each participant using a sticky pad and helped the measurement of neck inclination, shown in Figure 35.

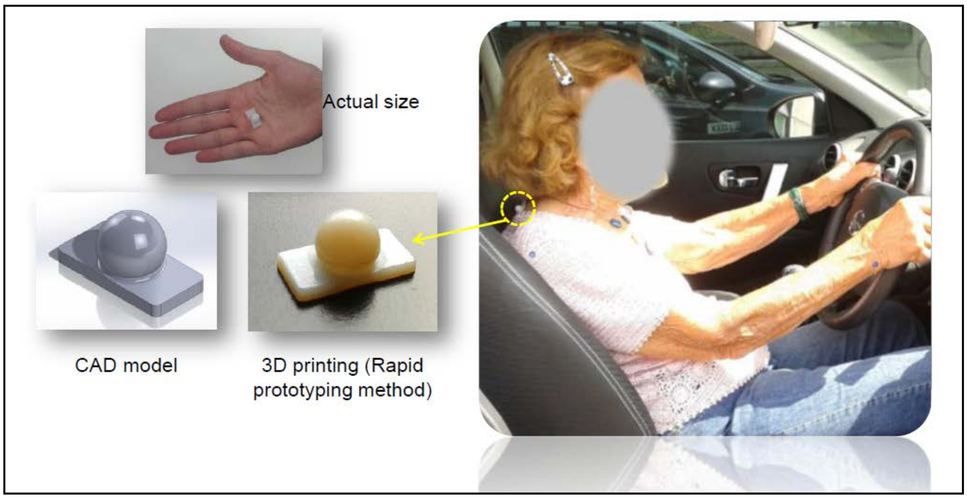

Figure 34: Neck inclination marker (c7)

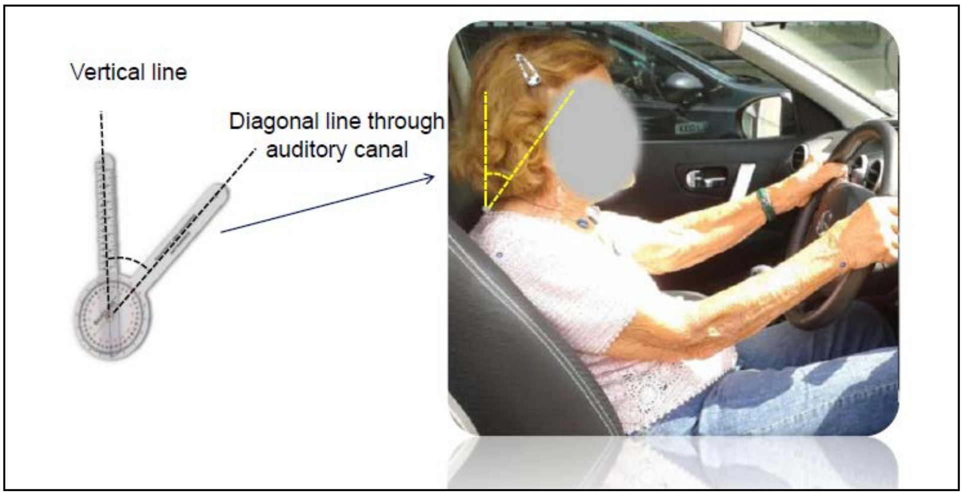

Figure 35: Measuring the neck inclination

5.4- Data collection

The majority of participants who took part in this study were selected from the respondents of the previous study (questionnaire survey). These were members of organisations such as University of the Third Age (voluntary action), Institute of Advanced Motorists and Probus (retired professionals). Agreement was obtained from these organisations for the distribution of a flyer about the research to their members. Snowballing techniques were used as a strategy to increase participation. Figure 36 shows the main locations travelled to conduct the in-depth audit.

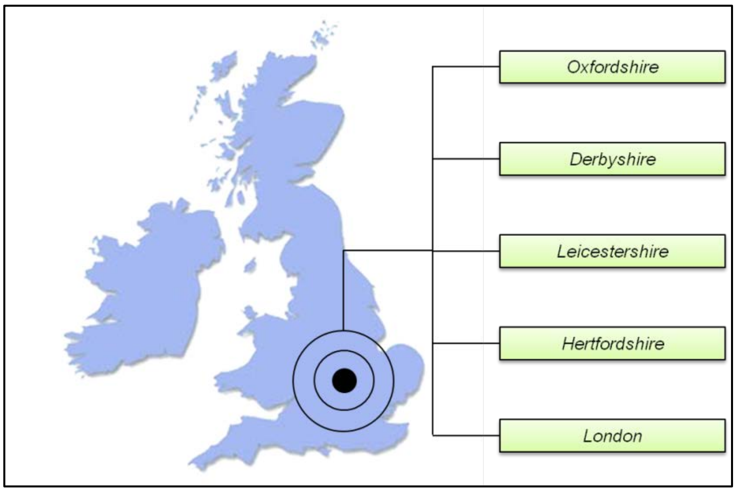

Figure 36: Locations travelled to conduct the study

5.4.1- Sampling strategy

Figure 37 shows the sampling strategy adopted for this study is a stratified purposive sampling strategy. The target sample size was *n*=36-48, a smaller sample compared to the previous study as it involved more detailed data collection. Age criteria was set as 50 years and over. The sample was divided into three sub groups focusing on age and gender (approximately 50% for each category) to allow comparisons of the different groupngs.

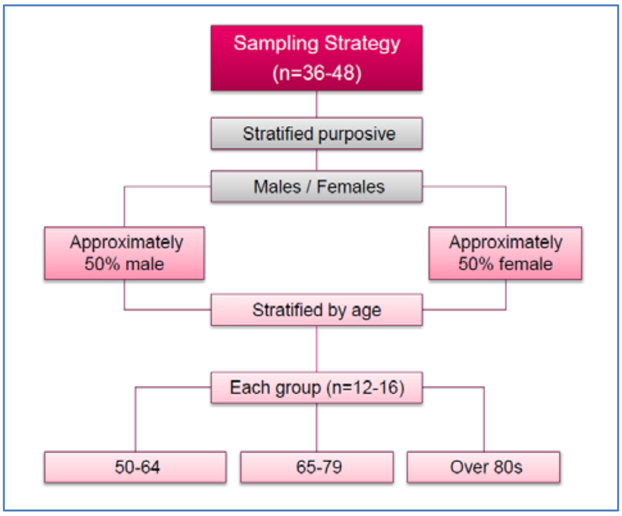

Figure 37: Sampling strategy (In-depth audit)

The target number for each sub-group was 12-16 participants and these were formed of three different age groups; 50-65 (youngest), 65-79 (older) and over 80s (oldest).

5.5- Data analysis

Data were analysed using SPSS (version 20) and Excel, firstly to gain a general understanding of the whole sample, and then to explore differences between age and gender. Specific statistical methods were used depending on the data type. ANOVA, Chi-squared test and Binary Logistic regression test (Nominal) were used to analyse the results from the ergonomics audit and emotional design of seat controls. In order to analyse the video data obtained during seat set-up process, a Wilcoxon test (Non-parametric) was used on this Ordinal data. In order to analyse the postural data an ANOVA test (Ordinal) was used.

5.5.1- Video analysis

The initial step for video analysis was to carryout data coding. There were a total of 96 videos (max 6 minutes each) capturing the seat set-up process for both the familiar and unfamiliar vehicle. Each video required at least 45 minutes to code for analysis. This includes:

- A breakdown of the task
- The sequence (order) of the seat set-up task
- Time taken to operate each control e.g. seat lifter, lumbar support
- The total time (seconds) to set-up their seat
- Participant commentary
- Observation checklist
  - Ease of finding the controls
  - Whether assistance is given
  - Any stress/anxiety observed
  - Other points of interest e.g. level of physical effort spent

An example of the data coding for a 78 year old male participant is illustrated in Figure 38. As shown, each seat control was coded in numbers; these were then recorded to illustrate the task sequence (order). Additionally, the adjustment type for each seat control was recorded for both (familiar and unfamiliar) vehicles. The same process was carried out for each of the video recordings.

Participant	Control	Code	Own Vehicle	Adjustment type	Time taken (s)	Total time (s)	Task (order)
Barry D. (own vehicle)	Seat fore/aft	1	Seat fore/aft	Bar	4	22	7,3,1,3,4,2,1
	Seat height	2	Seat height	Lever	5		
	Seat recline	3	Seat recline	Dial	6		
	Head rest height	4	Head rest height	Button	1		
	Lumbar support	5	Lumbar support	Dial	N/A		
	Steering wheel	6	Steering wheel	Lever	N/A		
	Seat belt	7	Seat belt		6		
	Other	8	Other	Door			

Participant	Control	Code	Own Vehicle	Adjustment type	Time taken (s)	Total time (s)	Task (order)
Barry D. (test vehicle)	Seat fore/aft	1	Seat fore/aft	Bar	11	57.5	7,1,3,1,5,4,6
	Seat height	2	Seat height	Lever	5		
	Seat recline	3	Seat recline	Lever	37		
	Head rest height	4	Head rest height	Button	2		
	Lumbar support	5	Lumbar support	Dial	0		
	Steering wheel	6	Steering wheel	Lever	0		
	Seat belt	7	Seat belt		2.5		
	Other	8	Other				

Figure 38: Video analysis (data coding) – 78 year old male participant

5.6- Results

This section will present the key findings focusing on the following areas:

- Descriptive data analysis.
- Comparison of age and gender.
- Comparison of familiar (own vehicle) and unfamiliar vehicle (Nissan Qashqai).
- Comparison of functional performance assessments with age, gender, vehicle type.

5.6.1- Sample distribution

In total 47 people took part in the audit (Figure 39). Of the 47 people; 38% were females and 62% were males, drivers over 80 years represented 32% (*n*=15) of the sample (Figure 40).

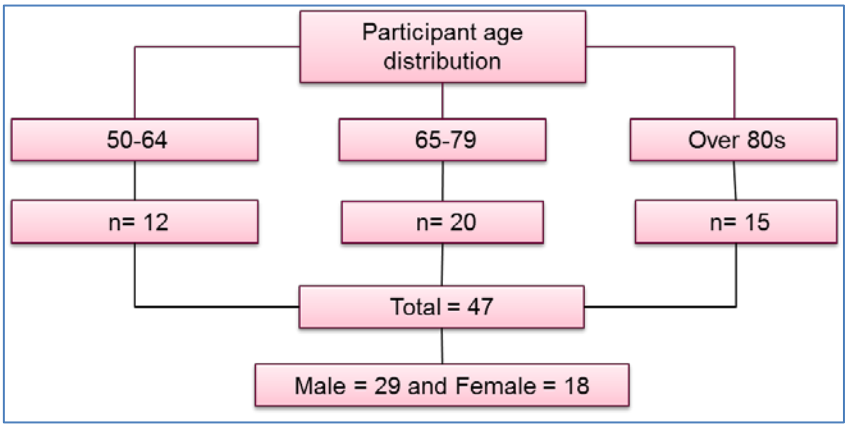

Figure 39: Sample distribution

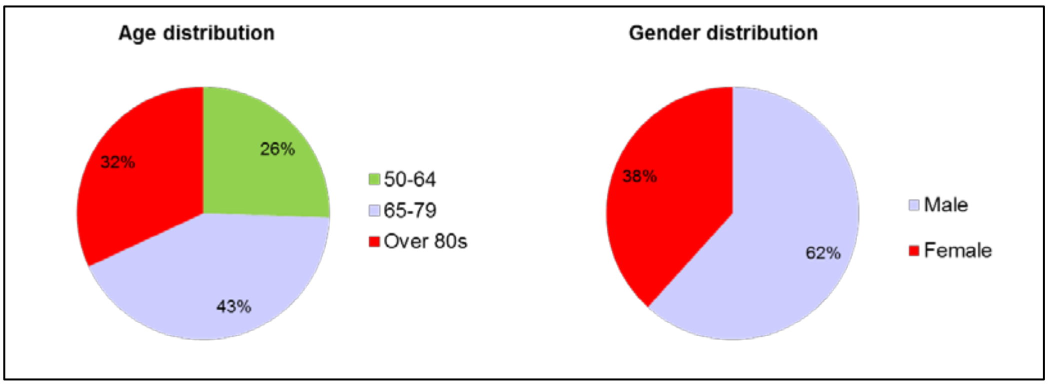

Figure 40: Age and gender distribution

5.6.2 – Seat set-up process (observations)

Important observations were made using the photographic images from the video analysis. The majority of participants (all age groups) had difficulty with adjusting the head rest height in both vehicles (test vehicle and participants own vehicle). Many older participants (approximately 40%) had difficulty with turning their head and body around to reach and operate the headrest, the majority of these were in the over 80s cohort (Figure 41).

Figure 41: Male participant, aged 78 years old, experiencing difficulty with adjusting the head rest height

Most participants had difficulty finding/locating specific seat controls such as the seat recliner, lumbar support adjustment and steering wheel adjustment (Figure 42). In addition to this, many participants (particularly the over 65s) had difficulty with the operation of the seat controls in terms of their direction of motion and stiffness. The steering wheel adjustment and dial type seat recliners were particularly problematic. Once this was observed by the researcher, assistance was given on operation of these controls. This was observed in both familiar and unfamiliar vehicles.

Figure 42: Participants experiencing difficulty with finding steering wheel adjustment

Approximately 25% of participants leant forward in order to operate the lumbar support adjustments, shown in Figure 43. During this position their back was not resting against the seat, therefore they reported that they did not receive any feedback during the operation. This was mainly observed in the unfamiliar vehicle.

Figure 43: Participants leaning forward in order to access and operate lumbar support

Figure 44 shows images of 3 participants (over 80s) as they are trying to adjust the head rest height during vehicle set up process. They all experienced difficulty with turning their head and body around and tried alternative ways of adjusting the head rest height. Another difficulty they experienced was with finding and operating the button to operate the head rest in both the familiar and unfamiliar vehicle.

Figure 44: Participants trying to adjust head rest height (over 80s)

Some participants had difficulty accessing specific seat controls such as the lumbar support adjustment and the seat recliner (Figure 45). They frequently had to open the door in order to have enough space for hand/arm movements during operation.

Figure 45: Users opening the door in order to access controls

As well as identifying issues/difficulties experienced by participants, there were also things that were found to be acceptable by participants. For instance the seat itself in the test vehicle was reported as comfortable by most participants providing good support around the body. Participants particularly with short stature (under 1.55cm) were also satisfied with the seat height adjustment range of the test vehicle (unfamiliar vehicle) as they were able to obtain a good field of view and felt confident. Also in terms of ingress/egress, particularly the over 80s reported getting into and out of the test vehicle was easier than their own vehicle as the seat was located at a higher level. This resulted in less force being exerted during ingress/egress.

It was observed that in general the seat lifter and fore/aft controls were easy to locate and operate in both the familiar and unfamiliar vehicles. The lumbar support adjustment in the unfamiliar vehicle was also reported as pleasant due to its design; "it has a rubber texture easy to grip with a soft feel and rotates smoothly" was reported by a user. Some participants who did not have lumbar support in their own vehicle considered this control as a desirable and important feature after experiencing it in the test vehicle.

It is interesting that the majority (60%) of older females (over 80s) had made design modifications to their own vehicle e.g. seat pads to increase their seat height as shown in Figure 46. Most of these females were short in stature (under 155cm). One female participant was not aware that her car seat was equipped with a seat height adjustment until the researcher pointed this out. Although she used the same vehicle for the past 10 years, in order to increase the seat height, she placed a cushion on her seat.

Figure 46: Examples of additional items to increase their seat height

Similarly, a 71 year old male added a foot rest for his left foot (Figure 47), placed a cushion underneath his thighs to extend the cushion length (Figure 48) and a soft sponge to rest his knee against (Figure 49).

Figure 47: User added a foot rest for the left foot

Figure 48: Cushion underneath thighs to extend the cushion length

Figure 49: Placed a sponge in the door pocket to rest his knee

Figure 50 shows another example from a 70 year old female who in this case made her own adaptations to reduce her lower back pain and improve ingress/egress. She used a cushion to provide lower back support and a plastic shopping bag to reduce seat cushion friction and assist her swivelling her body during ingress/egress.

Figure 50: Cushion for lower back and shopping bag to swivel (ingress/egress)

These design adaptations indicate that participants were not satisfied with the original design of the seat in their own vehicle. It shows that they know the problems affecting their comfort and as a solution they made design changes.

5.6.3 - Set-up process (video analysis)

The coded video data was analysed by focusing on the order of the tasks carried out in each vehicle (familiar + unfamiliar). Table 18 shows a list of the controls used during the set-up process and that each control is given a number from 1 to 8. It is important to note that some participants did not have all these features in their own vehicle e.g. steering wheel and lumbar support adjustment.

Table 18: Control type and allocated number

Control type	Control number
Seat fore/aft	1
Seat height	2
Seat recline	3
Head rest height	4
Lumbar support	5
Steering wheel	6
Seat belt	7
Other (e.g. mirror, door etc.)	8

Table 19 shows an example of data obtained from the video analysis of the seat set-up process from a participant in his own vehicle showing the order of the tasks carried out. It shows that the participant conducted the set up process in the following order; seat height adjustment (control 2), seat recline (control 3), seat fore/aft (control 1), head rest height (control 4) and seat belt (control 5). The data was then re-arranged using normalised order. For instance, the example data in Table 19 shows the participant carrying out 5 tasks in total; this is then divided by 100 and equally distributed for each task, starting from 0 and increased by a value of 25 for each task, ending with the value 100 for the final task (data for the whole sample can be found in Appendix 8). Once this process was completed for the whole sample data, the median and quartile values were obtained for both vehicles, shown in Table 20.

Table 19: Example data - operation order of controls and normalised data (assigned with values 0 to 100)

Control operation order	**1st** (Control 2)	**2nd** (Control 3)	**3rd** (Control 1)	**4th** (Control 4)	**5th** (Control 7)
Normalised order	0	25	50	75	100

Table 20: Median and quartiles for both vehicles (the order of the tasks carried out by whole sample)

Seat controls		**Own vehicle**			**Test vehicle**		
Control type	Control number	25% ile	Median	75% ile	25% ile	Median	75% ile
Seat fore/aft	1	0	22.5	38	0	17	40
Seat height	2	18	40	65	16	25	33
Seat recline	3	17	33	50	13	20	41
Head rest height	4	50	66	75	67	80	83
Lumbar support	5	40	50	86	66	67	80
Steering wheel	6	29	53	80	40	50	64
Seat belt	7	100	100	100	100	100	100
Other	8	44	61	83	42	60	100

The next procedure involved statistical analysis of the results to compare the order of the tasks carried out in both vehicles. The statistical method involved a Wilcoxon-signed rank test, a non-parametric test which does not assume scale data and it also does not assume normal data. Based on the analysis, significant differences were found between vehicles for the order of the operation of the head rest height adjustment and seat recliner (Table 21). No significant differences were found between other controls based on their order of operation. This was checked by comparing the median values and the *p* values obtained through Wilcoxon signed rank test. The results indicate that there are similarities in the order of the tasks carried out in both vehicles for most controls and some differences were found in the operation order of seat recliner ($p<0.01$) and head rest height adjustment ($p<0.01$).

Table 21: Order of controls - comparing both vehicles for the whole sample)

Control type	Control number	Median (own vehicle %)	Median (test vehicle %)	P values
Seat fore/aft	1	22.5	17	***NS***
Seat height	2	40	25	***NS***
Seat recline	3	33	20	0.012
Head rest height	4	66	80	0.010
Lumbar support	5	50	67	***NS***
Steering wheel	6	53	50	***NS***
Seat belt	7	100	100	***NS***
Other	8	61	60	***NS***

The next stage of the analysis focused on understanding the order of the tasks carried out by the whole sample in their own vehicle. Table 22 shows the median values of the controls in the order they have been operated by the whole sample in their own vehicle. For instance the seat fore/aft adjustment had the smallest median value, which indicates that this control was operated at the beginning of the set-up process. The seat belt had the largest median value indicating that it was operated as the last step of the set-up process. A Wilcoxon signed-ranked test was conducted for the tasks carried out in the own vehicle.

Table 22: Order of the tasks carried out by the whole sample in their own vehicle (median values)

Control type	Order of operation	Median value (low to high)
Seat fore/aft	1st	22.5
Seat recline	2nd	33
Seat height	3rd	40
Lumbar support	4th	50
Steering wheel	5th	53
Other (door, mirror etc.)	6th	61
Head rest height	7th	66
Seat belt	8th	100

Table 23 shows the results (*p* values) obtained from the Wilcoxon signed ranked test by comparing all 8 controls against each other through a matrix table in participants own vehicle.

Table 23: Wilcoxon signed-ranked test - showing p values obtained by comparing all 8 controls against each other (own vehicle)

Control type	**Control number**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Seat fore/aft	1		0.005	0.024	0.000	0.003	0.000	0.000	0.046
Seat height	2			***NS***	0.013	***NS***	0.077	0.000	***NS***
Seat recline	3				0.000	0.012	0.021	0.000	***NS***
Head rest height	4					***NS***	***NS***	0.000	***NS***
Lumbar support	5						***NS***	0.001	***NS***
Steering wheel	6							0.000	0.068
Seat belt	7								***NS***
Other	8								

Looking at the median values obtained (Table 22) and the results (*p* values), obtained through Wilcoxon signed-ranked test (Table 23), it is possible to gain a general idea on the order of the controls operated during the seat set-up process for the whole sample in their own vehicle. Participants used the controls in the following order:

1. Seat fore/aft adjustment
2. Seat recliner **or** Seat height
3. Lumbar support **or** Steering wheel **or** Head rest height adjustment
4. Seat belt

The same analysis was also carried out on the data obtained from the test vehicle (unfamiliar vehicle) for the whole sample. Table 24 shows the median values from the data showing the order they were operated by the whole sample. Once again, a Wilcoxon signed-ranked test was conducted for the whole sample for the test vehicle. The *p* values are shown in Table 25.

Table 24: Order of the tasks carried out by the whole sample in the test vehicle (median values)

Control type	Order of operation	Median value (low to high)
Seat fore/aft	1st	17
Seat recline	2nd	20
Seat height	3rd	25
Steering wheel	4th	50
Other (door, mirror etc.)	5th	60
Lumbar support	6th	67
Head rest height	7th	80
Seat belt	8th	100

Table 25: Wilcoxon signed-ranked test - showing p values obtained by comparing all 8 controls against each other (test vehicle)

Control type	Control number	1	2	3	4	5	6	7	8
Seat fore/aft	1		***NS***	***NS***	0.000	0.000	0.000	0.000	***NS***
Seat height	2			***NS***	0.000	0.000	0.000	0.000	***NS***
Seat recline	3				0.000	0.000	0.000	0.000	0.027
Head rest height	4					0.086	0.000	0.000	***NS***
Lumbar support	5						0.001	0.000	***NS***
Steering wheel	6							0.000	***NS***
Seat belt	7								***NS***
Other	8								

Comparing the *p* values with the mean values obtained for the test vehicle, participants operated the controls in the following order:

1. Seat fore/aft adjustment **or** Seat height **or** Seat recline
2. Steering wheel
3. Other (door, mirror etc.)
4. Lumbar support
5. Head rest height
6. Seat belt

Based on the individual analysis of participants own vehicle (Table 23) and the test vehicle (Table 25), it is possible to obtain an individual breakdown of the order of the controls carried out by the whole sample as follows:

1. Seat fore/aft
2. Seat recline
3. Seat height
4. Steering wheel
5. Other (door, mirror etc.)
6. Lumbar support
7. Head rest height
8. Seat belt

5.6.4- Posture analysis

The posture angles of each participant were obtained after setting up their car seat in a comfortable driving position (familiar and unfamiliar vehicles). Age and gender differences were explored and an ANOVA test was conducted in order to explore statistical significance. Table 26 shows significant differences by age group for the unfamiliar vehicle (test vehicle). Few significant differences were found with increasing age and only an increase in neck inclination was identified ($p<0.05$) for older age groups.

Table 26: Postural data for test vehicle (age differences)

Age	Trunk-thigh angle	Arm flexion	Elbow angle	Knee angle	Ankle angle	Neck inclination	
50-64	103	33	122	111	94	42	**Test vehicle (Qashqai)**
65-79	104	33	125	118	92	48	
Over 80s	103	32	123	113	92	51	
ANOVA test	*NS*	*NS*	*NS*	*NS*	*NS*	$p<0.05$	

In terms of gender, significant differences were found between males and females for trunk-thigh angle, arm flexion and elbow angle with the test vehicle (Table 27).

Table 27: Postural data for test vehicle (gender differences)

Gender	Trunk-thigh angle	Arm flexion	Elbow angle	Knee angle	Ankle angle	Neck inclination	Test vehicle (Qashqai)
Male	102	36	131	116	92	47	
Female	106	27	113	113	94	48	
ANOVA test	*p*<0.05	*p*<0.01	*p*<0.01	***NS***	***NS***	***NS***	

Differences with age and gender were also checked for posture data obtained from participants with their own vehicle (familiar vehicle). Table 28 shows the differences in age for the familiar vehicle and once again, only an increase in neck inclination was identified ($p < 0.05$).

Table 28: Postural data for own vehicle (age)

Age	Trunk-thigh angle	Arm flexion	Elbow angle	Knee angle	Ankle angle	Neck inclination	Participants vehicle
50-64	100	34	125	116	94	41	
65-79	101	32	126	120	92	48	
Over 80s	100	32	121	115	91	48	
ANOVA test	***NS***	***NS***	***NS***	***NS***	***NS***	*p*<0.05	

Table 29 illustrates the differences between males and females. Significant differences were found between males and females for arm flexion and elbow angle in their own vehicle.

Table 29: Postural data for own vehicle (gender)

Gender	Trunk-thigh angle	Arm flexion	Elbow angle	Knee angle	Ankle angle	Neck inclination	Participants vehicle
Male	99	36	131	117	91	46	
Female	103	27	114	118	93	46	
ANOVA test	***NS***	*p*<0.01	*p*<0.01	***NS***	***NS***	***NS***	

5.6.5- Seat and seat controls evaluation

Participants were asked to evaluate the seat controls of both vehicles as part of understanding the seat set-up process. They gave their responses based on the reach distance, accessibility and operability for each vehicle. This includes seat recliner, seat lifter, lumbar support adjustment, head rest height adjustment and seat fore/aft adjustment. Results for the whole sample are shown in Table 30 for the participants own vehicle. A high proportion (40.5%) of participants reported the reach distance (reach) of the head rest control as ‘too far away’ in their own vehicle (familiar vehicle). Additionally, 36.9% in total reported the reach distance for the lumbar support as either ‘too close’ (15.8%) or ‘too far’ (21.1%). The head rest (50%), lumbar support (36.8%) and seat recliner (34%) controls were also frequently reported as being more difficult to access (hand/arm access). The head rest control (65.9%) and the lumbar support adjustment (42.1%) were also more frequently reported as difficult to operate. In addition, difficulties were found with the seat recliner (25.5%) and seat lifter controls (25%) by the whole sample.

Table 30: Ergonomics evaluation of seat controls in participants own vehicle (familiar vehicle)

Own vehicle	**What do you think of the reach distance of the following controls of the seat? (Reach)**			**How accessible are the following controls of the seat in terms of hand/arm access? (Hand/arm access)**		**How easy is it to operate the following controls of the seat? (Operability)**	
Seat controls	**Too close (%)**	**OK (%)**	**Too far (%)**	**Easy (%)**	**Difficult (%)**	**Easy (%)**	**Difficult (%)**
Seat lifter	4.3	89.4	0	66	34	74.5	25.5
Seat recliner	0	100	0	83	10.6	75	25
Lumbar support adjustment	15.8	63.2	21.1	63.2	36.8	57.9	42.1
Seat fore/aft adjustment	0	89.4	10.6	91.5	8.5	93.6	6.4
Head rest height adjustment	2.4	57.1	40.5	50	50	34.1	65.9

Table 31 illustrates the results for the whole sample for the unfamiliar vehicle. In terms of reach, head rest and lumbar support controls were more frequently reported as being ‘too far away’ in the test vehicle (38.3% and 34% respectively). The lumbar support (74.5%), head rest (66.0%), and seat recliner (36.2%) were more frequently reported as difficult to access (hand/arm access). In addition, 87.2% of participants reported experiencing difficulty with the operation of the head rest height control, and 23.4% reported difficulty operating the lumbar support adjustment.

Table 31: Ergonomics evaluation of seat controls in the test vehicle (unfamiliar vehicle)

Test vehicle	**What do you think of the reach distance of the following controls of the seat? (Reach)**			**How accessible are the following controls of the seat in terms of hand/arm access? (Hand/arm access)**		**How easy is it to operate the following controls of the seat? (Operability)**	
Seat controls	**Too close (%)**	**OK (%)**	**Too far (%)**	**Easy (%)**	**Difficult (%)**	**Easy (%)**	**Difficult (%)**
Seat lifter	12.8	78.7	6.4	63.8	36.2	93.6	6.4
Seat recliner	2.1	97.9	0	97.9	2.1	97.9	2.1
Lumbar support adjustment	14.9	51.1	34	25.5	74.5	74.5	23.4
Seat fore/aft adjustment	0	93.6	6.4	95.7	4.3	95.7	4.3
Head rest height adjustment	6.4	55.3	38.3	34	66	12.8	87.2

Age and gender were compared. No significance was found for gender. However, more difficulty was reported by older individuals with accessing the head rest control ($p<0.05$).

5.6.6- Emotional design

During this part of the audit participants rated the controls (in both vehicles) in terms of the perceived pleasure and enjoyment by considering its texture, shape and responsiveness. Results for the whole sample are shown in Table 32 for the familiar vehicle. With their own vehicle (familiar), the texture of the head rest control was reported as the most unpleasant (19.0% of the whole sample). Also (in contrast to the unfamiliar vehicle), approximately 16.0% reported the texture of the lumbar support adjustment as unpleasant and 10.9% the fore/aft adjustment. In terms of shape, 23.8% of participants reported the head rest as unpleasant, 15.8% reported the shape of the lumbar support adjustment as unpleasant, followed by the seat lifter with 11.4%. Participants reported the responsiveness of the seat controls as unpleasant in the following order; head rest height adjust (54.8%), lumbar support adjust (31.6%), seat lifter (13.6%) and seat recliner (10.6%).

Table 32: Emotional design evaluation of seat controls in participants own vehicle (familiar vehicle)

Seat control (Own vehicle)	**Category**	**Unpleasant (%)**	**Neutral (%)**	**Pleasant (%)**
Seat recliner	*Texture*	4.3	59.6	36.2
	Shape	6.4	42.6	51.1
	Response	10.6	29.8	59.6
Seat lifter	*Texture*	4.3	55.3	40.4
	Shape	4.3	42.6	53.2
	Response	2.1	29.8	68.1
Lumbar support adjustment	*Texture*	4.3	38.3	57.4
	Shape	8.5	42.6	48.9
	Response	25.5	40.4	34
Seat fore/aft adjustment	*Texture*	8.5	51.1	38.3
	Shape	2.1	51.1	46.8
	Response	2.1	34	63.8
Head rest height adjustment	*Texture*	21.3	61.7	17
	Shape	34	48.9	14.9
	Response	61.7	29.8	8.5

Focusing on texture of the controls, with the test-unfamiliar vehicle (Table 33), the head rest height control was more frequently reported as unpleasant in terms of its texture (21.3% of the whole sample) whereas the lumbar support adjustment was reported as the most pleasant control in terms of its texture (57.4%). In terms of the shape of each control, the head rest control was the most frequently reported control as unpleasant (34.0% of the whole sample). All other controls were reported as either being pleasant (approximately 50.0%) or neutral (more than 40.0%) in terms of their shape. The majority of participants (61.7%) reported the response received from the head rest height control as unpleasant with the unfamiliar vehicle. Additionally, 25.5%

reported the response from the lumbar support adjustment as unpleasant, followed by the seat recliner (10.6%).

Table 33: Emotional design evaluation of seat controls in the test vehicle (unfamiliar vehicle)

Seat control (Test vehicle)	Category	Unpleasant (%)	Neutral (%)	Pleasant (%)
Seat recliner	*Texture*	4.3	51.1	44.7
	Shape	6.4	40.4	53.2
	Response	10.6	36.2	53.2
Seat lifter	*Texture*	6.8	36.4	56.8
	Shape	11.4	31.8	56.8
	Response	13.6	29.5	56.8
Lumbar support adjustment	*Texture*	15.8	52.6	31.6
	Shape	15.8	47.4	36.8
	Response	31.6	21.1	47.4
Seat fore/aft adjustment	*Texture*	10.9	41.3	47.8
	Shape	4.3	39.1	56.5
	Response	4.3	19.6	76.1
Head rest height adjustment	*Texture*	19	50	31
	Shape	23.8	47.6	28.6
	Response	54.8	26.2	19

The ergonomics audit and emotional design of controls were checked for age and gender differences. Initially, Chi-squared analysis was considered but, there was a need for a different type of analysis as the sample size was small (47 participant), it looks into age and gender separately and is not capable of exploring iteration between the two groups. Therefore it was more appropriate to conduct a Binary logistic regression. This is more sophisticated statistical analysis compared to Chi-squared analysis and is capable of exploring both age and gender at the same time. It can also look into any iteration between these two groups. In order to apply Binary logistic regression on the data obtained, the results were combined into two categories (e.g. easy and difficult). For example, the options: Very easy, Easy and Ok were rearranged as ‘Easy’ and options Difficult and Very difficult were rearranged as ‘Difficult’. No significant differences were found by age or gender for both the ergonomics audit and the emotional design of seat controls.

5.6.7- Functional performance tests

Functional performance tests were conducted as part of the audit, namely: self-rated confidence questionnaire; 9-hole peg test; arm reach test; clock reading test and contrast sensitivity test. These focus on age-related characteristics relevant to driving and were used as tools to help assess older drivers’ functional capabilities.

For the self-rated confidence questionnaire, each participant rated their level of confidence with carrying out specific driving tasks such as, driving at night, driving on long trips, driving in bad weather, driving in busy traffic etc. The questionnaire used a scale, 0 (not confident at all) to 10 (completely confident) and the average score was calculated. Figure 51 shows the distribution of the results of the average scores for each age group, males and females. For the whole sample in general, the oldest group (over 80s) scored lowest compared to other two groups ($p < 0.01$). With gender, females had reduced confidence compared to males ($p < 0.01$). This led to the question of whether older females were less confident. An ANOVA test was used to investigate interactions between the variables age and gender but no significance was found.

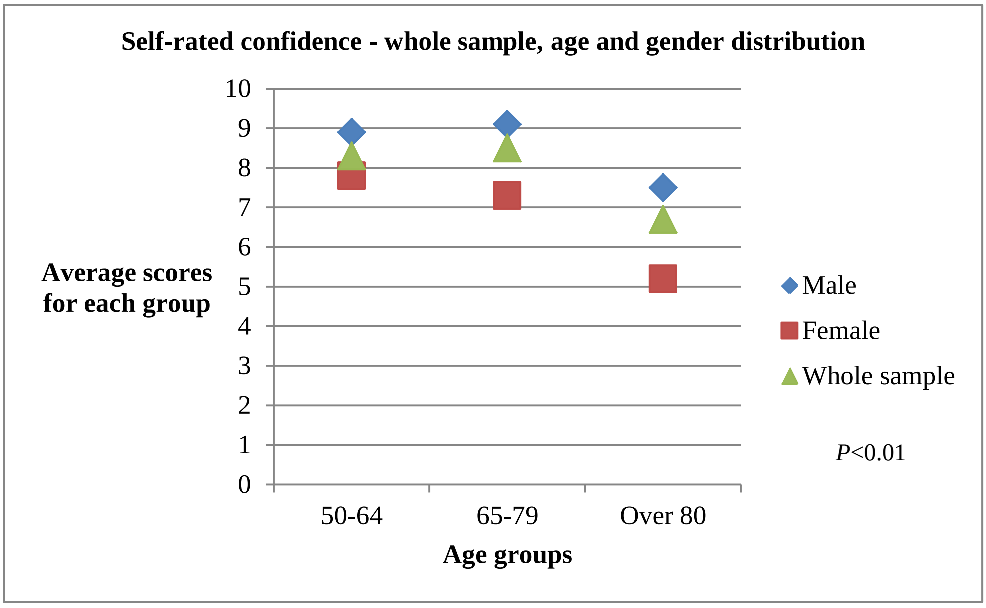

Figure 51: Self rated confidence (whole sample)

The 9-hole peg test was conducted to assess the hand coordination and dexterity of the participants. The task required them to place pegs into a peg board one at a time and then remove them. The test was conducted with both dominant and non-dominant hand. The score is the time taken to complete the task. The results are reported in Table 34 which shows the average time taken to complete the test for each age group using both dominant and non-dominant hands. With increasing age, a decline in hand coordination/speed was observed for both hands ($p<0.01$). No significance was found with gender.

Table 34: 9-hole peg test (whole sample)

Age ($p< 0.01$)	**Dominant hand (sec)**	**Non-dominant hand (sec)**
50-64	20.7	21.6
65-79	22.9	25.2
Over 80s	27.3	30.1

An arm reach test was also conducted to assess shoulder flexibility. Participants were asked to raise their hand as high as they could in a seated position; this was carried out for both hands. The score is pass or fail, if their elbow is below their shoulder height then it is a fail. The results showed that only one participant failed the arm reach test. This was a participant within the oldest group and they had an arm injury which prevented them completing the test (Table 35).

Table 35: Arm reach test (whole sample)

Age	**Pass**	**Fail**
50-64	12 (100%)	0 (0%)
65-79	20 (100%)	0 (0%)
Over 80s	14 (93.3%)	1 (6.7%)

A clock reading test was conducted to assess upper body flexibility and range of motion of the participants. The researcher stands 3m behind the participant holding a cardboard clock with the hands set to 3.00 or 9.00. It was used to measure the ability of a driver to look over their shoulder and read the time; the score is pass/fail. Overall 9 participants' failed the clock reading test, 20% of 65-79 year olds and 33.3% of participants over 80. Significant differences were found between age groupings but not gender; the older and oldest age groupings were more likely to fail the test ($p< 0.05$, Table 36).

Table 36: Clock reading test (whole sample)

Age (*p*< 0.05)	**Pass**	**Fail**
50-64	12 (100%)	0 (0%)
65-79	16 (80%)	4 (20%)
Over 80s	10 (66.7%)	5 (33.3%)

Finally a contrast sensitivity test was conducted – the Hamilton Veale, where the person reads as many uniformly large letters (which fade out towards the bottom) as possible from a 1 metre distance using both eyes then each eye separately. The score is the faintest triplet for which 2 of the 3 letters are correctly identified. A significant decline in contrast sensitivity was observed with increasing age ($p<0.01$) and by gender ($p< 0.05$), particularly for the oldest group (over 80s). For example, only 60% of the over 80s scored up to level 13 compared with 92% of 50-64 year olds (Figure 52). There was an interaction between the variables age and gender, statistical analysis (ANOVA test) showed that the decline in contrast sensitivity was more common in older females ($p<0.01$) for both eyes. For each eye separately, a decline in contrast sensitivity was also observed with increasing age, but no significant differences were found, for example, only 27% scored level 13 for the test (left eye, Figure 53). Younger participants' (aged 50-64) had higher score levels for the right eye (Figure 54). Again no significant differences were found by gender for each eye separately.

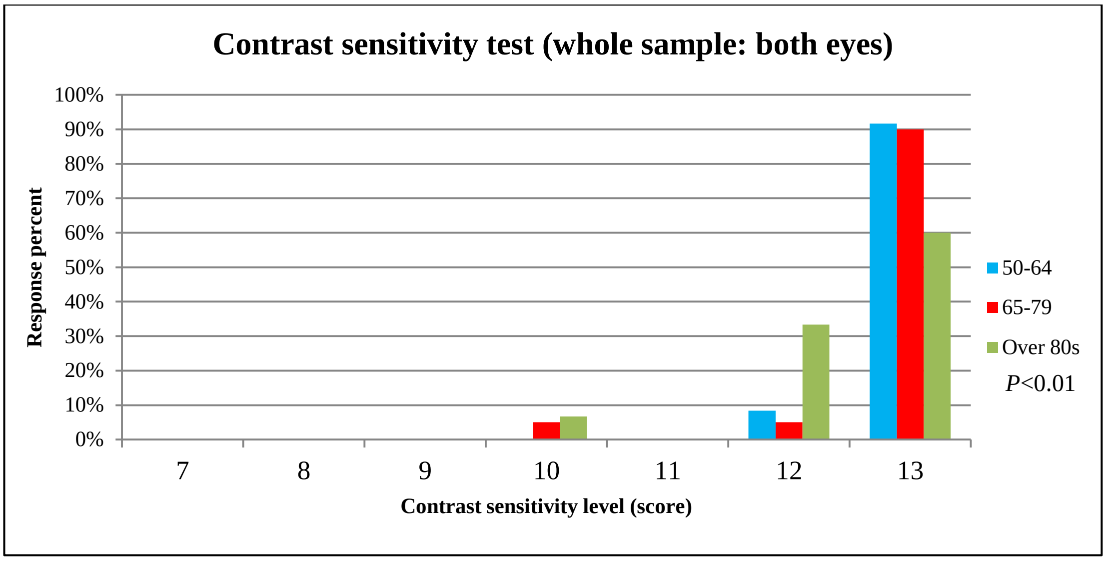

Figure 52: Contrast sensitivity test (both eyes)

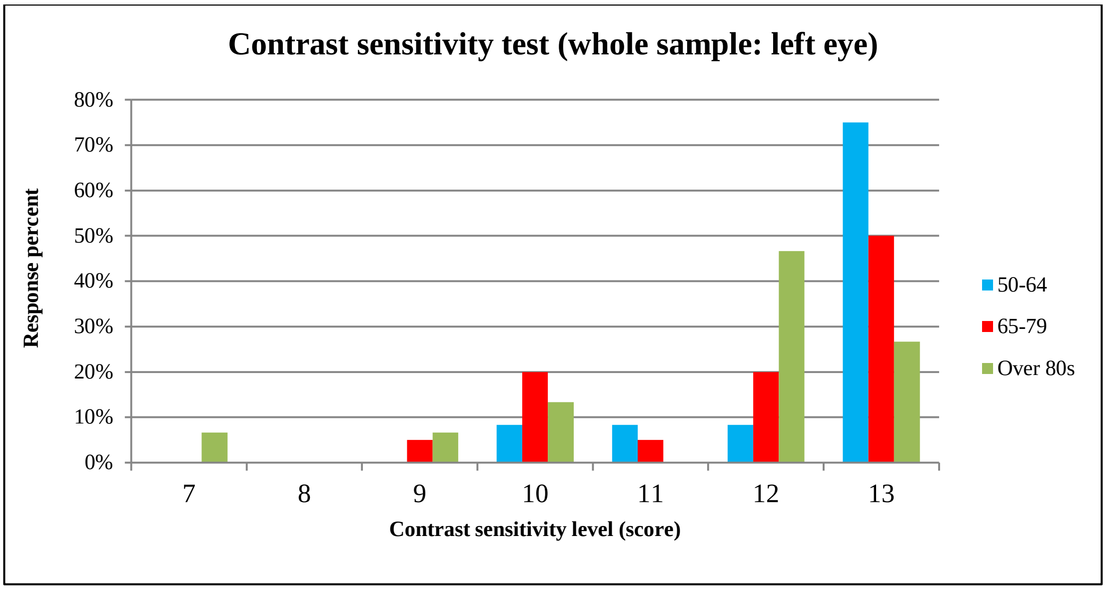

Figure 53: Contrast sensitivity test (left eye)

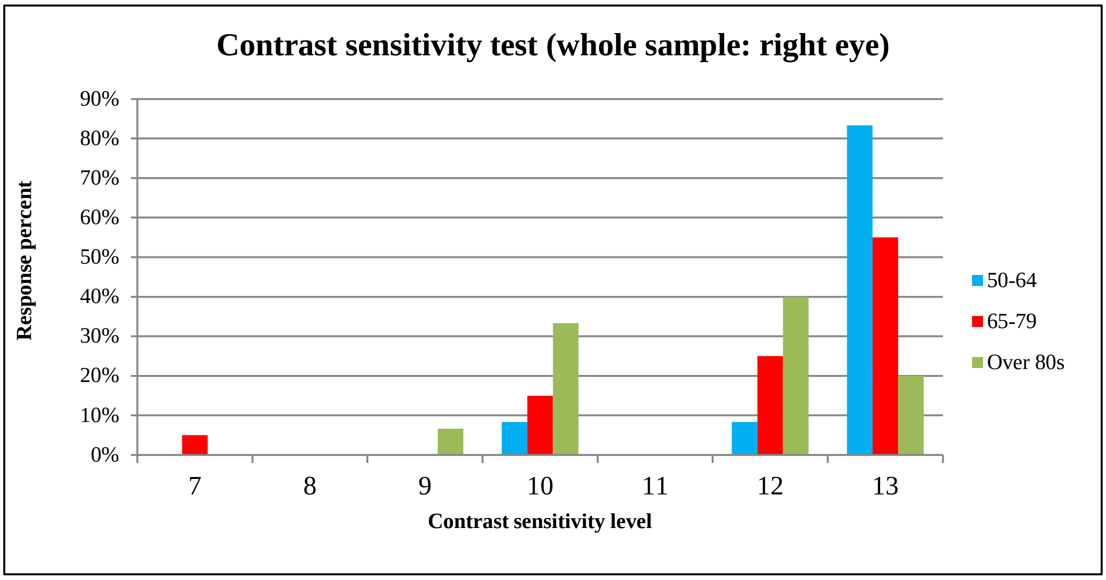

Figure 54: Contrast sensitivity test (right eye)

5.7- Discussion

The study was conducted to address the objective 2 of this research: to understand how design of the vehicle cab impacts on posture, comfort, health and well-being in older drivers. The in-depth audit has provided a large data set enabling more detailed understanding of the main difficulties of older drivers within the vehicle cab. This section discusses the main findings of the current study together with a focus on issues identified and highlights the future focus areas. The structure of this discussion is organised by addressing the research questions established in Section 5.1. of this thesis. Many issues were identified related to the seat controls such as operating, accessing, reaching and finding; these were common for both vehicles (familiar and unfamiliar). For example, the majority of participants had difficulty operating the head rest height adjustments, approximately 40% of the participants had difficulty turning their head and body around to operate this control, and the majority of these were over 80. This specific difficulty was also observed in the questionnaire survey reported in Chapter 4.

Focusing on the findings from the ergonomic evaluation of seat controls, a high proportion of the sample reported difficulty with reach distance to the head rest height and the lumbar support adjustment. Schifferstein and Hekkert (2008) recommend that products should be designed for the user to be able to use with one hand in front of the body and if possible it should be designed to avoid needing both hands. In addition the author states that reaching out to the sides or back while sitting is difficult (particularly for older individuals). Considering the location of the lumber support and the head rest height adjustments in most vehicles, users are required to reach out to the sides or back (using both hands for the head rest). This explains why majority of participants were not happy with the reach distance of these controls in the current study. In this case, it would be more appropriate to place these controls in a location where users are not required to reach to the side/back and it would be more beneficial to design the headrest to be operated by one hand only. Kroemer (2001) provides a detailed guideline on the design of controls and also recommends that they should be oriented with respect to the user or they should move into the orientation of the operator agreeing with Schifferstein and Hekkert (2008).

Regarding the accessibility and operation of controls evaluated during the ergonomics evaluation, the head rest height adjustment and lumbar support adjustments were reported to be difficult by majority of the sample. For instance the head rest height adjustment was difficult to operate due to the physical demands that it requires during its operation; the button is too stiff, fiddly and hard to press as reported by participants and it was difficult to find/locate. According to Guestello (2006), large size controls are normally used to enable the exertion of large forces. In the case of the head rest height adjustment it is often small (push button- to fit finger operation) and requires a large force to push and release the locking system. In addition, moving the head rest up/down was also hugely challenging for all these older participants (particularly in the test vehicle) because it was stiff. For instance, pushing the release button and keeping it pressed in order to move the head rest up/down until a suitable height is determined requires steady force and this may be challenging for older people due to decline in their hand function. A study conducted by Ranganathan et al. (2001) focused on three aspects; handgrip strength, maximum pinch force (MPF) and steady pinch force at three force levels and compared 27 younger (20-35 years) with 28 older participants (65-79 years). The study identified that compared to younger, older participants had 30% weaker handgrip force, 26% lower maximum pinch force. Together with these older participants' ability to maintain steady submaximal pinch force and a precision pinch posture was significantly low. Considering the physical capabilities of older participants, these controls need to be reviewed and designed more carefully by including this group of users in design process.

In relation to accessibility of the lumbar support adjustments it was reported to be difficult to access in both vehicles (particularly the test vehicle, reported by 74.5%) due to lack of sufficient space for hand access. The operation of lumbar support adjustments in the familiar vehicle (own vehicle) was also reported to be difficult. This control in the test vehicle was observed to be easier to rotate (smooth), had a good grip and was able to be grasped with the tip of the fingers. However, it was located in a tight space for good hand access and was also very difficult to locate/find with participants requiring assistance. Similarly, seat recliners (particularly dial type) were also difficult to access due to insufficient spacing for whole hand operation. These controls were also reported to be difficult to operate (particularly in participants own vehicle), these were stiff and required extra force compared to the controls in the test vehicle in terms of the operation. In relation to this, McCauley-Bush (2012) suggests that the force or torque applied by an operator to actuate a control should be kept as low as possible especially if the operation must be repeated often. In this case, controls such as lumbar support and seat recliner adjustments are continuous and they should be adjusted until the driver is satisfied with the seat position, and designed to operate with minimal effort. For the ergonomics evaluation of the seat controls, the results gained through Binary Logistic regression showed no significant differences with age and gender. It may be that due to the small sample size (n=47), the analysis did not provide clear statistical evidence. When some of the results were plotted as graphs it was observed that there was a trend with increasing age, for instance more difficulty was reported by older individuals with accessing the head rest control in the unfamiliar vehicle.

A study carried out by Williams et al. (2011) looked into user-centred design and evaluation of electrically operated seat adjustment controls in 6 luxury vehicles. Data were based on the analysis of positive and negative comments made by the participants (n=101) after using the controls in each vehicle. Comments were categorised on ease of use, accessibility and feel. It is important to note that this study did not look into age and gender and did not focus on manual controls. Some of the findings of this study were compared to the findings in the current study. The controls in the study by Williams et al. (2011) were all located on the side of the seat; results showed that negative comments were related to obstruction and space restriction when accessing the controls in some vehicles, for instance the arm rest was causing restriction in some vehicles during operation. This was also observed in the current study where participants had to open the door in order to allow sufficient space to operate.

Williams et al. (2011) also reported that the positive comments were made about the controls as a whole (not individually) since they were grouped in one location. There are some implications arise in terms of understanding the controls, in relation to their feedback, direction of motion and shape in order for comparison with the current study. The author also reported that some negative comments were made about targeting the backrest, lumbar support and memory controls under the category of ‘ease of use’. Comments based on accessibility (negative ones) were also related to seat adjustment as a whole but not individual controls. It is interesting that no negative comments were made on reach distance, and on the head rest height adjustment, lumbar support and seat recliner controls. The reason may be that when using electrically operated controls, controls are located in one easy to access place, and participants don’t need to twist their body around or lean forward during the operation. This points to a clear need for controls to be placed at a visible location for the user to find easily. It is also important to design them to be intuitive to use and in a way that enables users to understand the purpose of that control. One real world example of this was with an older female (89 years) who used a seat pad to increase seat height and was not aware that there was a lever on the side of her seat to do this; sadly she had owned the car for 10 years.

The evaluation carried out on emotional design aspects of controls showed interesting findings. The lumbar support adjustment in the test vehicle was reported to be the more pleasant in texture and shape due to its touch feel, good grip and for rotating smoothly. It had a soft rubbery touch feel (with a ridged texture). Only 4.3% reported this control as unpleasant for its texture and 8.5% for its shape compared to 15.8% for the ones in their own vehicle. In terms of its responsiveness, it was reported to be unpleasant by 25.5% of participants in the test vehicle and 36.8% in their own vehicle due to lack of sufficient feedback. In general, the lumbar support adjustment in the test vehicle was perceived to be more pleasant by higher proportion of the sample (texture, shape and response) compared to the ones in their own vehicle. According to Jordan (2000) materials and finishes of products could determine how easy a product is to grip in the hand. The author gives an example of a toothbrush with a handle coated/produced from a rubbery plastic material and pointed out such material can provide good hand grip even if the handle is wet. This may be one of the reason why the lumbar support adjustment in the test vehicle was perceived to be more pleasant compared to other controls in participants own vehicle. Van Gorp and Adams (2012) support this by adding that people can feel wide range of emotions when interacting with objects, for instance a rubber grip on a hand tool might give the feeling of “control” or “confidence” because it is perceived to have better handling by the user. The seat lifter and seat recliner were also reported as pleasant (in texture) by high proportion of the sample in the test vehicle. For participants in their own vehicle the most unpleasant controls were reported as the head rest adjustment, lumbar support and fore/aft adjustment in terms of their texture, the reason was that these controls were also perceived as cheap and low quality compared to the ones in the test vehicle. Additionally the headrest height adjustment control in both vehicles was reported as most unpleasant control in all three categories (texture, shape and response) by very high proportion of participants. The reason was that participants found the head rest controls to be rigid, too small, and difficult to operate/push, due to these experiences it may be that they reported this as unpleasant. For instance, Van Gorp and Adams (2012) describe that people unconsciously judge their experiences in two main categories; good or bad and sometimes between the two. Therefore due to the experience of the difficulties raised during the operation of this control, users perceive it as bad experience (unpleasant).

Of the three categories (texture, shape and response), the majority of unpleasant comments were in the category of their responsiveness. This was mainly to do with not getting enough feedback during the operation of the controls. Taking the lumbar support adjustment in the test vehicle as an example, it was perceived to be more pleasant in its texture and shape but it was more unpleasant in response due to lack enough feedback. McCauley-Bush (2012) recommends that, there should be apparent effect with the action of the control and its resulting outcome, and this should be consistent with the user expectations. The author also gave a good example from Ledbetter (2001) who carried out user testing during the initial stages (early prototypes) of the Microsoft Intellimouse Explorer. It was identified that incorporating a red light on the back of the mouse was perceived to be more responsive and alive by the users. Such feedback also gave them a sense of control. According to Norman (2004) users should receive immediate feedback during the operation of a control, if there is a delay, users could get bored easily and give up on the task, and even a delay of a tenth of a second can have a negative impact. Therefore a feedback system could be incorporated for such systems/products to provide the user with visual/auditory/tactile feedback regarding progress through the operation of the control. In the example of lumbar support adjustment it would be useful to incorporate more apparent tactile feedback for the user to feel the change on their lower back when rested on the back rest.

For the current study the overall picture concerning postural angles shows few significant differences in the postures adopted by each age group in their own vehicle compared to the test vehicle, only an increase in neck inclination was identified in age. In terms of gender some differences were found, but neck inclination showed no significance in both vehicles (familiar and unfamiliar). Similar results were found in the study conducted by Porter & Gyi (1998). With increasing age there was a steady increase in the neck inclination. For instance, the average neck inclination for each age group obtained in the test vehicle follows as: 50-64 (42degrees), 65-79 (48 degrees) and over 80 (51 degrees) but as Porter & Gyi (1998) did not compare age in their study, a comparison cannot be made with the current study. A study conducted by Kuo et al. (2009) obtained postural measurements (including neck slope and head tilt angle) from 22 older (60-83) and 24 younger (17-27 years) adults in seated and standing positions. The procedure involved placement of reflective markers on specific anatomic landmarks, then the posture of each participant was recorded on video and angle measurements were obtained using specialised software (angles were calculated using x and y coordinates). The study, (like the current study) also found that older participants had higher neck inclination angles (neck more forward) compared to younger in both sitting positions: this was also found for standing postures.

With regard to 'arm flexion' and 'elbow angle', significant differences were found with gender for both vehicles for the current study. Females had lower arm flexion and elbow angles compared to males, and similar results were reported by Porter & Gyi (1998). This indicates that females adopt their driving postures more closely to the pedals/steering wheel compared to males. Also the measurements obtained from the seat position of each participant show that in general shorter people bring their seats closer to the pedals.

Postural angles captured as part of this study in both vehicles were also compared with those of Porter & Gyi (1998). As illustrated in Table 3, if the posture measurements are within the ranges provided by Porter & Gyi (1998) then the posture selected is likely to be comfortable for the participants. A large proportion (more than 94%) of the whole sample fit within the comfort ranges suggested by Porter & Gyi (1998), indicating that the seat adjustment controls allowed the selection of a good posture for driving. Interestingly, the results of a questionnaire survey study conducted by Herriotts (2005) also revealed 95.2% of drivers were able to adopt a comfortable driving position based on their responses. The results for the current study clearly showed that a very high proportion of participants were aware of what postures are comfortable for them. However, as discussed previously in this section many had difficulties using and finding the controls during the seat set-up process and were given assistance in order to help them achieve their desired comfortable postures.

Understanding the order of the tasks carried out during the seat set-up process is important, this may bring advantages when designing car seat features for users. For instance knowing the sequence of the tasks carried out by users may improve the location and mapping of the controls when designing new vehicles. This will then make the set-up process easier for the user by knowing their expectations/preferences. The results from the video analysis provided a good understanding of the order of the tasks carried out during the seat set-up process. Based on the findings from the two vehicles separately, the following conclusion was made (please refer to section 5.7.3) on the order of the tasks carried out within both vehicles by the whole sample:

1. Seat fore/aft
2. Seat recline
3. Seat height
4. Steering wheel
5. Lumbar support
6. Head rest height
7. Other (mirror, door etc.)
8. Seat belt

There may be several reasons for participants to carry out the tasks in this order. For instance, the first four controls are necessary to reach the pedals and the steering wheel, some are located on the side of the seat cushion and some located in front where it does not require the driver to rotate their body around. All other controls require the driver to rotate their head and body around to reach for the control. As a result participants may have started with the controls they find easier to reach and access or the ones they need for driving. Another reason may be that participants may have more experience using the first three controls such as fore/aft, seat recliner and seat height compared to other controls. Based on the order of the controls identified in the current study, it would be beneficial for manufacturers/designers to group them into a specific location. Kroemer (2001) recommends that controls should be grouped based on their sequential relations and in relation to their particular function (to reduce difficulty of reach and operation). Based on these factors, controls should be arranged depending on their operational importance and sequence. This principle could be applied to the findings from the current study and based on the sequences identified, controls can be clustered.

The use of additional items (e.g. cushions to increase seat heights) was commonplace, particularly for the over 80s. It is of interest that the use of additional items was also reported by Herriotts et al. (2005) in a questionnaire survey. They found that up to 31% of older drivers reported using additional items in their own vehicle, 6% using bead mat and 24.9% using a seat cushion (compared to only 2.1% of younger drivers). Unfortunately, the reasons for using these additional items were not reported. In the current study it was identified that, three older females (over 80s) used seat pads in their vehicles to increase their seat height. All of these females were short in stature (under 155cm), and reported that the seat height was too low for their stature even when it's at maximum height and therefore they did not have a clear view on the road. This finding is important information in terms of seat function. The industry needs to consider diverse users, for example people with short stature (particularly older females) and design seats with a greater level of adjustment.

One of the interesting things found during this study was the design adaptations made by these older drivers themselves. These are things such as adding a foot rest, use of sponge to extend the seat cushion, and placing a sponge in the door pocket to rest the knee. As mentioned previously the use of additional items is reported in the literature, but no literature was found related to design adaptation/modifications made to the driving cabin. This shows that there is a clear need to focus on the design of seats to include older people who care about achieving comfort whilst driving (e.g. size, shape, profile, seat slope, materials, height etc.). As a result they are adapting their own vehicle and looking for their own solutions to tackle these problems. An interesting study conducted by Bradley et al (2008) involved older drivers being brought into the design process as experts (through participatory design). Through this study, the expectations of older drivers in terms of new vehicle technologies were explored. The study involved number of activities and data collection tools to gain a detailed understanding of older drivers expectations of new technologies; these were through questionnaires, interviews and focus groups, on-road experiments and testing simulation based prototypes. This study revealed two key issues experienced by older drivers: unintentional speeding and reverse parking. These then led to exploration of enhanced in-car speedometer displays with visual information and warnings incorporated with haptic feedback together with new technologies to assist reverse parking. These sort of participatory design studies can be useful to understand the needs of older drivers for better seat design.

Another example of seat adaptation was based on improving ingress/egress. A 70 year old participant was using a plastic shopping bag to assist her swivelling her body during ingress/egress. It may not be the best idea, but the shopping bag helped reduce friction in order to help her swivel out of the seat. It is also suggested by Shaheen and Niemier (2001) that seat surfaces should be designed to minimise friction for ease of ingress/egress. During the observations within the unfamiliar vehicle (test vehicle) it was observed that ingress/egress was also easier for older participants (over 80s), because it was an SUV, and the seat was higher above the ground. A study conducted by Namamoto et al. (2003) explored muscular stress during entering/exiting vehicles using various MVC (maximum-voluntary-contractions). This involved a comparison of two groups (younger vs. older), a group in their 20s and a group in their 60s. One of the key outcomes of this study was that the older group had approximately 20% higher muscular stress compared to younger in the same vehicle conditions. This result was achieved by measuring the myoelectricity when entering/exiting the vehicle. Exerting high muscular strength is likely to be one of the reasons that older people struggle with ingress/egress. The questionnaire survey conducted by Herriotts (2005) supports the fact that a lower seat height may have negative impact during ingress/egress for older drivers. For instance 'lifting legs out and/or pulling oneself up' was reported as the most difficult task by 39.3% of older drivers and 13.2% reported 'low cars' as having a negative impact on egress. It is important to note that there are also other vehicle features which may affect comfort during ingress/egress, for instance the cant rail (the roof), if it's too low it may cause discomfort during ingress as identified by Giacomin and Quattrocolo (1997). These researchers then reduced the seat height which had positive effect on the comfort of taller occupants, however shorter occupants had more varied responses. When designing cars to include older occupants it is important for the seat to be slightly higher from the ground and cushions should be designed to reduce friction to assist older occupants to swivel.

The functional assessments conducted during the in-depth audit have provided a clear understanding of the effects of ageing on the body particularly related to the driving task. The results obtained through self-rated confidence questionnaire showed that with increasing age there is a reduced confidence in the oldest group (over 80s, $p<0.01$) and maybe one of the reasons for older drivers stopping driving. It may be that as drivers get older they become aware of their reduced capabilities and as a result this affects their confidence in carrying out specific driving tasks. There was also significant differences by gender, females had lower confidence scores compared to males in general. There was no interaction between the variables age and gender, so it was not just associated with older females but it more related to older drivers in general (particularly over 80s) and females in the whole sample. Interestingly, the same questionnaire was used by Marottoli et al. (1998) but there were no significant differences by age and gender, but males were more likely to drive in conditions which may be considered more risky compared to females. It was also reported that the confidence scores were correlated with driving frequency ($p<0.05$). It is important to point out the fact that these authors had participants aged 72 years and older ($n=165$) to complete the questionnaire, their mean age was 81.4 years. This may be the reason for not finding significant differences in age and gender.

The results of the clock reading test showed that 20% of 65-79 year olds and 33.3% of over 80s failed the test due to their reduced upper shoulder flexibility and range of motion. Significant differences were found with age groups ($p<0.01$), this was more related to the older (65-79 year olds) and oldest (over 80s). A study of older compared to younger drivers was conducted by Isler et al. (1997) looking at the head movements of drivers and its effects on the useful field of view. The study included various ages and it was identified that with increasing age the angle of maximum head movement decreases. Difficulties turning the head and body around were identified in many areas of the current research, i.e. questionnaire survey study (chapter 4), the literature, and this audit. In the literature, its effects were mainly associated with difficulties with parking, reversing and checking mirrors (please refer back to section 2.6, Table 4) but its effects have not been associated with problems interacting with seat controls i.e. head rest or any other feature that demands rotation of body or over reaching.

Based on the assessment carried out of hand coordination and dexterity using the 9-hole peg test with increasing age, a decline in hand coordination and speed was observed for both hands. This was also found by Wang et al. (2014), whereby the results obtained in both studies show a gradual decline with age for both males and females. Interestingly, the results of Wang et al. (2014) were quite similar to the ones obtained in the current study. The author reported that the average time taken to complete the test by three age groups were as follows; 50-59 (20.6 seconds), 60-69 (22.8 seconds) and 70-85 (23.8 seconds) on average. For the current study the following results were obtained for three age groups of; 50-64 (20.7 seconds), 65-79 (22.9 seconds) and over 80 (27.3 seconds) on average. This clearly shows an indication on the accuracy and validation of the test as well as how age affects the speed.

The Hamilton Veale contrast sensitivity test showed that a decline in contrast sensitivity was observed with increasing age which was similar for both eyes tested together and separately. The studies conducted by Mantyjarvi & Laitinen (2001) and Elliott et al. (1990), also reported that older participants scored lower points compared to younger. Although these studied were conducted using the Pelli-Robson test, it uses similar principles to Hamilton Veale but the pointing system is different. There are similarities in general with the outcome of the current study which shows that with increasing age there is a decline in contrast sensitivity level impacting the driving task. For instance, a decline in contrast level may also have a negative impact on seating and its controls, therefore these features should be designed with appropriate contrast level to enable older drivers to distinguish between the control and its background in order to find/identify these features easily.

In a study conducted by Elton (2012) with 38 participants aged between 65-87. The LogMAR acuity chart was developed in order to be used for the study. The charts used in the study involved 90%, 70% and 30% contrast level. The size of letters used in the test was calculated based on the viewing distance of 1m. It was identified that lower contrast levels (50% and 30%) showed reduced visual acuity tested in three ambient illumination levels (overcast, in-house and street lighting). For the letters printed with higher contrast level (90% and 70% contrasts) the three conditions, overcast, in-house and street lighting had smaller effect. The author relates the effect of illumination with lower contrast levels (50% and 30%) due to the fact that older people experience decline in contrast sensitivity as a result of ageing.

With regards to the arm reach test (assessing shoulder flexibility), only one person failed this test and this was a participant within the oldest group and they had an arm injury which prevented them carrying out the test properly. When this is compared to the study conducted by Ball et al. (2006) with drivers aged 55 years and over, the proportion of the people failing the arm reach test was also small (less than 1% of a sample of 1910) participants. Both results show similarities in that only a tiny proportion of people failed. This seems most likely to happen due to special circumstances such as arm/shoulder injury etc.

5.8- Limitations of the study

There are some limitations with this study which need to be mentioned. Since the audit was conducted in a static vehicle condition (no road driving), some participants reported they would prefer to do a test drive to ensure that the posture they selected was comfortable and to know if they needed to make further adjustments. A recent study conducted by Mansfield and Hazlett (2015) of 20 drivers (aged 18-24), comparing postures and seat positions selected using a laboratory buck and a real vehicle has found that it is unlikely that drivers will adopt exactly the same driving position each time they get into a vehicle. Most importantly, the results showed that these drivers selected similar driving positions with only minor variations each time. Another limitation of the study may be related to postures adopted in the unfamiliar vehicle (test vehicle); it may be a perceived posture for comfort since they only experienced the vehicle for the first time. It is also necessary to consider that the quantitative measurements taken to capture the driving posture, may involve slight inaccuracies. During postural measurements, markers were placed on anatomical landmarks and some participants were wearing thick clothing, such that during the measurement process the clothing may slightly change the location of these markers. This may cause slight inaccuracies in measurements, but the average of three measurements was recorded to minimise the problem.

5.9- Contribution to the knowledge

This study has identified specific issues which have not been addressed in literature and confirmed that some areas covered in literature still exist. These are as follows:

- The difficulty of turning the head and body around is known to have an impact on parking, reversing and checking mirrors. However, it hasn't been specifically identified that this could cause difficulty interacting with seat controls such as the head rest height adjustment.
- The use of additional items placed on the seat by the user (e.g. cushions) has been reported in the literature; however design adaptations/ideas by users to improve their driving and seating comfort has not been reported. This shows that older drivers are very aware of their needs and they try to address these with their own solutions. Older drivers are experienced drivers and their opinions/ideas are of value; automotive companies should consider including them in the design process, through participatory design.
- The driving postures/measurements obtained from older drivers have shown that they are aware of comfortable postures, but they require assistance during the seat set-up process in order to achieve their desired driving positions. This is particularly the case for the over 80s.
- Functional assessments showed similarities with the current literature and the results were as anticipated for most of the assessments carried out. These practical assessment tools could help provide an understanding of the functional effects of ageing.
- It has been identified that there is a clear gap in optimising the positioning and operation of the seat controls for older drivers. This may prevent all drivers from obtaining a comfortable driving position.

5.10- Conclusions

The in-depth audit has provided an understanding of some specific issues experienced by older drivers in relation to the vehicle cab. Three main themes emerged for potential exploration which would potentially improve the driving experience of older drivers. These are as follows:

1. The optimum positioning and operation of controls for older drivers focusing on access e.g. lumbar, head rest (location, reach, spacing needed for operation).
2. The optimum seat design for older drivers for an improved seating comfort and ease of ingress/egress with a focus on size, shape, profile, seat slope, materials and seat height.
3. Ways of facilitating setting up the driving seat e.g. advice on posture, role of technology, sales support service.

Although design for seat comfort is very important, if the driver cannot understand/manage to use the seat controls, they will not be able to adopt a comfortable and optimum driving position. Therefore, following discussion with the automotive industry client it was decided to focus on the 'optimum positioning and operation of controls for older drivers' in the next stage of the research.

Chapter 6: Getting back in control – car seat design workshops

6.1- Introduction

The previous chapter 'in-depth audit' showed that there are issues and difficulties with the operation, reach and access to specific automotive seat controls such as the head rest height adjustment, lumbar support and seat recliner and in some cases the seat lifter controls. Although these difficulties were common for the whole sample of 47 participants, the levels of difficulty experienced by older drivers were much greater than those experienced by younger drivers as identified during the observations. The aim of this stage of research was to explore the optimum positioning and operation of controls for older drivers with a focus on e.g. size, shape, material, type, operation, location and accessibility. As a result a workshop study was conducted in order to explore design solutions to specific age-related challenges (objective 3) and to make best practice recommendations for the automotive industry.

6.2- Research Method

6.2.1- Study design and rationale

After considering various options it was decided to conduct a workshop study. This was convenient since it was more appropriate to include the users into the design process (participatory design exercise) for a detailed focus on the problems they experience in order to understand the user expectations and requirements for better designed car seat controls. This would then open a path to make recommendations for the automotive industry. As mentioned in Section 5.7, a study conducted by Bradley et. al. (2008) used a similar approach and explored the preferences of older drivers for new technologies such as automated parking systems and dashboard displays. Older drivers worked closely with the research team and tested the prototypes. Their responses and opinions were taken into account in order to look for effective solutions. A similar approach was taken for the current study whereby older people are involved in the discussion of the problems they experience and worked in groups to demonstrate their ideal car seat controls focusing on the optimum positioning and operation. As a result they communicated their ideas through sketches, models and photographs and physical mock-ups. Langford and McDonagh (2003) discuss how to follow good practice in running workshops/focus groups. They gave very good examples on activities which may be included in workshops such as getting people to create models, drawings etc. This was very useful in the development of this workshop study.

6.2.2- Ethical clearance

The ethical clearance form was completed and approval was obtained on 16/05/2014 from the Loughborough University committee. Detailed participant information (Appendix 9) sheet was also prepared for participants to read and understand the details of the study. After reading the information sheet an informed consent form (Appendix 10) was given to each participant for them to sign and agree to take part in the study.

6.2.3- Procedure

Figure 54 shows a graphical representation stating each part of the workshop and how long each part took. The study was designed to last for 1 hour in total for each group (4 groups in total) and consisted of three main parts. The material and the equipment used in the workshop was selected based on their suitability in order to enable the workshops to be conducted in different locations (university or public meeting halls) to improve the accessibility for potential volunteers.

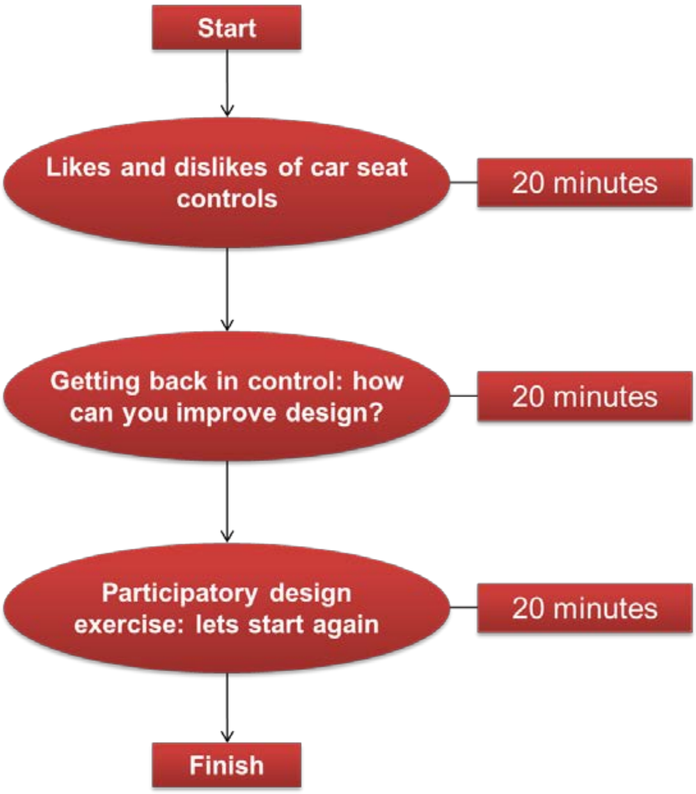

Figure 55: workshop timeline and stages

6.2.4- Part 1: Likes and dislikes

In the previous study 'in-depth audit' difficulties were identified with the operation, accessibility and reach distance to controls such as the head rest, lumbar support, seat recliner and seat height controls. The initial part of the workshop focused on the likes and dislikes of car seat controls generally and was set to last around 20 minutes. Participants were asked to discuss their experiences with their own seat controls. This was a warm up activity to get them into the topic and think about their own experiences by communicating these with each other. They were given prompts such as: enjoyment, ease of use, attractiveness, complexity, shape, technology, improvement on health and wellbeing in order to guide them through the topic of discussion. This warm up session was important in order to prepare them for the next section of the workshop.

6.2.5- Part 2: Workshop - Getting back in control

The next section of the workshop was based on the topic 'getting back in control: how can you improve design?' This particularly focused on the head rest, lumbar support, seat recliner and seat height controls. It aimed to involve participants in developing design solutions and get their opinions on their ideal seat controls. Participants were shown 'real world' examples of problems with design (photographic images) in order to discuss re-designing each. Based on these 'real world examples' they were asked to discuss what they like/or dislike. They were asked to give their own opinion on how they would like these controls to work or what would they advise car designers to do to make it easier/better? Additionally, the methodology involved exploration of new ideas. For this section prompts included position, size, shape, colour, contrast, and materials were included in the conversation to guide participants through the topic.

6.2.6- Part 3: Participatory design exercise – let's start again

The last section of the workshop was designed to build on the discussion and focus on designing. A physical mock-up i.e. car seat buck with models/images of different control types and other materials such as pens for sketching, card, tape and clay for modelling were used in order to enable them to express their ideas in different formats. This part of the workshop specifically focused on the positioning, size, type, shape, colour, contrast, spacing and materials for the ideal controls and the reasons for their choices. The group worked together to cooperate on producing a specific concept to demonstrate their optimal design. In order to show their ideal location/position of their specific concept participants were then asked to demonstrate this on the car seat buck.

6.3- Pilot study

A pilot study was conducted on the workshop format in order to establish the following:

- To test the flow of structure of the workshop and the prompts used.
- To capture the time taken to complete the workshop.
- To make sure the methods/tools used elicited the required data.

6.3.1- Participants

A convenience sample of 4 drivers was obtained (2 male and 2 female); all were research students or university staff and owned a car.

6.3.2- Key points

The pilot study enabled specific modifications and improvements to be made to the study. For the first part of the workshop 'likes and dislikes of car seat controls' it was identified that prompts were important to direct the conversation in order to enable all participants to contribute fully. Initially participants were given pencils and sketch pads etc. to communicate their opinions and experiences. During the pilot study, it was identified that providing template diagrams facilitated presenting their opinions and ideas (Figure 56). This was also useful for people who were not comfortable sketching.

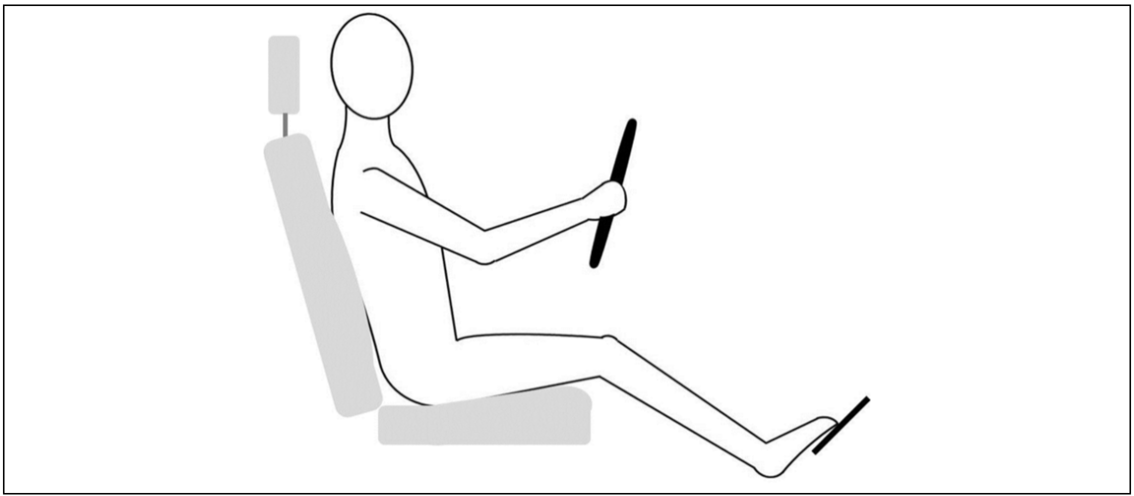

Figure 56: Driving position diagram template

Opinions in the pilot study (likes and dislikes) were initially recorded on A3 sized paper for brainstorming warm-up activity. It was identified that there was a need for two separate sheets to record these, one for likes and another for dislikes, and this would then make the data analysis easier. It was identified that some participants were struggling to communicate their experiences on specific topics; therefore prompts were developed to order to direct the discussion during each topic. This showed a showed an improvement and allowed participants to get involved with the discussions.

For the participatory design exercise section of the workshop participants were provided with various shapes and types of control types (models). Although these had a basic shape and geometry, it was identified that showing these to them had influenced their solutions/ideas. Therefore the decision was made to ask them to sketch their ideas, produce models using plasticine models as a template for them to develop or add to.

Additionally, for participants to be able to demonstrate their concepts on the provided seat buck, plastic templates were cut out to be mounted on the side of the seat (shaped in the form of the actual seat). This was to allow participants to place/mount their concepts on the surface of the template. Since this template had a smooth surface (plastic) it would then enable participants to stick their ideal controls on this template using stickers. During the pilot study it was identified that this was unnecessary due to the fact that the location of the ideal controls may not be on the side of the seat. Also the material of the actual seat was suitable to use stickers in order to mount the controls without the need of the template.

6.4- Data collection

For this study organisations and personal contacts were approached for assistance in recruiting participants. These include Probus (retired professionals) and University of the Third Age as well as personal contacts. This comprises a subset of the previous study. 95% of the participants recruited were involved in the audit study. The advantage of including some of the same participants is that they easily adapted to this final study. Having the same participants also provided many advantages: they already knew the general aim of the research and they were familiar with the research team; this also made them more confident to talk about their ideas and opinions. As in the previous study and in order to increase the likelihood of achieving the target sample size the location of the workshop were arranged so that participants only had to travel short distances. Two of the workshops were conducted at Loughborough Design School; third group was conducted in Banbury and the fourth in Matlock Derbyshire.

6.5- Sampling strategy

The target sample size for the workshop study was 16-20, divided into small subgroups. Each group was formed of 4-5 participants. The target age range was defined as 65 years and over.

6.6- Data analysis

The analysis of the data was based on a thematic qualitative data analysis which was conducted by selecting top themes. Data included the following:

- Workshop audio recordings of about 1.5 hour each.
- Photographic images of the models created to communicate ideas. These showed ideas for ideal types of seat controls and images showing the optimum position and location of these controls selected by participants using the rig provided.
- Sketches and brainstorming notes from the interviews.
- Video recordings of demonstrations of optimum positioning and location of controls on the seat buck.

Data analysis software (NVIVO) was used; data was coded and the top themes were selected. These are based on the comments made about the likes/dislikes of seat controls, and the design ideas communicated by participants. These are presented in Tables in the results section of this chapter. Also some examples of word frequency diagrams included in Appendix 11.

6.7- Results

6.7.1- Sample distribution

Data were collected over the one period July-August 2014. Four workshops took place with a total number of 18 participants; 33% were females and 67% were males. Drivers over 80 years represented 28% (*n*=5) of the whole sample (Figure 56). The workshop was not focusing on a particular group, each participant needed to be over 65. There was a single group of over 80s and all the other three groups were over 65s with one participant aged over 80.

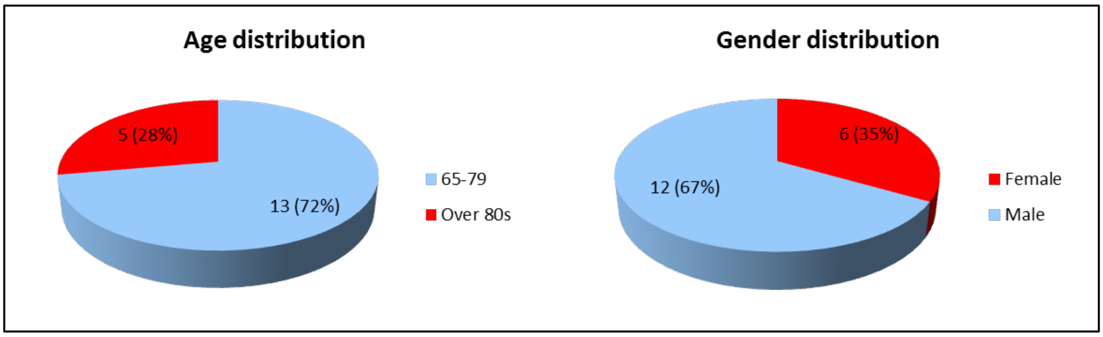

Figure 57: Age and gender distribution (whole sample)

6.7.2- Part 1: Likes and dislikes of car seat controls

This section will summarise the discussion around the 'likes and dislikes of car seat controls'. Over 80% of the comments were negative about the car seat controls. Controls that were particularly identified as being problematic were the head rest height adjustment, lumbar support and the seat recliner.

6.7.3- Group 1: Likes and dislikes

Through the discussions carried out with Group1 on the likes and dislikes of their car seat controls, the analysis on NVivo showed that there were 48 references in total for both likes and dislikes. Only 12% of the comments were based on likes and 88% were based on the dislikes. Focusing on the dislikes, Table 37 shows the percentage distribution of the top themes based on the dislikes of seat controls.

Table 37: Dislikes of car seat controls (Group 1): top themes

Dislikes	Top themes (Group1)	Percentage
Lumbar support	No vertical adjustment to suit the back, lack of enough feedback / Difficult to operate dial type adjustment / Cannot see the control on the side of the seat	21%
Head rest	Difficult to operate (requires effort) / The release button is too small and difficult to access	19%
Seat lifter	Seat moves diagonally, not vertically / Seat movement is very gradual / Low quality of controls	17%
Seat design	Getting in and out of the seat: seat cushion with raised bolsters, small interior spacing (two door car) and difficult to swivel out of the seat.	12%
Seat recliner	Insufficient space for accessibility/ Difficult to operate for people with arthritis (dial type) / Unable to get the right feel - optimum angle	10%

Fore/aft	Seat shooting back unexpectedly with release of control / Difficult to locate the control underneath the seat / Seat maximum aft position too small (tall driver)	7%
General design	Having controls on the seat / Going down or leaning to get to a control / Leather seats: sticky	7%
Seat belt	Seat belt located too far back for reach.	5%
Pedals	Placing foot on the wrong pedal or pressing two pedals at the same time.	2%

6.7.4- Group 2: Likes and dislikes

Table 38 shows the distribution of the top themes selected based on the discussion carried out with Group 2 on the dislikes of their seat controls. There were 50 references in total and 92% of these were based on the negative comments. Majority of these negative comments were made on the head rest height adjustment (40%).

Table 38: Dislikes of car seat controls (Group 2): top themes

Dislikes	Top themes (Group 2)	Percentage
Headrest	• Operation: Need to sit on the rear seat in order to adjust height. / Button is too stiff. / Difficult to squeeze the button. • Location: Head rest is too far from the head. / Too high for short drivers. / Button is on wrong location. • Function: It only moves up and down.	40%
Seat recliner	• Accessibility: Located on the right side of the seat. / Not enough space for hand access. • Control type: Dial type control takes more manipulation. • Backrest: Seat shoots forward and hits the driver on the back when lever type control is released to set the backrest angle.	17%
General dislikes	• Material: Metal feels cold. / Sharp edges on controls makes it uncomfortable. • Colour: Red is not preferred on controls. • Size: If the control is too big, it is uncomfortable.	15%
Lumbar support	• Control type: lever type control flips back to beginning after adjusting. • Accessibility: Not enough space for hand access.	13%
Seat lifter	• Movement direction: Seat moves diagonally, not vertically. The knee interferes with the dash/steering wheel.	11%
Fore/aft	• Location: Difficult to find/locate under the seat.	4%

6.7.5- Group 3: Likes and dislikes

Similarly, out of 67 references (comments) made on the likes and dislikes of seat controls by Group 3, 91% of these comments were negative. The top themes were selected and most negative comments were made on head rest height adjustment (45%, Table 39).

Table 39: Dislikes of car seat controls (Group 3): top themes

Dislikes	Top themes (Group 3)	Percentage
Headrest	• Operation: Difficult to adjust and operate the head rest / It is in awkward position / Hard to find the control / Two handed job • Headrest button: Difficult to pinch/press the button with finger / Hard to push etc. • Size: The head rest button is too small and hard to locate	45%
Lumbar support	• Accessibility and operation: Not enough space for hand access / Due to insufficient space it is difficult to turn the control to adjust. • Functionality and feedback: Not getting enough or good feedback during operation.	18%
General dislikes	• Difficult to reach seat belt • Hard to access controls on the side of the seat	16%
Seat recliner	• Accessibility and location: Difficult to access the control between the seat and the door, lack of space for operation. • Seat function: Backrest moves too quick, shoots forward.	10%
Fore/aft	• Egress: Need to move seat back in order to get out or prevent bumping knee on the steering wheel. • Operation: The adjustment is too stiff to operate.	8%
Seat lifter	• Functionality: The seat is not high enough for shorter drivers.	3%

6.7.6- Group 4: Likes and dislikes

There were a total of 43 references based on the likes and dislikes of car seat controls by group 4 from the discussions. Interestingly, 84% of these references were negative comments (dislikes) on specific seat controls and functioning of the seat. The following themes were identified based on the dislikes: seat lifter and seat function (25%), head rest height adjustment (19%), dislikes about control types (17%), lumbar support adjustment (14%) and seat recliner (11%). Also 14% of the references were related to other general aspects of controls. For instance, 67% of the references in relation to the seat lifter were specifically related to the function of the seat, these comments were directly related to seat not being high enough (Table 40). A female participant described this as: *'it is at its maximum height but I would like it higher.'*

Table 40: Dislikes of car seat controls (Group 4): top themes

Dislikes	**Top themes (Group 4)**	**Percentage**
Seat lifter	Seat does not go high enough.	25%
Head rest height adjustment	Difficult to operate / Need to get out of the vehicle to adjust	19%
Control type (Electrical or Manual)	Mechanical type controls are complicated to operate / Wheel type control is difficult to operate / Mechanical controls are funky. Electrical controls are expensive	17%
Lumbar support	Hard to access / Need to open the door to operate. Leaning forward during operation / Not getting feedback.	14%
General dislikes	Takes long time to find / Does not adjust as you want it to / Difficult to control backrest angle	11%
Seat recliner	Seat (backrest) shoots forward with the release of handle. Need to open the door to access.	11%
Fore/aft	Difficult to lean forward to reach	3%

6.8- Part 2: Workshop - Getting back in control

Following the discussions of the 'likes and dislikes of car seat controls', participants were asked questions about their ideal controls and shown images of 'real world' examples to remind them of current designs. Discussions focussed on one specific control at a time i.e. head rest, lumbar support, seat recliner and seat lifter and in some cases it was in general.

6.8.1- Group 1: Results

Table 41 shows the breakdown of the results obtained during the discussion carried out with Group 1 based on their ideal controls which they gave their opinions/ideas and concepts. There were 83 references in total and the top themes were selected based on the most frequently used words and concepts which participants used to describe their suggestions. As it can be seen on Table 41 majority (84%) of the ideas were based on the general design of the controls as a whole mainly focusing on preferred location, operation method, physical layout and preferred type e.g. electrical.

Table 41: Part 2 (Re-designing seat controls): Group 1- Word frequency and concepts

Re-designing controls	**Top themes (Group1)**	**Percentage**
General design ideas	• Preferred location: In the front, on the steering wheel, on the dashboard, easy to reach location etc. • Operation method: Using buttons, via remote control, electrical, incorporated with seat memory (passenger settings), labelled with arrows (symbols). • Design and layout: Touchscreen, visual, display, picture, intuitive etc. • Size: Wrist operation (90mm dial), finger operation (60mm dial) and button (less than 40mm diameter) • Preferred control type: Electrical • Preferred colour: Don’t want high contrast colours, would prefer blended in.	84%
Lumbar support adjustment	Should be intuitive to operate / Can be adjustable vertically and horizontally to suit the back of the user.	7%
Head rest height adjustment	Important to adjust when reversing or before every trip	4%
Pedals	Automatic cars can be more suitable to prevent interference with wrong pedals	3%
Seat height	Higher seat for getting in/out of the car / Seat height should suit both taller and shorter drivers.	2%
Fore/aft	Can be located on the side rather than underneath the seat to find it easily.	1%
Seat lifter	Seat should go high enough to accommodate shorter users	1%

6.8.2- Group 2: Results

There were 90 references (comments) in total made by Group 2 based on their suggestions/ideas on their ideal seat controls. Similarly, 71% of these were focusing on the general layout/design of the controls. The top themes were based on their ideal location, type of control, their physical shape, colour, size etc. (Table 42). These ideas can be seen by the most frequently used words and concepts (top themes).

Table 42: Part 2 (Re-designing seat controls): Group 2- Word frequency and concepts

Re-designing controls	Top themes (Group 2)	Percentage
General design	• Location: Dashboard, front, reach, easily, near, central etc. • Control type: Touch, buttons, touchscreen, electrical. • Design: Seat shape, diagram etc. • Colour: Yellow not preferred gets dirty easily. • Size: Big, enough, fine, press (large enough to press by finger) • Accessibility: Enough spacing between each control, easily locate.	71%
Head rest	• Location: Front, forward, leaning, see etc. • Distance from head: Pivoted to bring closer to the head.	13%
Lumbar support	• Location: Within reach zone, on the sun shade, dashboard. • Function: Need to feel it.	6%
Seat recliner	• Control type: Dial type control	6%
Seat lifter	• Seat function: Prefer higher seat. Should move vertically not horizontally.	2%
Fore/aft	• Location: Should have a standardised location.	1%

6.8.3- Group 3: Results

The results obtained through the discussion carried out with Group 3 showed that, there were 160 references (comments) in total based on their ideal seat controls. The majority of these comments (ideas/concepts) were focusing specifically on the design of head rest height adjustment (29%), lumbar support adjustment (25%) and general design of controls (23%) as shown in Table 43. Top themes identified were mainly to do with control type e.g. electrical or mechanical, their location e.g. in the front, on the dashboard etc.

Table 43: Part 2 (Re-designing seat controls): Group 3- Word frequency and concepts

Re-designing controls	Top themes (Group 3)	Percentage
Head rest	• Control type: Button, switch, similar, dial. • Location: Front, dashboard, see etc. • Colour: Incorporated, blend, black etc. • Size: Big enough to hold/use • Design and shape: Picture of the seat.	29%
Lumbar support	• Location: Side, left, right, room, seated, hand etc. • Control type: Dial, wheel, rotate • Operation: Back, seated, keep etc. (Keeping seated during operation) • Size: Bigger, larger, wheel, dial • Accessibility: Hand, able, around, drops, get, got, naturally etc. • Functionality: Back, feel, feels, need. • Material: Finger, grip, rubberised.	25%
General design	• Material: Good, rubber, rubberised, grip, better, feel. • Colour: Blending, grey, red, yellow. • Control type: Electrical • Location and operation: Easy, reach • Size: Easy to press/grip	23%
Seat recliner	• Material: Feel, notchy, rubbery • Control type: Dial, wheel • Size: Smaller	12%
Seat lifter	• Colour: Blend, black • Height function: Higher, increased • Location: on the right • Material: Flesh, fleshy, grip • Size: Not too long (lever)	8%
Fore/aft adjustment	• Function: Ratchet, move (should move on ratchet)	3%

6.8.4- Group 4: Results

Based on this session carried out with Group 4, there were 111 references identified in total. These are based on the ideas, suggestions and concepts proposed by all participants in order to improve design or explore suggestions for the industry during the discussion. The most frequently discussed topics were related to general design (30%), head rest height adjustment (22%), lumbar support adjustment (17%), preferred type of controls (13%), general location of controls (11%), seat lifter and seat function (10%), seat recliner and seat function (6%) and shape/labelling of controls (3%). The most frequently discussed topic was the head rest height adjustment and 50% references on this topic were related to the suggestions on improving the location of this control for ease of reach during the operation. Table 44 is showing the most frequently used words; this gives a general idea on the preferred location of this control by older users of Group 4.

Table 44: Preferred locations for the head rest height adjustment (Group 4)

Re-designing controls	Top themes (Group 4)	Percentage
General	• Preferred location: within arm reach, near the door, touch/feel. • Design and layout: Intuitive, pleasing, picture/symbol to identify etc. • Colour: Irrelevant, blended in with the seat. • Operation: electrically, run smoothly, gradual movement	30%
Head rest height	• Location: within reach, dashboard, steering wheel, elbow height. • Operation: Without moving body • Control type: Electrical	22%
Lumbar support	• Location: Side of the seat cushion, within reach, door arm rest. • Control type: Wheel, rotational • Function: Feel (feedback), keep seated during operation, lean back.	17%
Control type	• Preferred control type: Electrical, button, push.	13%
Seat lifter	• Function: Higher seat, use seat cushion, more feedback during operation. • Operation: pump, push button.	10%
Seat recliner	• Function: Adjust gradually, shouldn't shoot forward.	6%
Fore/aft	• Function: Adjust gradually without shooting backward. • Location: Dashboard	3%

Another topic frequently discussed was the lumbar support adjustment; similarly 47% of the references were focusing on improvement of its location. Some of the most frequently used words were: seat, side, cushion, dash, door etc. Also, 32% of the references identified for this control were focusing on the function of the seat during operation of this control on how to improve feedback during the operation of this control. As mentioned earlier, 13% of the references were based on preferred control type. Out of these references 86% were based on electrical controls and 14% were manually operated controls. In terms of the preferred locations of controls in general, the most frequently used words were: controls, door, feel, find, reach, arm etc. which gives an indication where users prefer locations where they can easily reach and access to. Additionally, 6% of the references were related to shape and labelling of the controls; some of the most frequently used concepts were: easy, intuitive, intuitively, good, pleasant etc.

6.8.5- General comments

Some of the examples of ideas/concepts from all 4 Groups are presented in Table 45 to show some of the concepts in relation to specific controls.

Table 45: Getting back in control - examples of design ideas (whole sample)

	Head rest	Lumbar support	Seat recline	Seat height
Reach	Reach without distorting the body (don't want to stretch too far)	Should be at a reachable distance to prevent leaning or twisting the body.	Easy to reach (not too far/too close)	Easy to reach (not too far/too close).
Operation	Reduced work load (i.e. using one hand only instead of two).	Smooth operation with more precise feedback. Easy to twist with soft feel.	It should move gradually without shooting forward using less force.	If the control is operated vertically, the seat should move vertically, not diagonal.
Location	Shouldn't be located too high (particularly for females with short stature).	Height should not exceed elbow level.	Enough spacing should be provided for hand access	Enough spacing should be provided for hand access
Size	Big enough to locate and press easily with space around.	A larger dial would be beneficial allowing wrist to rotate (arthritis and reduced mobility). Avoid fingers only action.	Flat shaped levers without sharp edges, with some space groove at the bottom.	Flat shaped levers without sharp edges, with some space groove at the bottom
Colour	Manual controls blended in with the seat. Good contrast for electronic.	Manual controls blended in with the seat. Good contrast for electronic.	Manual controls blended in with the seat. Good contrast for electronic.	Manual controls blended in with the seat. Good contrast for electronic.
Material	Non-slip, good touch feel etc.	Dial type controls should be round, ridged and rubberised.	Non-slip material. e.g. 'flesh' pattern,	Non-slip material. e.g. 'flesh' pattern,

6.9- Part 3: Design exercise

Participants built on the discussions which took place in section 2 of the workshop and communicated their ideas during this exercise session. Each group involved in the workshop came up a range of ideas and presented these through sketches, models and demonstrated it on the seat buck provided to them.

Throughout the workshop everyone shared their opinions and ideas. After their discussion, they had to agree/compromise to reach the final design. When there were differences of opinion, the group members discussed the advantages and disadvantages of the opinions/ideas.

6.9.1- Group 1: Design exercise

For the design exercise, Group 1 developed two concepts. The first concept was based on the idea of having a touch screen to display the seat controls. This would be located on the dashboard in front of the driver and passenger (ideally at the centre for both to reach easily and adjust their seat position). The sketch is shown in Figure 58 where the user has the seat controls on a touch display (picture of the seat) on front of them.

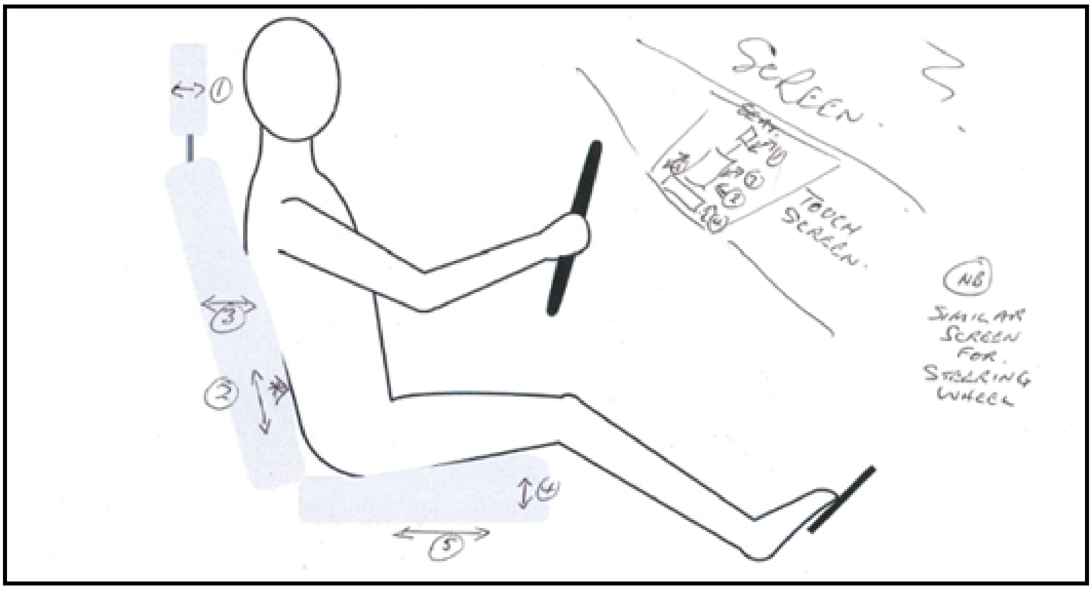

Figure 58: Seat control concept - touch screen technology

The group sketched various other concepts based on electronic controls in the form of a remote control to adjust the seat settings (Figure 59). The group then developed this idea and created a model to represent it, incorporating buttons and labels to demonstrate the method of operation as shown in Figure 60.

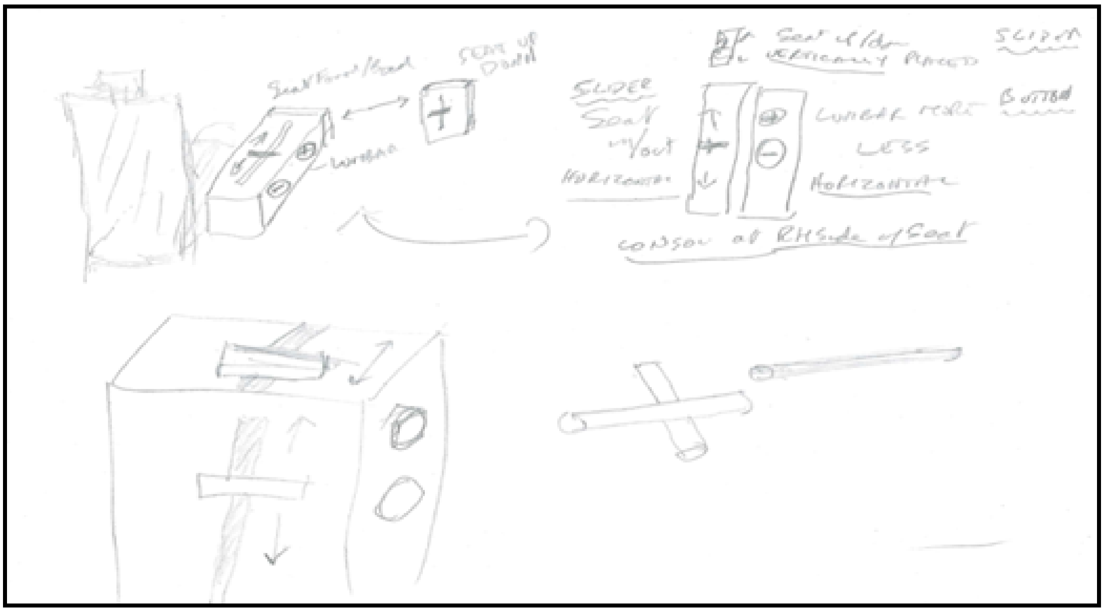

Figure 59: Seat control concepts – Electronic control (remote control)

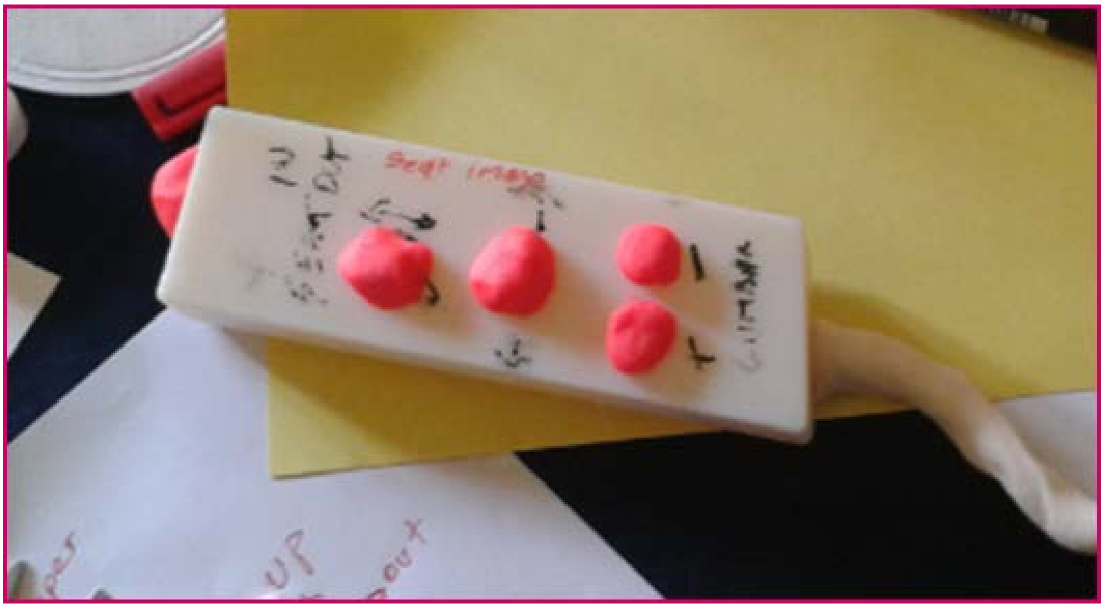

Figure 60: Electronic seat control model (remote control)

Their idea was a concept to prevent reaching or leaning forward during operation i.e. the user picks up the control and brings it closer their body. This enables the user to stay seated without moving their body during the operation allowing them to get good feedback, e.g. during the operation of lumbar support. A demonstration of the model can be seen in Figure 61. The views of the group on the optimum position and the location of the control when not in use is shown in Figure 62– ideally in front of them e.g. on the steering wheel.

Figure 61: User holds the control and sets the seat position (demonstration)

Figure 62: User shows the optimum position chosen for the control to be located when not in use (in front)

6.9.2- Group 2: Design exercise

Group 2 also produced a range of concepts and ideas to demonstrate their ideal type of seat controls (Figure 63). Similar to Group 1, they came up with two concepts; the first one was an electronic control (Figure 64). They also wanted a button for the front passenger to be able to use these features and set the passenger seat position. They sketched and mapped out the controls by focusing on the shape, location, size, colour and material. Controls were mapped out in the shape of the seat itself with a movement indicator to provide visual feedback to the user. They also wanted the option of four different pre-defined seat position settings.

The second control was a touch screen display based seat control (Figure 65). The group selected a design using electronic controls with buttons.

Figure 63: Group 2 generating ideas and making to demonstrate their ideas

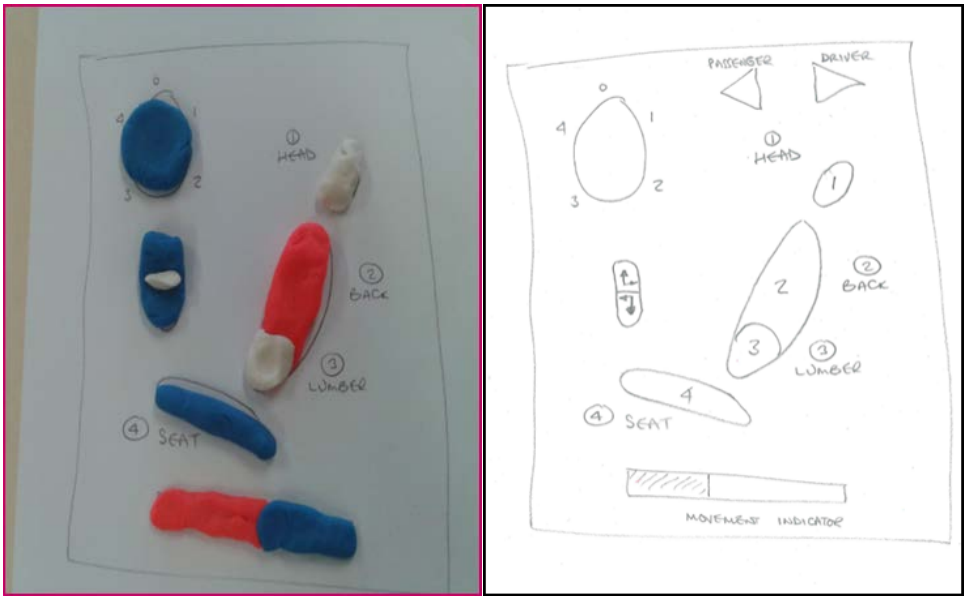

Figure 64: Electronic seat controls for the driver and front passenger

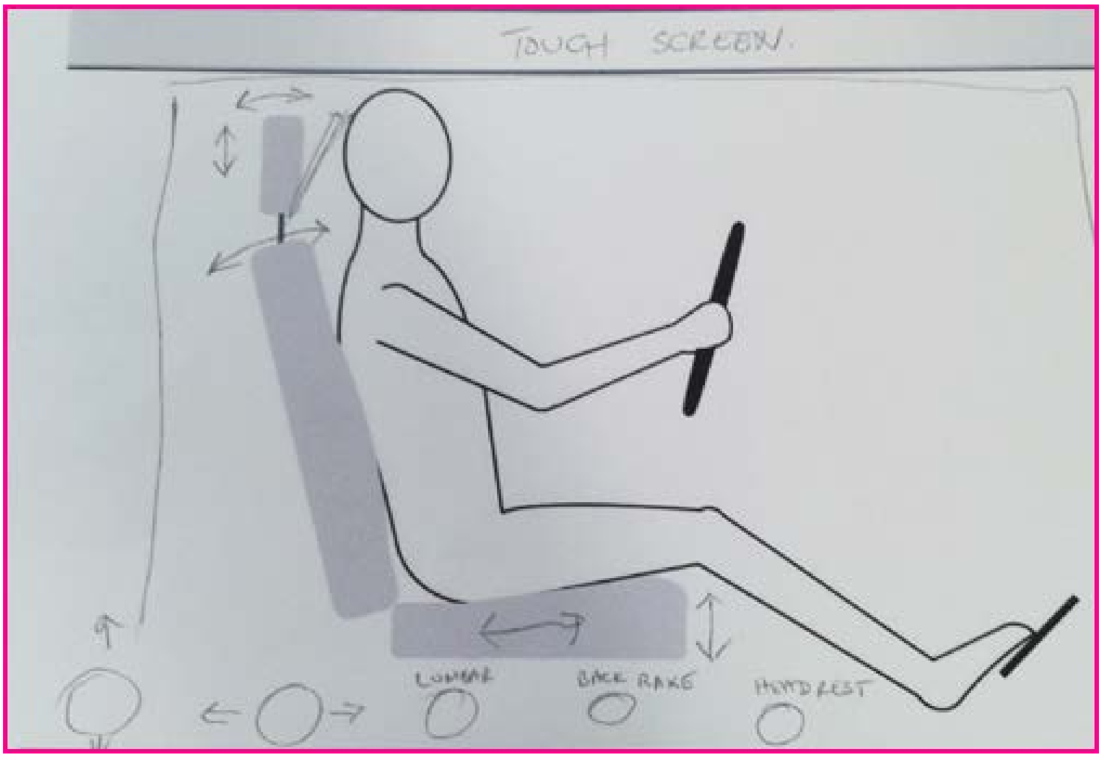

Figure 65: Electronic seat control with touch screen technology

Participants decided that the best location for the touch screen control was in front of the gear stick under the cup holder/storage box, as shown in Figure 66. Additional features were then discussed, for example, the front seat passenger could operate the same control by selecting a ‘passenger’ button to set his/her passenger seat.

Figure 66: Optimum position and the location of the seat controls chosen by the group

6.9.3- Group 3: Design exercise

Group 3 (Figure 67) recommended car seat controls which were partially manual and partially electronic. For instance the group decided that the head rest height adjustment should be electronic and placed in a location in front of them to prevent them needing to turn their body around and minimise workload and the effort of reaching during operation; this is shown in Figure 68. The main reason given for this was that adjusting the head rest was for them the most challenging part of the seat set-up process.

Figure 67: Group 3, participatory design exercise session

Figure 68: Group 3, head rest height adjustment (optimum positioning) - electronic control

The group's ideal type of control for the seat recliner was a dial type control: round, ridged and rubberised with a soft-touch feel. They illustrated this by using one of the models and covering it with soft play dough. For the seat lifter, they made a decision on a lever type control (as in many existing vehicles) but with grooves added to avoid finger slip. In terms of the colour preference, they stated they would like the controls to be blended with the colour of the seat. Particularly for controls located on the side, it was reported that they use tactile sense rather than visual in order to find the control. Both the seat recliner and the seat lifter controls were positioned in a location where they could be reached easily and where the hands naturally drop without interference between the elbows and bolsters. The optimum position and location of both controls as selected by this group is illustrated in Figure 69.

Figure 69: Seat recliner and the seat lifter (manual - dial and lever type adjustments)

In terms of the lumbar support adjustment an identical control to the seat recliner was chosen by the group. This was a manually adjusted dial type control, round, rubberised with a soft touch feel. This was located on the left side of the driver's seat as show in Figure 70. The size was also big enough to hold with the palm instead of using the finger tips, to provide more space for the hands to access and operate the control.

Figure 70: Lumbar support adjustment - manual control (optimum positioning and location)

6.9.4- Group 4: Design exercise

Two concepts were made in order to demonstrate their ideal headrest and lumbar support adjustments. The first was a cross-shaped control, the blue section is the 'up/down' feature to adjust the head rest height and red section is the 'left/right' feature to adjust the lumbar support (in/out). The second control was a joystick type (ball shaped) control, as shown in Figure 71.

Figure 71: Lumbar support and head rest controls - electronic type concepts

Many different models and shapes were discussed but the group then decided their seat controls should be electronic and operated via a joystick type of control located near the door on the driver's side (Figure 72).

Figure 72: Group 4, optimum positioning and location (head rest and lumbar support controls)

6.9.5- Overall summary: Design exercise

This section focuses on the priorities related to size, shape, material and type of the controls and communicated from the models/sketches created during the design exercise.

All groups agreed that controls should be intuitive to use (e.g. using a seat shape). Looking at the models/sketches created by the groups it is clear that they would like to be able to understand the function/use of their seat controls immediately. Two of the groups tried to address this need by using labels/symbols on the sketches and models as well as different shapes. Controls should be designed intuitively and any labels should be clear and easily visible. They should be placed or labelled to indicate their direction of motion and address its function. Discussions throughout the workshops revealed that some controls are too stiff and require too much force/physical effort to operate. Therefore sharp edges should be avoided to prevent discomfort to the palm/fingers due to the need for a high pressure grip.

With regards to materials and shape, dial type controls should have a soft comfortable touch feel (e.g. rubberised) with a ridged texture and function/turn smoothly. These were identified in the workshops, for instance; a good example would be Nissan Qashqai lumbar support adjustment. For lever type, a ‘flesh’ texture pattern may be preferred, it has non-slip texture.

The size of the control should be easy to see, feel and locate. Dial type controls should allow ‘whole hand operation’ and not just the fingers (90mm diameter was found to be a good size). Lever controls were liked but they should have a soft comfortable feel, be large enough to locate and have grooves at the bottom for good grip. Movement of the seat should be gradual. The colour of manual controls should blend with the seat colour for aesthetic appeal. It is more reasonable to use colour on electronic controls (if they are located at one point) in order to distinguish between controls.

Electronic buttons should be large enough to locate and press/grip easily with sufficient spacing around, in order to consider users with reduced hand coordination and prevent interfering with another control. Instant feedback should be provided so that the user can ‘feel’ the change in seat position increasing the chance of obtaining a comfortable seat position.

6.10- Discussion

In the current literature there is a lack of research that specifically focuses on design of car seat controls for older users. As mentioned in Chapter 2, section 2.10 of this thesis there are materials on general control design principles and these provide design guidelines from an ergonomic perspective by the authors McCauley-Bush (2012); Kroemer (2001); Guastello (2006); Nicolle et al. (2011) and Vink (2004).

As identified in the previous study ‘in-depth audit’, the workshop discussions mainly evolved around the problems of positioning, accessibility, operation and feedback from seat controls. Based on the discussions carried during the sessions on ‘likes/dislikes’ and ‘getting back in control’, the majority of the comments and opinions addressed the issues related to the physical workload experienced during the reach, accessing and operation of the specific seat controls. The other main focus areas were related to the feedback and intuitively designed seat controls. This became more apparent during the ‘design exercise’ session conducted with all 4 groups. Participants communicated their ideal controls through their design in order to address difficulties in operation. In general, all four of the groups had similar outcomes on their ideal type car seat controls. During the discussion more detailed information was found in relation to seat function and controls. These are based on the unexpected functioning of the seat with the operation of some controls. For example, participants noted how a seat can suddenly slide backwards with the operation of fore/aft adjustment or the backrest could suddenly shoot forwards with the operation of the control.

There were lot of similarities with all 4 groups based on the outcome of the preferred locations of the controls such as at the front or the sides or at a reachable location without distorting their body around. This was very obvious through their demonstrations during the ‘design exercise’ session where all groups located their final concepts at reachable locations to keeps them in their seated position without the need of moving their body around e.g. leaning or rotating. With this also participants tried to address some of the key issues identified in earlier studies such as locating controls at a specific area to prevent the need to move their body, rotate or lean forward. For instance the issue with leaning forward and twisting body around resulted during the use of lumbar support and head rest controls as identified in the previous study (Chapter 5). This generally requires a lot of physical demand and more challenging task for older drivers since turning the head and body around becomes more difficult with increasing age (Isler et al., 1997; Smith, 1993; Bradley et al., 2008). Similarly this was also identified in the survey study and observed during the audit with older drivers. According to Vink (2004) in his review, posture and movements determined by the product may cause discomfort and in the future it may even lead to musculoskeletal disorders. Therefore it is reasonable to locate the controls at a specific point that does not require a lot of movement and rotation of the body. With general control design principles in the literature Kroemer et al. (1994) and Bhise (2012) suggest that controls should be oriented with respect to operator, be easily reached and located based on the driver expectancy.

In the study conducted by Williams et al. (2011) (as referred in section 5.8 of this thesis) out of 101 participants only 11 were aged over 60; the study focused on the evaluation of electronic seat adjustment controls in 6 luxury (SUV type) vehicles. The study did not compare age and gender. When participants was asked on their preferred position/location of seat controls, 51% reported the seat, 17% current position, 17% door, 10% dash board and 4% reported the steering wheel. Out of the 51% who reported the seat as preferred location, 22% reported ‘side of the seat’ and

16% reported ‘right side’ (UK). All of these locations are generally at a reachable distance and mainly in front of the driver. Comparing these results with the current study, there are some similarities in terms of location preferences. In the current study older drivers reported that they prefer controls (particularly electrical) in front of them (at a reachable distance); this was communicated during the ‘design exercise’ session by all groups. In the previous study (in-depth audit) it was identified that some controls (manually operated) are located on the side of the backrest (lumbar support) or underneath the head rest (head rest height adjustment button) in many vehicles and these were the problematic locations in terms their requirements for reaching, rotating body etc. In the study of Wiliams et al. (2011) none of the participants preferred their ideal location on the side of the backrest or near the head rest; it may be that participants prefer their controls to be located at visible and reachable locations.

The relationship between the location of control and the feedback seems very important. In the previous study (In-depth audit- Chapter 5) it was observed that the higher the location of lumbar support adjustment the more users had to lean forward in order to obtain a posture to adjust the seat. In a study conducted by Sang et al. (2009) on understanding musculoskeletal disorders of sales representatives (drivers) it was identified that most participants that responded to a questionnaire were satisfied with the adjustable features of their car and the postures adopted. However, 25% of respondents reported they were dissatisfied with the lumbar support adjustment.

With the interview sessions carried out during this study it was identified that older drivers want intuitive designs. The design of the control should address its function, based on the shape, use of symbols/labels etc. For example, Norman (1998) describes the term ‘natural mapping’ in relation to design of controls, the author describes this term as the relationship between movement of controls and their outcome results. He gives a good example of a natural mapping of a seat adjustment control (electric control, Figure 73) from a Mercedes-Benz car.

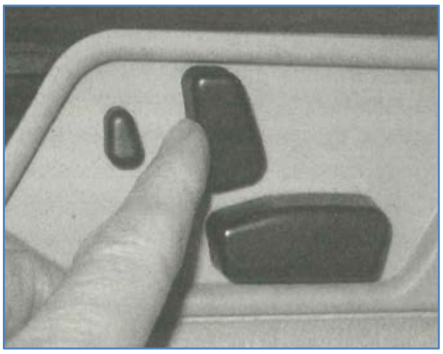

Figure 73: Mercedes-Benz car seat control (adapted from Norman, 2004)

The control is in the shape of the seat itself. This sort of control can easily be associated with the seat and depending on the seat feature to be adjusted the same feature can be selected on the control e.g. increase the seat height, the front part of the button is lifted. In one way the user sees the miniature version of the seat in front of them and easily selects the section/part of the seat to be adjusted. The movement of the control is also mapped in the way that the seat would move in real life.

During the workshops it was confirmed that older drivers prefer electronic controls to be easy to see, feel and large enough to locate and operate easily, as would be expected. During the 9-hole peg-test assessment (in-depth audit) with older drivers it was identified that there is a decline in hand coordination and dexterity with increasing age. A decline in dexterity was also observed in the study conducted by Wang et al. (2014) where the author compared gender and age by conducting 9-hole peg test. In addition, many older people suffer bone and joint disorders such that operating a control that is small may be difficult. If the spacing around the control is not sufficient enough, this could cause interference with another control. Nicolle et al. (2011) has conducted a detailed literature review on design of controls (guidelines for household appliances) and suggests that for older and disabled people the spacing for push buttons should be minimum 10mm on a vertical surface and 7mm on a horizontal surface. For instance, participants reported during survey study and the workshops (manual type) head rest buttons as too small, fiddly and hard to push. It is important to point out that the guidelines provided by Nicolle et al. (2011) are based on guidelines for household appliances; therefore it may conflict with an in-vehicle recommendation, so care is needed before applying these. Guastello (2006) indicated that, in the past in order to move large physical forces, large-size controls were used.

Considering the process during the operation of head rest height adjustments, the user is required to push the button with one hand and adjust the height with other hand. This requires high physical demand on users. Therefore controls should be designed considering all these factors.

Dial type controls (also lumbar support controls) should allow ‘whole hand operation’ and not just fingers (e.g. 90mm diameter). Bhise (2012) suggests that the control should provide enough surfaces to grasp and there should be enough clearance for hand/finger access. In many case this was observed during the ‘in-depth audit study’ and reported in the workshop where some drivers are required to open the door in order to get hand access to adjust controls such as seat recliners and lumbar support adjustments.

If there is not enough clearance around the control e.g. dial type seat recliner on the side of the seat, there is a risk of interference of the knuckles on the door pocket during the operation of the control, making it difficult for the user. Also if the controls e.g. dial type lumbar support is too small and can only be rotated by finger tips, then the space for hand to move freely during the operation can become insufficient. These were also observed during the audit study.

Controls such as button, knobs, handles etc. should have pleasing feel by considering touch characteristics that can be measured (Bhise, 2012). The preferred type of controls in general (electronic and manual) in terms of touch feel was reported as non-slip texture e.g. soft ‘flesh’ type. For the dial type controls such as lumbar support and seat recliners rubberised texture was preferred (soft feel with ridged texture). This was identified by showing participants different examples of controls with various textures and materials. Similar results were found during the ergonomics evaluations carried out on the seat controls during the in-depth audit (Chapter 5). This shows that older drivers do not prefer hard plastic controls with large finger grips and no sharp edges. Also, such controls should operate smoothly without using too much physical effort. A study conducted by Ranganathan (2001) has explored the effect of age on the changes in handgrip and finger-pinch strength. The study found that handgrip force of older participants (over 65) was 30% weaker than younger participants. Similarly, older participants’ maximum pinch force (MPF) was 26% lower than younger participants. From this result it can be understood that older people would experience higher physical effort during the operation of dial type controls such as seat recliners and if they do not provide comfortable touch feel e.g. hard plastic they could cause pain and discomfort as reported in the workshop study by participants.

For electronic controls, participants prefer high contrast between the controls and the background in order to see the control easily. In a study conducted by Ryu (2009) with older drivers which also explored older drivers interaction with temperature controls and air conditioning controls propped that adding red or blue colour on the switch improves the visibility and operability of the control. But it is important to indicate that this finding may depend on the background colour where the switches are located, for instance Nicolle et al. (2011) recommends that for colour displays the following combinations are not recommended i.e red/green and blue/yellow, but instead white or yellow is suggested on black or dark colour background.

In terms of aesthetics, a manual control would be blended in with the seat. With manual controls located on the seat it was reported that participants would use the touch feel in order to get to the control rather than leaning and looking for it. This is also supported in the literature, some controls can be found and operated without looking, and that is by blind positioning of hands and tactile and/or shape coding of the grasp areas of the controls (Bhise, 2012). Looking at the responses based on the colour preferences of controls, it was interesting that for manual controls participants preferred them to be blended in with the seat, in other words they did not want high contrast colours.

6.11- Limitations to the study

Some participants had concerns about the feasibility of their ideas/opinions based on the factors such as cost and manufacturing methods. This was identified in all four groups. These participants thought it would be cheaper to produce manually operated controls; as a result they initially focused their opinions/ideas based on manual type of controls. Once they were informed not to be concerned about these aspects (cost and manufacturing method) they pointed out that electrically operated controls would be more beneficial for them due to their physical limitations, as a result some of them may have limited themselves expressing their opinions on during the initial stages of the workshop. The other limitation may be that during the ‘Design exercise’ session participants were asked to do sketches, make models using card, tape and clay. Some have reported not being able to communicate their ideas in this way and was not forced but they were willing to make comment rather than doing hands on exercise. Therefore it was difficult to understand some of their ideas in some cases.

6.12- Contribution to knowledge

This study has identified the requirements of older drivers for optimum positioning and operation of seat controls by understanding their preferences with a focus on:

- Ideal location
- Type of control e.g. electrical or manual or combination of both
- Functioning of the seat e.g. unexpected movement, limited height for short statue drivers etc.
- Size and material and colour preference

6.13- Conclusion

This study was conducted in order to address objective 3 of this PhD: to explore design solutions to specific age-related challenges. This was carried out by focusing on the selected theme ‘optimum positioning and operation of seat controls’: one of the main themes identified during the audit (Chapter 5). The study has provided foundational data to make design recommendations for the automotive industry which has been discussed in Chapter 4 of this thesis. These recommendations will focus on improving the operation, location, type, size, colour and materials of car seat controls in order to meet the requirements of drivers of all ages particularly older. Additionally, the outcome of this study shows that some of the findings of the current study and the ones from Chapters 4 and 5 can also be applied to different areas which may be relevant for older users; these include transport, domestic appliances and living spaces.

Chapter 7- Recommendations and conclusions

Designing vehicles to accommodate the needs of older drivers could have social and economical impact for the users and the manufacturers. On the one hand users older drivers could drive for a longer period. For example, in current circumstances if someone has to stop driving due to decline in their functional capabilities as part of the ageing process then by addressing the needs of this user and improving the design of vehicles, this period can be extended for few years. This would then allow older drivers to maintain their independence, and they could remain socially integrated (shopping, visiting relatives, etc.). On the other hand, this could bring various advantages to automotive manufacturers. By understanding the characteristics of this age group and designing vehicles according to it would accommodate drivers of all ages. This would then increase their sales benefiting both the user and the manufacturer.

As discussed in Chapter 1, there is a growing population of older drivers in the UK and around the world. This demographic trend information indicates that the automotive industry is facing a changing target population. This research has identified many factors that affect the driving experience of drivers of all ages, as well as those specific to older drivers. The findings and outcomes of this research indicate that there are a number of opportunities for the automotive industry to focus on the needs of older drivers in order to meet their design requirements. As a result this chapter will provide recommendations for the automotive industry which will also address Objective 4 of this research. Some of these recommendations could also be applied in different areas to target older users in order to improve their experiences when interacting with products, services or environments where these will be discussed throughout the chapter. These recommendations have been categorised into 3 areas:

- Visual, environmental, physical and cognitive factors
- Seat design and driving posture
- Seat controls

7.1- Generic recommendations: Visual, environmental, physical and cognitive factors

- From the survey, half of the sample (47% - both younger and older) reported that other driver's lights restrict their vision when driving at night. This is estimated to represent 47% of drivers in the UK. Therefore increasing headlight brightness too much could have unintended consequences on other drivers.
- Functional assessment (9-hole peg test) showed that there is a decline in hand coordination and dexterity with increasing age. There should be enough spacing around each control to prevent interference with another control.
- Based on the Hamilton Veale test (contrast sensitivity test) a decline in contrast sensitivity was observed with increasing age, as expected from the literature. This indicates that driving in bad weather and night time conditions is likely to have greater effect on the vision of older drivers compared to younger.
- Due to a decline in physical capabilities, parallel parking and turning the head and body around when reversing is an for older drivers. There are now vehicles equipped with technologies to assist drivers with parking: it is important that these features are designed to be easy to use by older age groups.
- In general, females are shorter than males and with increasing age there is also a decline in stature. The automotive industry should consider people with short stature when designing specific features of cars. For example, reaching and pulling the boot door down to close was difficult for older females due to reduced physical function, reduced reach and being shorter in stature.
- The questionnaire survey and literature supports the fact that older drivers are not keen on new technologies unless they are easy to use. These technologies should be designed in most simplistic ways for older drivers to be able to use them, also by considering their reactions being slower compared to younger (identified during survey study and literature).

7.2- Generic recommendations: Seat design and driving posture

This section provides recommendations in relation to seat design and driving posture based on the key results identified through this research during the audit.

- Based on the key findings of this research, seat design and driving posture is another important area that requires further research and in-depth understanding. For instance making adaptations to seat was common for drivers over 65 years; three main purposes were identified for making adaptations to the seat in this research.
- This shows that there is a clear focus needed on the design of seats to include older people who care about achieving comfort whilst driving. As a result they are adapting their own vehicle and looking for their own solutions to tackle these problems.
- The seat needs to be designed with better functionality i.e. height should be adjustable to accommodate people below 155cm. Improving this could also improve their safety on the road by boosting their confidence once they have clear visibility of the road as well as ingress/egress.
- For ease of entry/exit a low friction material is an advantage. Another important factor to consider is the seat height; older drivers find it easier to get out of seats higher above the ground, SUVs are good example for these. A flatter seat profile with reduced slope is also helpful for people with mobility problems. It is beneficial to design the seats by focusing on the following criteria: size, shape, profile, seat slope, materials and height.
- It is important to consider that in order to adopt comfortable postures during the posture analysis, most of the ‘over 65s’ needed assistance/guidance during their seat set-up process with finding and using seat features. This shows that this needs further exploration for manufacturers to come up with ways of facilitating setting up their seat; this could focus on advice on posture, role of technology or sales support service.

7.3- Recommendations: Seat controls

- All controls should be intuitive to use (e.g. using a seat shape) and any labels should be clear and easily visible. They should be placed/labelled to indicate their direction of motion. All controls should be intuitive (e.g. shape, symbols, labels).
- Operation of all types of controls (electric or manual) should run smoothly with minimum effort; Nissan Qashqai lumbar support adjustment is a good example.

- Appropriate feedback from the control and the seat is very important, during the operation of the controls. For example, this could be related to the progress of specific operation.
- Once the controls are operated, the seat should not function unexpectedly e.g. when operating fore/aft it should not suddenly slide backwards or the backrest should not shoot forward once the control is operated.
- In general, electronic or manual controls preferably would have comfortable touch feel with a non-slip texture.
- Preferably, the rotational type controls such as lumbar support adjustment and seat recliners should have a soft touch feel with ridged texture (rubberised). This was identified during the audit; similar responses were gained during the workshop study.
- Hard plastic controls with large finger grips should be avoided for dials. For all types of controls, sharp edges should be avoided.
- For manual type controls, particularly the lumbar support and seat recliner, adjustments should be located on the side of the seat cushion to enable users to access the control with natural drop of hands, avoiding leaning, twisting or interfering with the seat bolsters. Seat lifters were reported as easiest controls in terms of their reach distance, ease of access and the spacing around it, this should be similar for lumbar support and seat recliners.
- Functional assessment (9-hole peg test) showed that there is a decline in hand coordination and dexterity with increasing age. Controls should be large enough to locate (visually or touch) and press/lift easily, for example the head rest buttons were highlighted as a problem as they are small, fiddly and hard to push as reported by participants during all three studies of this research.
- Dial type controls should allow ‘whole hand operation and not just the fingers’ (e.g. 90mm diameter); this size is also preferred for lumbar support adjustments.
- For electronic controls, there should be contrast between the controls and the background in order for them to be seen easily.
- For aesthetics, a manual type control would be blended in with the colour of the seat if this does not affect operability.

7.4- Recommendations for other applications

It is important to note that some of the findings of this research can be applied in other industries/areas and may be relevant to consider when designing for older users in order to improve their experiences when interacting with products, services or environments where these will be discussed throughout this section.

7.4.1- Public transport

Older people also experience issues with public transport. Fiedler (2007) and AIHW (2007) reported one of the issues is to do with getting on/off the public transport, issues with balance and there are occasions that there is not enough time to sit before the vehicle starts moving. Considering these factors, there are stages that a passenger needs to go through in order to get in and out of public transport such as getting in to the vehicle, finding a seat, getting on to the seat, approaching location, getting out of the seat and then from the vehicle itself. Therefore getting into and out of passenger seats may be difficult when the vehicle is moving for older and physically impaired passengers.

Some of the workload can be reduced by designing some seats slightly higher above the ground for older passengers in order to get on to and out of without less physical effort. Additionally, designing the seat surface with a low friction material may help the passenger to swivel or move their body forward to get out of the seat. In addition if the seats are too low, a passenger may not have a clear view during the trip. In the current research it was identified that older drivers were using additional seat cushions in order to increase their seating height to get a clear field of view due to their short stature. Having an optimum seat height could improve the confidence of passengers with short stature and they will be more confident by knowing their current location.

Grab rails should be located at a position which does not require passengers to twist their body around or lean forward to reach. This will then allow them to obtain better balance even if the vehicle is moving. During the current research it was identified that controls with ridged texture and soft touch feel were perceived to be pleasant and easier to operate, therefore the grab rails could be implemented with such hand grips for passengers to hold on to.

7.4.2- Living environment

This research has identified issues with reaching/accessing in-vehicle controls as well as reaching and pulling the boot door down to close. These were more common for older females; some even used additional seat cushion in order to increase their seat height (all under 155cm in stature). This shows that, older people with short stature could also struggle with simple tasks in their daily life living environments. Therefore, homes and kitchens should be designed and equipped in a way to accommodate older users with short stature (under 155 cm). An observational study carried out by Boschetti (2002) with 14 older participants (average age 68.5) has identified this. The study was looking into the tasks carried out by older users in standard kitchens and how they interact with kitchen features during meal preparation, using appliances and kitchen design. There were difficulties with reaching appliances and cabinets (both low and high locations). Out of 14 participants; five were unable to reach above the lowest shelf in the wall cabinet, three used a reacher (assistive device) to get items from upper shelves and two participants were unable to reach into base cabinet or lower shelf of a refrigerator. This shows that shorter stature (particularly females) could have an impact on simple daily tasks for independent living in older users.

7.4.3- Consumer products

The recommendations made on the design of seat controls through this chapter could also be applied to many other applications such as consumer products which older users interact within their daily life. According to Kroemer (2006), products such as keyboards, household tools, TV remote controls, medicine containers with child-safe locks, door handles, vacuum cleaners, stoves, razors etc. are difficult to manage/operate by many adults, in some cases these are impossible to use for a person with impairment. A study conducted by Goddard and Nicolle (2012) reported the older users perspective, a good design produces products that are easy to use, they function in the way they are expected to and are simple to understand. Some of the findings of this research support those reported by Kroemer (2006), e.g. many older users have problems using can and jar openers and with opening child-safe bottle tops. According to research carried out by Brownsell and Bradley (2003) the most common home-based technologies used by independent living older people are as follows: cooker (98%), microwave (45%), washing machine (52%), vacuum cleaner (98%), telephone (89%), television (100%), radio (98%) and video (44%). Such home-based technologies need to be designed in a simplest way for older age groups and physically impaired people to use and work according to their expectations. Based on these factors, the current research is relevant to usability for whole population, not only older drivers.

Since there are hundreds of consumer products and home-based technologies, it is necessary to provide some examples of how the findings of the current research can be implemented on these products. For example, with vacuum cleaners, the controls on these products can be located on the handle instead of the main body to avoid user to lean forward/down to reach and operate; this would then reduce the workload on the user. For instance with TV remote controls, buttons should have enough spacing around it to prevent interference with other buttons on these controls. The size of the buttons should be big enough for older people with reduced hand coordination and dexterity to locate and press easily. There should be contrast between the controls (for button/electrically operated type) and the background in order for them to be seen easily. For instance, jar lids can be designed for whole hand operation and the edge of the lids can have textured surface with soft touch feel (rubberised) in order to allow good hand grip. This can also be applied on many products such as cooker controls and microwave controls and door handles etc. Another example can be related to washing machine controls. The controls should be located where the user is not required to lean to reach; each control should have comfortable touch feel with a non-slip texture. All controls should be located in logical areas and clustered. Most importantly, controls should be intuitive to use and communicate its function through its design (e.g. shape, symbols and labels).

7.5- Conclusions

Through this research the requirements of older users were explored for an improved driving experience. This research has shown that older drivers continue to experience a number of difficulties and has led to a number of design recommendations. The following conclusions are supported by the research in this thesis:

1. *Key issues with the driving experiences of older compared with younger drivers.*

- Key issues with the driving experiences of older compared with younger drivers were identified (questionnaire survey) by focusing on: in-vehicles tasks, the vehicle seat features, ingress/egress, driving performance and driving behaviour. Specific issues were identified; these include physical, visual, environmental and cognitive factors. Specific examples include: physical factors, difficulties with accessing vehicle features such as bonnet release button in-vehicle and on the bonnet and adjusting seat features such as head rest (height and distance from the head); some of these issues are common for all ages and some are specifically associated with older drivers. For instance reaching and pulling the boot door down to close was reported to be more difficult by younger and older females. Specific focus areas were also identified that require further research (beyond the scope of this thesis) e.g. on the effect of other drivers' lights on vision, driving in bad weather (driving on a foggy day, driving in the dark etc.) and night time conditions. An example is that, both younger and older drivers representing 47% of drivers in the UK reported that other driver's lights restrict their vision when driving at night. With regards to cognitive factors, older drivers reported their reactions were slower than they used to be (e.g. braking in an emergency situation).

2. *How design of the vehicle cab impacts on posture, comfort, health and wellbeing in older drivers.*

- Two main themes were identified through this research within the vehicle cab area that had an impact on comfort, posture, health and wellbeing in older drivers. These are related to the optimum positioning and operation of seat controls and seat design and driving posture of older drivers (over 50s).

- The results from the in-depth audit provided clear evidence on the specific issues related to operating, accessing, reaching and finding the seat controls, mainly the head rest and lumbar support adjustments. The majority of these participants had difficulty operating the head rest height adjustments, approximately 40% of the participants particularly the oldest drivers had difficulty turning their head and body around to operate this control; the majority of these were over 80s. Although more than 94% of participants were within the comfort zone for posture suggested by the literature, many required assistance from the researcher in finding and operating head rest height, lumbar support, steering wheel adjustment etc. to help them achieve their desired comfortable postures. Issues related to seat function were also identified. For example, back rest shooting forward with the release of the handle, hitting users head or seat shooting backward with the release of the fore/aft handle.
- During the in-depth audit it was identified that making their own design adaptations to their driving seat was common for drivers over 65 years. Three main purposes were identified for these adaptations, firstly to improve seating comfort, secondly to increase sitting height for a better field of view and finally to improve ingress and egress (to get on and off the seat easier). Some examples of adaptations include: extending the seat cushion, placing the foot rest to increase seat comfort, using seat cushions to increase seat height, and using shopping bag to reduce friction during ingress/egress. The use of additional items was reported in literature but nothing was reported in relation to design adaptation or the reasons behind these adaptations.

3. *Design solutions to specific age-related challenges and recommendations for the automotive industry.*

- The workshop studies showed that older drivers prefer seat controls that are easy to find and access, operate with less effort and comfortable to use. For example, controls that operate without the need to twist the body or without leaning and allow easy access. Controls should also be intuitive to use (e.g. using a seat shape). The detailed findings of this workshop led to recommendations to incorporate the requirements of older users into the design process of car seat controls and other fields which may be relevant for older users. This research showed that older users are enthusiastic and keen to engage with researchers who aim to improve their driving experience. The automotive industry could benefit from increasing their testing with this user group.

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Appendices

Appendix 1: Questionnaire survey

Driving experience survey

A survey is being conducted by Loughborough University Design School, aiming to understand the experiences of car drivers of different ages and identify some of the key challenges for car design.

It takes approximately 10 minutes to complete. Please read each question carefully before answering. There are no right or wrong answers, so please respond freely and honestly. We are interested in your personal experiences and opinions.

Information provided will be held by Loughborough University and will be stored against a reference number to ensure anonymity. Information will only be used for this research and will conform to the requirements of the Data Protection Act 1998. We will not share individual responses with third parties, and summary information will not be produced in any way that could reveal your identity. Once you have read this information sheet and if you decide to take part now, you can still change your mind later without giving a reason. You may withdraw at any time and your data can be removed at your request.

The findings will be used to help direct future research in vehicle design.

Please **only** take part in this survey if you have driven a **vehicle** regularly in the **last 12 months**. If **not**, thank you for volunteering but please do not continue.

Please sign below to show you agree to take part in this survey.

Signed**:…………………………….. ** Date**:…………………………………...**

The research team comprises:

Sukru Karali	s.karali@lboro.ac.uk	+44 (0) 1509 228161
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Please mark the boxes☑ or ☒, or write the answers in the spaces provided.

Loughborough University

Background information

1. Age:

☐ 20-34 ☐ 35-49 ☐ 50-64 ☐ 65-79 ☐ Over 80

2. Gender:

☐ Male ☐ Female

....

3. Do you currently work?

☐Yes, full time ☐Yes, part time ☐No, retired

☐No, student ☐ No, other

3. a) If **'Yes'**, what is your **job title**? *(If **'No'**,* please go to question **8**).

____

4. How many **hours** do you work in a typical **week**?

Hours ________

5. How long have you worked for your current employer?

Years ________ Months ________

6. How many **years** and **months** have you worked in your current position for?
Years ________ Months ________

7. Do you drive regularly as part of your job?

☐Yes ☐No

7. a) If '**Yes**', approximately how many **hours** in a typical week?

Hours ________

About the main vehicle you drive

8. What is the make and model of the **main** vehicle that you drive or you have driven in the last 12 months? (e.g. Ford Focus, Nissan Qashqai, Renault Kangoo *if known*)

____

9. Does this vehicle have an automatic gear box?

☐ Yes ☐ No

10. How many years and months have you used the above vehicle?

Years_________ Months _________

11. On average how many **miles** have you driven this vehicle in the **last 12 months**?

☐ Less than 1000 ☐ 1000 to 2400 ☐ 2500 to 4900 ☐ 5000 to 7400

☐ 7500 to 9900 ☐ 10000 to 14900 ☐ 15000 to 19900 ☐ Over 20000

12. On average how many **hours** have you driven this vehicle in a typical **week**?

☐ Less than 1 ☐ 2 to 5 ☐ 6 to 10 ☐ 11 to 15 ☐ More than 16

13. Do you have any other comments regarding the main vehicle you drive?

____

____

Musculoskeletal symptoms

14. We are interested in your general health. Please answer **all** of the questions in the **first column**. If **'Yes'**, answer the questions in the other three columns for that body area.

Have you at any time in the **last 12 months** had symptoms (such as **ache, pain discomfort numbness or tingling**) in:	Have you had any symptoms in **the last 7 days**?	Have you at any time in the **last 12 months** been prevented from carrying out normal activities (such as job, housework, sport) because of these symptoms?	In your opinion, do you think these symptoms are directly **related to the work you do**?
Neck No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐
Shoulders No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐
Elbows No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐
Wrists / Hands No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐
Middle back No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐
Lower back No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐
Hips, thighs or buttocks No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐
Knees No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐
Ankles or feet No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐	No ☐ Yes ☐

15. Please indicate how you find **operating** the following controls in your **main** vehicle? If this vehicle does not have the feature please tick N/A.

	N/A	Very difficult	Difficult	OK	Easy	Very easy
Signals and lights						
Activating the head lights	☐	☐	☐	☐	☐	☐
Activating the indicator lights	☐	☐	☐	☐	☐	☐
Other controls						
Pressing the horn	☐	☐	☐	☐	☐	☐
Activating the windscreen wipers	☐	☐	☐	☐	☐	☐
Activating temperature controls	☐	☐	☐	☐	☐	☐
Operating the radio	☐	☐	☐	☐	☐	☐
Operating the pedals						
Pushing the clutch pedal	☐	☐	☐	☐	☐	☐
Pushing the brake pedal	☐	☐	☐	☐	☐	☐
Pushing the accelerator pedal	☐	☐	☐	☐	☐	☐
Operating hand brake						
Activating the hand brake	☐	☐	☐	☐	☐	☐
Deactivating the hand brake	☐	☐	☐	☐	☐	☐
Mirrors						
Adjusting the rear view mirror	☐	☐	☐	☐	☐	☐
Adjusting the side view mirrors	☐	☐	☐	☐	☐	☐

In-vehicle tasks

16. Do you have any other comments regarding the in-vehicle tasks?

The vehicle seat

17. Please indicate how satisfied you are with **adjusting** the following features of the **main** car that you drive**.** If this car does not have the feature please tick N/A.

	N/A	**Very dissatisfied**	**Dissatisfied**	**Ok**	**Satisfied**	**Very satisfied**
Moving the seat forwards and backwards	☐	☐	☐	☐	☐	☐
Backrest angle	☐	☐	☐	☐	☐	☐
Setting the seat height	☐	☐	☐	☐	☐	☐
Lumbar support						
In and out	☐	☐	☐	☐	☐	☐
Up and down	☐	☐	☐	☐	☐	☐
Head rest						
Height	☐	☐	☐	☐	☐	☐
Distance from your head	☐	☐	☐	☐	☐	☐
Seat belt						
Reaching for the belt	☐	☐	☐	☐	☐	☐
Pulling it across your body	☐	☐	☐	☐	☐	☐
Fastening/Unfastening the belt	☐	☐	☐	☐	☐	☐
Setting the belt height	☐	☐	☐	☐	☐	☐

The vehicle seat

18. Do you have any other comments regarding the vehicle seat?

Accessing your vehicle

19. Please indicate how comfortable you are with **getting in** and **out** of your **main** vehicle?

	Very uncomfortable	Uncomfortable	Ok	Comfortable	Very comfortable
Opening the driver's door					
From the outside	☐	☐	☐	☐	☐
From the inside	☐	☐	☐	☐	☐
Ingress/egress					
Getting into your vehicle	☐	☐	☐	☐	☐
Getting out of your vehicle	☐	☐	☐	☐	☐

20. Have you ever fallen/tripped as you were **getting in** or **out** of your vehicle?
Yes, when getting in ☐ Yes, when getting out ☐ Never ☐

20. a) If **'Yes'**, please describe how this fall/trip occurred?

____

21. Please indicate how you find **accessing** the following features of the **main** vehicle that you drive? If this car does not have the feature please tick N/A.

	N/A	Very difficult	Difficult	Ok	Easy	Very easy
The boot The control to open the boot	☐	☐	☐	☐	☐	☐
Reaching and pulling the boot door down to close	☐	☐	☐	☐	☐	☐
Car bonnet						
The release button in-vehicle	☐	☐	☐	☐	☐	☐
The release button on the bonnet	☐	☐	☐	☐	☐	☐
Lifting the bonnet	☐	☐	☐	☐	☐	☐
Opening the fuel cap	☐	☐	☐	☐	☐	☐

Accessing your vehicle

22. Do you have any other comments about accessing your vehicle?

Driving performance

23. Please indicate how you find **carrying out** the following **driving** tasks with the **main** vehicle that you drive?

	Very difficult	**Difficult**	**Ok**	**Easy**	**Very easy**
Parking					
Parallel parking between two cars at the side of a road	☐	☐	☐	☐	☐
Parking in a marked space in a car park	☐	☐	☐	☐	☐
Time of day					
Driving in day light	☐	☐	☐	☐	☐
Driving in the dark	☐	☐	☐	☐	☐
Reversing the vehicle	☐	☐	☐	☐	☐
Weather conditions					
Driving on a sunny day	☐	☐	☐	☐	☐
Driving in the rain	☐	☐	☐	☐	☐
Driving on a foggy day	☐	☐	☐	☐	☐
Making a right turn onto a main road	☐	☐	☐	☐	☐
Keeping a constant speed	☐	☐	☐	☐	☐
Keeping a safe distance from the car in front	☐	☐	☐	☐	☐
Driving in busy traffic	☐	☐	☐	☐	☐
Changing into another lane when driving on a dual carriageway	☐	☐	☐	☐	☐

Driving performance

24. Do you have any other comments regarding your driving performance?

Driving behaviours

25. To what extent do you agree with the following statements in relation to your **driving** experience? Please respond freely and honestly.

	Strongly disagree	**Disagree**	**Neither agree or disagree**	**Agree**	**Strongly agree**
I feel more safe driving below the speed limit.	☐	☐	☐	☐	☐
I sometimes have trouble judging the distance from the vehicle in front.	☐	☐	☐	☐	☐
I sometimes cannot judge my speed.	☐	☐	☐	☐	☐
I have difficulty judging the speed of oncoming vehicles.	☐	☐	☐	☐	☐
I sometimes push the wrong pedal.	☐	☐	☐	☐	☐
I sometimes cannot hear the horns of other vehicles/sirens from emergency vehicles.	☐	☐	☐	☐	☐
My reactions are slower than they used to be (e.g. braking in an emergency situation).	☐	☐	☐	☐	☐
I have difficulty turning my head and body around when reversing.	☐	☐	☐	☐	☐
Other drivers' lights restrict my vision when driving at night.	☐	☐	☐	☐	☐
My speedometer is hard to read during the day time.	☐	☐	☐	☐	☐
My speedometer is hard to read driving at night time.	☐	☐	☐	☐	☐
I sometimes have difficulty with identifying and reading road signs.	☐	☐	☐	☐	☐
Operating entertainment systems distract me from driving (e.g. playing radio).	☐	☐	☐	☐	☐
Operating navigation systems distract me from driving (e.g. looking at sat-navigation).	☐	☐	☐	☐	☐
I worry about having an accident.	☐	☐	☐	☐	☐

Driving behaviours

26. Do you have any other comments about your driving behaviour?

27. Do you have any additional comments regarding your driving experience?

Thank you for your time.

Appendix 2: In-depth audit (Participant information sheet)

Loughborough University

Better vehicle design for all
Participant Information Sheet

Researcher: Sukru Karali	s.karali@lboro.ac.uk	01509228161
Supervisors: Dr Diane Gyi	d.e.gyi@lboro.ac.uk	01509223043
Prof Neil Mansfield	n.j.mansfield@lboro.ac.uk	01509228483

What is the purpose of the study?

The aim of the project is to determine the requirements for older users. The research team is now conducting the second study of this project. The objective is to understand how design of the vehicle cab area impacts on posture, comfort, health and wellbeing particularly in older drivers. The results will enable the research team to explore design solutions to specific age-related challenges in order to make design recommendations for the automotive industry.

Who is doing this research and why?

The research will be carried out by me, Sukru Karali; I am a PhD student in Loughborough Design School at Loughborough University.

Are there any exclusion criteria?

Yes, in order to participate you'll need to be 50 years and over.

Once I take part, can I change my mind?

Yes! After you have read this information and asked any questions you may have, I will ask you to sign an Informed Consent Form. If you wish to withdraw from the study at any time, all you have to do is say so. You can withdraw at any time, for any reason and you will not be asked to explain your reasons for withdrawing.

Will I be required to attend any sessions and where will these be?

If you live outside Loughborough, we will visit you to complete the sessions, if you live in Loughborough then it is more suitable for you to complete the sessions by visiting our University.

How long will it take?

The session will last between 1.5 to 2 hours.

Is there anything I need to do before the sessions?

No, there is nothing you need to do before these sessions.

Is there anything I need to bring with me?
You can bring eyewear (glasses) if you need one.

What will I be asked to do?
I will ask about your decisions when setting your vehicle to adopt a driving position. Some measurements will also be taken from you while you are seated in the vehicle. Then I will ask you some questions about the seat controls focusing on their usability. All these procedures will be carried out using two vehicles (your own vehicle and a test vehicle). Then I will ask you to participate in lab session, this involves taking body measurements such as height and sitting height and mini trials such as visual contrast sensitivity test, arm reach test etc.

What personal information will be required from me?
Your name will be required purely for the contact sheet, in the write up of this data you will be kept in anonymous.

Are there any risks in participating?
There is no driving involved; therefore there are no risks in participating in this study.

Will my taking part in this study be kept confidential?
Information provided will be held by Loughborough University and will be stored against a reference number to ensure anonymity. Information will only be used for this research and will conform to the requirements of the Data Protection Act 1998. We will not share individual responses with third parties, and summary information will not be produced in any way that could reveal your identity.

What will happen to the results of the study?
The results of this study will be used for my PhD thesis and also for publication.

I have some more questions who should I contact?
Please feel free to contact me, or my supervisors.

What if I am not happy with how the research was conducted?
If you are not happy with how the research was conducted, please contact the Mrs Zoe Stockdale, the Secretary for the University's Ethics Approvals (Human Participants) Sub-Committee:

Mrs Z Stockdale, Research Office, Rutland Building, Loughborough University, Epinal Way, Loughborough, LE11 3TU. Tel: 01509 222423. Email: Z.C.Stockdale@lboro.ac.uk

The University also has a policy relating to Research Misconduct and Whistle Blowing which is available online at: http://www.lboro.ac.uk/admin/committees/ethical/Whistleblowing(2).htm. Please ensure that this link is included on the Participant Information Sheet.

Appendix 3: In-depth audit (Consent form)

Loughborough University

Better vehicle design for all

INFORMED CONSENT FORM

The purpose and details of this study have been explained to me. I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethics Approvals (Human Participants) Sub-Committee.

I have read and understood the information sheet and this consent form.

I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that all the information I provide will be treated in strict confidence and will be kept anonymous and confidential to the researchers unless (under the statutory obligations of the agencies which the researchers are working with), it is judged that confidentiality will have to be breached for the safety of the participant or others.

I agree to participate in this study.

Your name…………………………………..

Your signature………………………………

Signature of investigator……………………

Date…………………………………………

Appendix 4: In-depth audit (Data collection sheets)

- Demographic information

Year of birth:
Gender: Male ☐ Female ☐
Occupation:
Vehicle make/model:
Year:
Annual mileage:

- Self-rated confidence

Please indicate your level of confidence when **carrying out** the following **driving** tasks with the vehicle that you drive:

Driving condition	Not at all confident										Completely confident
	0	1	2	3	4	5	6	7	8	9	10
Parallel parking into a space between two cars											
Driving at night											
Driving on long trips											
Driving in bad weather											
Making a right turn onto a main road											
Driving in busy traffic											
Changing into another lane when driving on a dual carriageway											
Reacting quickly											
Pulling into traffic from a junction											
Driving on a motorway											

- Vehicle set-up process (familiar/unfamiliar car)

The video camera will be mounted in both vehicles, starting with the familiar vehicle. Both familiar and unfamiliar vehicles will be set to rear most and reclined position (approximately 110-150 degrees).

'Please get into your vehicle and set your driving position as if you were going to start driving...'

The set-up process will be recorded and shown to the participants and they will be asked questions based on their decisions during the set-up process:

- Own car set-up from standardised position
- Unfamiliar (Qashqai) car set-up from standardised position

'I will show you the video of you setting-up your seat. Please describe what you are doing as you are watching the video. I will also stop or re-play the video if you wish, or if I have a particular question.'

Once they have set up their vehicle, video will be shown to them and they will describe their decisions and choices (with prompts as necessary).

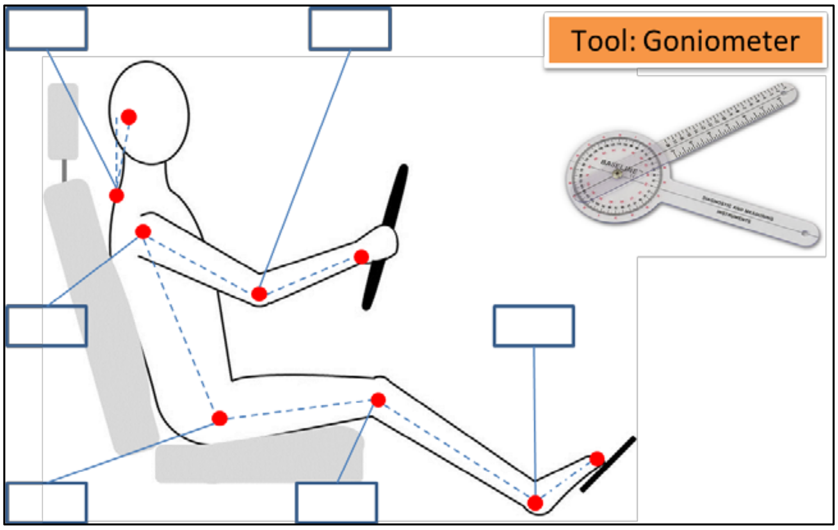
Tool: GoPro Hero 3 Silver version (wide angle camera)

- Posture analysis

Photographs will be taken after they have adopted their preferred posture. Their posture will also be measured using the anatomical landmarks and goniometers.

‘Before we move on to the next part, I would like to take some photographs and put markers on your body to measure your driving position.’

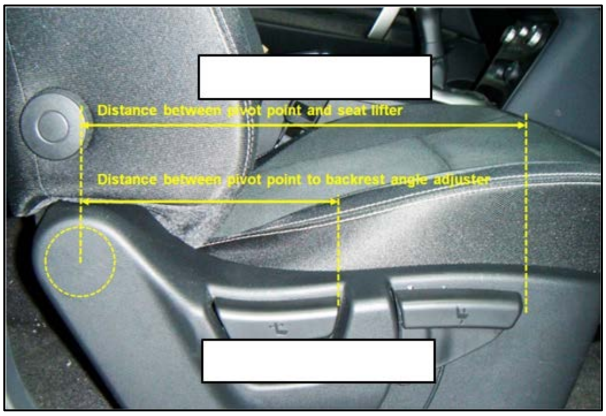
Postural measurements will be logged into the diagram below for the: trunk-thigh angle, arm flexion, elbow angle, knee angle, ankle angle and neck inclination.



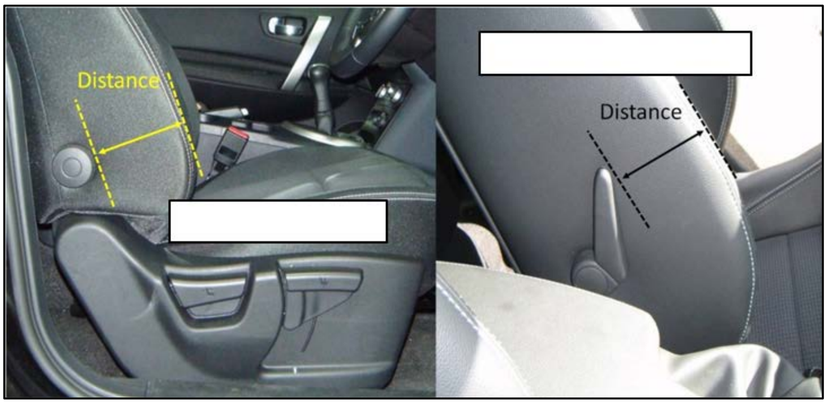
- Vehicle measurements (location and spacing of seat controls)

'I would like to take some measurements from your vehicle; these will be based on the location and spacing of the seat controls'.

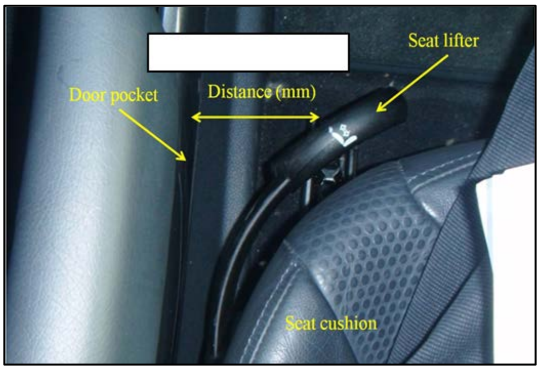
- Measurement points for the seat lifter and seat recliner:



- Measurement points for the lumbar support adjustments:



- Measurement points for seat lifter and seat recliner (measuring their spacing):

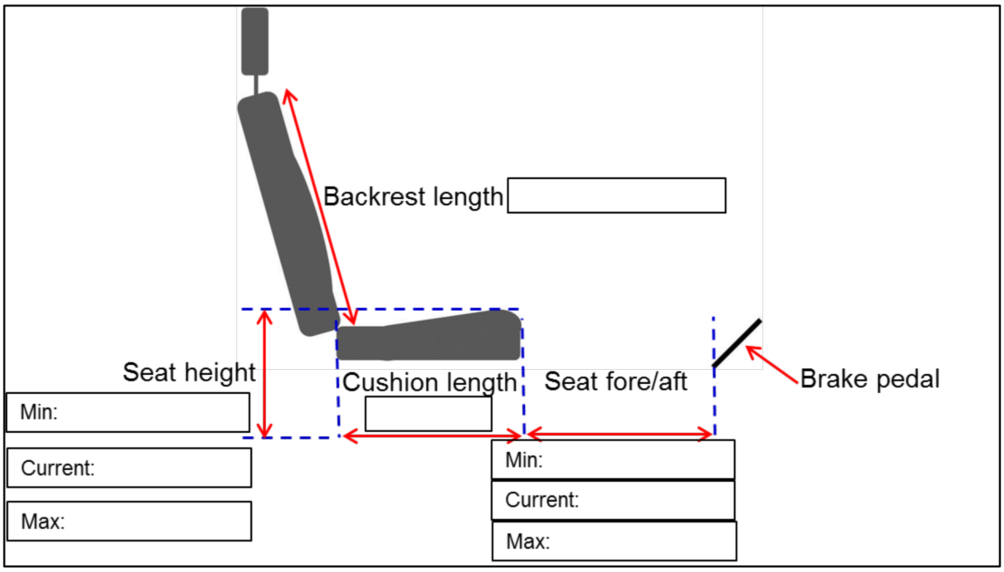


- Vehicle measurements (seat positions)

'I would like to take some measurements from your vehicle; these will be based on the position of your seat.' Measurements include:

- Seat position set by participants (seat height and fore/aft)
- Seat fore/aft (minimum and maximum distance)
- Seat height (minimum and maximum height)
- Seat size (backrest length, cushion length)

Measurements will be logged in to the diagram below:



- Ergonomics audit: evaluation of the seat controls

An ergonomics audit will be conducted with participants focusing on usability of the seat controls. Prompts include:

- Reach: e.g. distance, location and visibility.
- Hand/arm access: e.g. obstruction, natural hand/arm movements.
- Operability: e.g. grip, stiffness, direction of operation, comfort.

Both vehicles	What do you think of the reach distance of the following controls of the seat? (Reach)			How accessible are the following controls of the seat in terms of hand/arm access? (Hand/arm access)		How easy is it to operate the following controls of the seat? (Operability)	
Seat controls	**Difficult (%)**	**OK (%)**	**Easy (%)**	**Easy (%)**	**Difficult (%)**	**Easy (%)**	**Difficult (%)**
Seat lifter							
Seat recliner							
Lumbar support adjustment							
Seat fore/aft adjustment							
Head rest height adjustment							

- Emotional design (evaluation of the seat controls)

Thinking about pleasure and enjoyment, please give a rating for each control; considering its texture, shape and response. Prompts include:

- Texture: temperature, touch feel, smoothness.
- Shape: sharpness, comfort, thickness, fit.
- Response: Direction of motion, stiffness, tactile, effectiveness.

Seat controls	Category	Unpleasant (%)	Neutral (%)	Pleasant (%)
Seat recliner	*Texture*			
	Shape			
	Response			
Seat lifter	*Texture*			
	Shape			
	Response			
Lumbar support adjustment	*Texture*			
	Shape			
	Response			
Seat fore/aft adjustment	*Texture*			
	Shape			
	Response			
Head rest height adjustment	*Texture*			
	Shape			
	Response			

- Visual contrast sensitivity test (Hamilton Veale)

"Please occlude your right eye, read letters across left to right and down the lines….Now occlude your left eye and read letters across left to right and down the lines….Please repeat this with two eyes open."

Visual contrast sensitivity test		
Left eye	Level score	
Right eye	Level score	
Both eyes	Level score	

- Arm reach test (shoulder flexibility)

"Please raise your right arm as high as you can over your head. You may put your arm down… Now please raise your left arm high as you can over your head."

Arm reach test			
Pass		Fail	

- Clock reading test (upper body flexibility)

'Just as you would turn your head and upper body to look behind you to back your car or change lanes, please turn and read the time on the clock face I am holding behind you.'

Clock reading test			
Pass		Fail	

- 9-hole peg test (hand co-ordination and dexterity)

"This will be a practice test. Pick up the pegs one at a time using the hand to be tested only. Place them in the holes until all nine holes are filled. Then remove all of them one at a time. The pegs can be placed in the holes in any order. This is a practice test. Are you ready? Begin!"

"This will be actual test. Pick up the pegs one at a time using the hand to be tested only. Place them in the holes until all nine holes are filled. Then remove all of them one at a time. The pegs can be placed in the holes in any order. Ready? Begin!"

9-hole peg test	
Time taken (sec)- Dominant hand	
Time taken (sec)- Non-dominant hand	

- Anthropometric data

"I would like to take some measurements from you. These are your stature and sitting height."

Anthropometric measurements (mm)	
Stature	
Sitting height	
Sitting hip width	
Buttock knee length	
Knee height	
Popliteal lentgh	

Appendix 5: In-depth audit (Anthropometric measurements)

Participant anthropometric measurements (1 of 2).

Age	Gender	Stature (mm)	Sitting height (mm)	Sitting hip width (mm)
50-64	Male	1871	954	354
50-64	Male	1674	882	386
50-64	Male	1651	860	315
50-64	Male	1770	1009	345
50-64	Male	1730	881	367
50-64	Female	1640	839	423
50-64	Female	1680	877	412
50-64	Female	1590	801	370
50-64	Female	1575	844	432
50-64	Female	1725	906	420
50-64	Female	1721	915	353
50-64	Female	1656	860	398
65-79	Female	1532	805	317
65-79	Female	1535	799	408
65-79	Female	1680	804	377
65-79	Female	1556	813	407
65-79	Female	1560	770	354
65-79	Female	1550	762	430
65-79	Male	1760	881	423
65-79	Male	1925	891	353
65-79	Male	1700	885	419
65-79	Male	1830	947	396
65-79	Male	1750	822	417
65-79	Male	1820	896	383
65-79	Male	1684	832	362
65-79	Male	1760	893	396
65-79	Male	1880	912	380
65-79	Male	1821	910	459
65-79	Male	1726	853	327
65-79	Male	1700	866	385
65-79	Male	1710	857	371
65-79	Male	1720	859	330
Over 80s	Male	1680	831	348
Over 80s	Male	1780	912	422
Over 80s	Male	1736	874	371
Over 80s	Male	1740	858	395
Over 80s	Male	1660	801	345
Over 80s	Male	1800	861	409
Over 80s	Male	1845	914	423
Over 80s	Male	1710	863	381
Over 80s	Male	1730	907	367
Over 80s	Male	1750	866	370
Over 80s	Female	1492	725	328
Over 80s	Female	1600	781	442
Over 80s	Female	1540	797	466
Over 80s	Female	1500	740	325
Over 80s	Female	1544	382	368

Participant anthropometric measurements (2 of 2).

Age	Gender	Buttock knee length (mm)	Knee height (mm)	Popliteal length (mm)
50-64	Male	660	566	456
50-64	Male	577	516	417
50-64	Male	520	488	412
50-64	Male	510	533	440
50-64	Male	537	520	431
50-64	Female	496	502	410
50-64	Female	532	516	428
50-64	Female	470	492	381
50-64	Female	563	518	416
50-64	Female	527	529	426
50-64	Female	499	514	430
50-64	Female	569	499	450
65-79	Female	548	468	405
65-79	Female	548	484	391
65-79	Female	543	525	414
65-79	Female	560	478	386
65-79	Female	535	477	416
65-79	Female	541	508	401
65-79	Male	519	538	417
65-79	Male	623	612	481
65-79	Male	511	530	410
65-79	Male	618	593	467
65-79	Male	520	519	418
65-79	Male	656	582	470
65-79	Male	567	525	417
65-79	Male	637	514	422
65-79	Male	647	585	466
65-79	Male	706	583	462
65-79	Male	607	536	435
65-79	Male	617	536	427
65-79	Male	523	568	453
65-79	Male	569	515	409
Over 80s	Male	556	489	410
Over 80s	Male	522	560	426
Over 80s	Male	530	528	434
Over 80s	Male	528	540	436
Over 80s	Male	550	482	402
Over 80s	Male	661	576	455
Over 80s	Male	543	604	470
Over 80s	Male	566	540	437
Over 80s	Male	594	507	421
Over 80s	Male	623	544	435
Over 80s	Female	551	480	383
Over 80s	Female	558	519	424
Over 80s	Female	545	476	384
Over 80s	Female	482	462	399
Over 80s	Female	563	499	410

Appendix 6: In-depth audit: vehicle measurements (seat positions)

Measurements of seat positions (participants own vehicle 1 of 2).

Age	Gender	Vehicle model	Seat height (minimum)	Seat height (adopted)	Seat height (maximum)	Fore/aft (minimum)
50-64	Male	Ford Fiesta	23.2	24.4	27	33
50-64	Male	Renault Megane	20.7	25.6	25.6	N/A
50-64	Male	Toyota Avensis	25	27.4	26.5	29
50-64	Male	Toyota Verso	24.5	25.9	29.5	26
50-64	Male	Mercedes C350	13.5	13.5	17.6	34
50-64	Female	Vauxhall Astra	16.4	17	17.4	34
50-64	Female	Toyota Avensis	25	25.5	26.5	29
50-64	Female	Honda Jazz	22.5	25.3	26	30
50-64	Female	Citroen Picasso	26.5	31	34	23
50-64	Female	Mazda 6 T52	19	22.7	24	28
50-64	Female	VW Golf	19	19.5	28.2	27
50-64	Female	Toyota Verso	24.5	24.5	29.5	26
65-79	Female	Peugeot 207 GT	28.5	29.5	34	31
65-79	Female	VW Golf	22	25	25	26
65-79	Female	Peugeot 107	24.5	24.5	24.5	27
65-79	Female	Mazda 5	30	35	35	40
65-79	Female	BMW 328	13	17	23	31
65-79	Female	Honda CRV	26	26.4	30.5	28
65-79	Male	Honda Jazz	26	28	30	26
65-79	Male	Volvo V70	13.4	14.5	18.8	31
65-79	Male	Nissan Qashqai	22	23.8	30	30
65-79	Male	Jaguar XJ8	17.2	18.2	21.5	30
65-79	Male	Citroen C4	22.8	26.5	27	24.5
65-79	Male	BMW 328	13	18	23	31
65-79	Male	Rover 400	22	23	27	33
65-79	Male	VW Passat	12	13.5	16	33
65-79	Male	Audi A6	16.7	19.5	19.5	30
65-79	Male	Mazda 5	30	33	35	40
65-79	Male	Renault Scenic	N/A	37	N/A	18.5
65-79	Male	Vauxhall Corsa	N/A	21	N/A	31
65-79	Male	Rover 75 Tourer	22.8	26.6	26.6	30
65-79	Male	Peugeot 207	19	20.5	29.5	29
Over 80s	Male	Vauxhall	28	28	34.5	25
Over 80s	Male	VW Passat	17.2	19	22	35
Over 80s	Male	Toyota Avensis	18	21.5	23.5	30
Over 80s	Male	Mini Cooper	17	20.4	22	33
Over 80s	Male	Jaguar X type Diesel	13.4	26.8	32.7	34
Over 80s	Male	Ford Docus	21.6	24.7	26	29
Over 80s	Male	Skoda Octavie	20.2	23.4	26.5	27
Over 80s	Male	Citroen C3	25	25.8	32	27
Over 80s	Male	BMW 318Ci	13.2	14	16	36
Over 80s	Male	Peugeot 107	23	23	23	29
Over 80s	Female	Toyota Corolla	22.3	24.3	27	34
Over 80s	Female	Ford KA	N/A	28.2	N/A	30.5
Over 80s	Female	Mini Cooper	17	22.5	22	33
Over 80s	Female	Mercedes W168	19.5	25	25	33
Over 80s	Female	Fiat Punto	20.5	25.3	25.3	30

Measurements of seat positions (participants own vehicle 2 of 2).

Age	Gender	Vehicle model	Fore/aft (adopted)	Fore/aft (maximum)	Cushion length	Backrest length
50-64	Male	Ford Fiesta	50.5	52	48	59
50-64	Male	Renault Megane	38	N/A	52.5	55.5
50-64	Male	Toyota Avensis	34.5	53	46	60
50-64	Male	Toyota Verso	42.5	50	51	61
50-64	Male	Mercedes C350	48	60	53	59
50-64	Female	Vauxhall Astra	40	52	52	62
50-64	Female	Toyota Avensis	38.5	53	46	60
50-64	Female	Honda Jazz	37	52	52	60
50-64	Female	Citroen Picasso	38	45	48	55
50-64	Female	Mazda 6 T52	48	53	51	59
50-64	Female	VW Golf	40.5	46	51	64
50-64	Female	Toyota Verso	37	50	51	61
65-79	Female	Peugeot 207 GT	38	53	48.5	49
65-79	Female	VW Golf	32	48	51	64
65-79	Female	Peugeot 107	48	52	49	57
65-79	Female	Mazda 5	41	51	50	60
65-79	Female	BMW 328	34	55	57	63
65-79	Female	Honda CRV	43	46	45	59
65-79	Male	Honda Jazz	39	50	51.5	60.5
65-79	Male	Volvo V70	53	53.5	52.5	62
65-79	Male	Nissan Qashqai	40	52	54	60
65-79	Male	Jaguar XJ8	42	56	51	69
65-79	Male	Citroen C4	44	44	46	51
65-79	Male	BMW 328	50	55	57	63
65-79	Male	Rover 400	40	54	50.5	60
65-79	Male	VW Passat	54	55	52	61
65-79	Male	Audi A6	50	50	51	60
65-79	Male	Mazda 5	50	51	50	60
65-79	Male	Renault Scenic	38.5	40	51.5	55
65-79	Male	Vauxhall Corsa	44	49	51	63
65-79	Male	Rover 75 Tourer	42	50	51	61
65-79	Male	Peugeot 207	45	50	51	58
Over 80s	Male	Vauxhall	35.5	41	50	66
Over 80s	Male	VW Passat	49.5	49.5	52	60
Over 80s	Male	Toyota Avensis	43	54	54	64
Over 80s	Male	Mini Cooper	50	52	51	66
Over 80s	Male	Jaguar X type Diesel	39.5	50.5	50	65
Over 80s	Male	Ford Docus	45	52	51	65
Over 80s	Male	Skoda Octavie	42	50	52	62
Over 80s	Male	Citroen C3	42	48	53	62
Over 80s	Male	BMW 318Ci	43.5	58	50	60
Over 80s	Male	Peugeot 107	45	53	48	56.5
Over 80s	Female	Toyota Corolla	36	50	50	60
Over 80s	Female	Ford KA	35	49	50	63
Over 80s	Female	Mini Cooper	40	52	51	66
Over 80s	Female	Mercedes W168	37	60	49	60
Over 80s	Female	Fiat Punto	36	51	54	65

Measurements of seat positions (test vehicle 1 of 2).

Age	Gender	Vehicle model	Seat height (minimum)	Seat height (adopted)	Seat height (maximum)	Fore/aft (minimum)
50-64	Male	Nissan Qashqai	22	23	32	27
50-64	Male	Nissan Qashqai	22	28.1	32	27
50-64	Male	Nissan Qashqai	22	32	32	27
50-64	Male	Nissan Qashqai	22	23.2	32	27
50-64	Male	Nissan Qashqai	22	20.8	32	27
50-64	Female	Nissan Qashqai	22	27.3	32	27
50-64	Female	Nissan Qashqai	22	28	32	27
50-64	Female	Nissan Qashqai	22	26.1	32	27
50-64	Female	Nissan Qashqai	22	22	32	27
50-64	Female	Nissan Qashqai	22	24.5	32	27
50-64	Female	Nissan Qashqai	22	24	32	27
50-64	Female	Nissan Qashqai	22	24	32	27
65-79	Female	Nissan Qashqai	22	N/A	32	27
65-79	Female	Nissan Qashqai	22	30	32	27
65-79	Female	Nissan Qashqai	22	27.5	32	27
65-79	Female	Nissan Qashqai	22	26.4	32	27
65-79	Female	Nissan Qashqai	22	30.8	32	27
65-79	Female	Nissan Qashqai	22	31.2	32	27
65-79	Male	Nissan Qashqai	22	27.5	32	27
65-79	Male	Nissan Qashqai	22	24	32	27
65-79	Male	Nissan Qashqai	22	24	32	27
65-79	Male	Nissan Qashqai	22	26	32	27
65-79	Male	Nissan Qashqai	22	27	32	27
65-79	Male	Nissan Qashqai	22	25.7	32	27
65-79	Male	Nissan Qashqai	22	31	32	27
65-79	Male	Nissan Qashqai	22	26	32	27
65-79	Male	Nissan Qashqai	22	27.3	32	27
65-79	Male	Nissan Qashqai	22	27.3	32	27
65-79	Male	Nissan Qashqai	22	29.5	32	27
65-79	Male	Nissan Qashqai	22	25	32	27
65-79	Male	Nissan Qashqai	22	28.5	32	27
65-79	Male	Nissan Qashqai	22	N/A	32	27
Over 80s	Male	Nissan Qashqai	22	N/A	32	27
Over 80s	Male	Nissan Qashqai	22	21.7	32	27
Over 80s	Male	Nissan Qashqai	22	26	32	27
Over 80s	Male	Nissan Qashqai	22	26.5	32	27
Over 80s	Male	Nissan Qashqai	22	26.5	32	27
Over 80s	Male	Nissan Qashqai	22	22	32	27
Over 80s	Male	Nissan Qashqai	22	N/A	32	27
Over 80s	Male	Nissan Qashqai	22	22.2	32	27
Over 80s	Male	Nissan Qashqai	22	20	32	27
Over 80s	Male	Nissan Qashqai	22	21.6	32	27
Over 80s	Female	Nissan Qashqai	22	29.2	32	27
Over 80s	Female	Nissan Qashqai	22	26.6	32	27
Over 80s	Female	Nissan Qashqai	22	23.8	32	27
Over 80s	Female	Nissan Qashqai	22	32	32	27
Over 80s	Female	Nissan Qashqai	22	28	32	27

Measurements of seat positions (test vehicle 2 of 2).

Age	Gender	Vehicle model	Fore/aft (adopted)	Fore/aft (maximum)	Cushion length	Backrest length
50-64	Male	Nissan Qashqai	46	52	54	60
50-64	Male	Nissan Qashqai	42.2	52	54	60
50-64	Male	Nissan Qashqai	34	52	54	60
50-64	Male	Nissan Qashqai	41.5	52	54	60
50-64	Male	Nissan Qashqai	42	52	54	60
50-64	Female	Nissan Qashqai	40	52	54	60
50-64	Female	Nissan Qashqai	39	52	54	60
50-64	Female	Nissan Qashqai	36	52	54	60
50-64	Female	Nissan Qashqai	38	52	54	60
50-64	Female	Nissan Qashqai	44	52	54	60
50-64	Female	Nissan Qashqai	39	52	54	60
50-64	Female	Nissan Qashqai	37	52	54	60
65-79	Female	Nissan Qashqai	N/A	52	54	60
65-79	Female	Nissan Qashqai	37	52	54	60
65-79	Female	Nissan Qashqai	49	52	54	60
65-79	Female	Nissan Qashqai	38	52	54	60
65-79	Female	Nissan Qashqai	32.6	52	54	60
65-79	Female	Nissan Qashqai	39	52	54	60
65-79	Male	Nissan Qashqai	44	52	54	60
65-79	Male	Nissan Qashqai	40	52	54	60
65-79	Male	Nissan Qashqai	42	52	54	60
65-79	Male	Nissan Qashqai	52	52	54	60
65-79	Male	Nissan Qashqai	45	52	54	60
65-79	Male	Nissan Qashqai	46	52	54	60
65-79	Male	Nissan Qashqai	33	52	54	60
65-79	Male	Nissan Qashqai	52	52	54	60
65-79	Male	Nissan Qashqai	47	52	54	60
65-79	Male	Nissan Qashqai	52	52	54	60
65-79	Male	Nissan Qashqai	40.5	52	54	60
65-79	Male	Nissan Qashqai	44	52	54	60
65-79	Male	Nissan Qashqai	42	52	54	60
65-79	Male	Nissan Qashqai	N/A	52	54	60
Over 80s	Male	Nissan Qashqai	N/A	52	54	60
Over 80s	Male	Nissan Qashqai	52	52	54	60
Over 80s	Male	Nissan Qashqai	44	52	54	60
Over 80s	Male	Nissan Qashqai	46	52	54	60
Over 80s	Male	Nissan Qashqai	41	52	54	60
Over 80s	Male	Nissan Qashqai	43	52	54	60
Over 80s	Male	Nissan Qashqai	N/A	52	54	60
Over 80s	Male	Nissan Qashqai	48	52	54	60
Over 80s	Male	Nissan Qashqai	42	52	54	60
Over 80s	Male	Nissan Qashqai	45	52	54	60
Over 80s	Female	Nissan Qashqai	37	52	54	60
Over 80s	Female	Nissan Qashqai	35	52	54	60
Over 80s	Female	Nissan Qashqai	33	52	54	60
Over 80s	Female	Nissan Qashqai	27	52	54	60
Over 80s	Female	Nissan Qashqai	42	52	54	60

Appendix 7: In-depth audit: vehicle measurements (location and spacing of seat controls)

Location and spacing of seat controls (participants own vehicle 1 of 2).

Age	Gender	Vehicle model	Distance from backrest pivot point to seat lifter	Distance from backrest pivot point to seat recliner	Space between door pocket and seat lifter
50-64	Male	Ford Fiesta	48	On pivot point	6
50-64	Male	Renault Megane	25	On pivot point	3.9
50-64	Male	Toyota Avensis	29	16	4.7
50-64	Male	Toyota Verso	41	22	5.5
50-64	Male	Mercedes C350	34	31	5
50-64	Female	Vauxhall Astra	47	On pivot point	4
50-64	Female	Toyota Avensis	29	16	4.7
50-64	Female	Honda Jazz	40	20.5	4.8
50-64	Female	Citroen Picasso	52	10.5	13
50-64	Female	Mazda 6 T52	25	18	5.5
50-64	Female	VW Golf	34	On pivot point	7
50-64	Female	Toyota Verso	41	22	5.5
65-79	Female	Peugeot 207 GT	31	On pivot point	4
65-79	Female	VW Golf	34	On pivot point	4.2
65-79	Female	Peugeot 107	N/A	On pivot point	N/A
65-79	Female	Mazda 5	41	On pivot point	10
65-79	Female	BMW 328	35	29	5.5
65-79	Female	Honda CRV	32	21.5	5
65-79	Male	Honda Jazz	44	20	4.5
65-79	Male	Volvo V70	38	32	3
65-79	Male	Nissan Qashqai	38.5	22	3.8
65-79	Male	Jaguar XJ8	N/A	N/A	N/A
65-79	Male	Citroen C4	30	On pivot point	5
65-79	Male	BMW 328	35	29	5.5
65-79	Male	Rover 400	36	25	3.8
65-79	Male	VW Passat	44	37	7
65-79	Male	Audi A6	48	On pivot point	7.5
65-79	Male	Mazda 5	41	On pivot point	10
65-79	Male	Renault Scenic	N/A	N/A	N/A
65-79	Male	Vauxhall Corsa	57	On pivot point	6
65-79	Male	Rover 75 Tourer	41	27.5	6.5
65-79	Male	Peugeot 207	50	On pivot point	7
Over 80s	Male	Vauxhall	36	On pivot point	4
Over 80s	Male	VW Passat	36	On pivot point	4
Over 80s	Male	Toyota Avensis	39	21	6
Over 80s	Male	Mini Cooper	54	On pivot point	6
Over 80s	Male	Jaguar X type Diesel	26	On pivot point	5
Over 80s	Male	Ford Docus	40	On pivot point	4.3
Over 80s	Male	Skoda Octavie	34.5	On pivot point	3.7
Over 80s	Male	Citroen C3	28	On pivot point	4.8
Over 80s	Male	BMW 318Ci	36	30	4.5
Over 80s	Male	Peugeot 107	N/A	On pivot point	N/A
Over 80s	Female	Toyota Corolla	30	17	4.5
Over 80s	Female	Ford KA	N/A	On pivot point	N/A
Over 80s	Female	Mini Cooper	54	On pivot point	6
Over 80s	Female	Mercedes W168	29	On pivot point	4.5
Over 80s	Female	Fiat Punto	40	On pivot point	3

Location and spacing of seat controls (participants own vehicle 2 of 2).

Age	Gender	Vehicle model	Space between door pocket and seat recliner	Distance from seat bolster to lumbar support adjustment
50-64	Male	Ford Fiesta	14.5	N/A
50-64	Male	Renault Megane	11.5	11
50-64	Male	Toyota Avensis	5	N/A
50-64	Male	Toyota Verso	5.5	N/A
50-64	Male	Mercedes C350	5	7
50-64	Female	Vauxhall Astra	6	10.5
50-64	Female	Toyota Avensis	5	N/A
50-64	Female	Honda Jazz	4.5	N/A
50-64	Female	Citroen Picasso	20	N/A
50-64	Female	Mazda 6 T52	6	11
50-64	Female	VW Golf	4.2	N/A
50-64	Female	Toyota Verso	5.5	N/A
65-79	Female	Peugeot 207 GT	11	N/A
65-79	Female	VW Golf	7	N/A
65-79	Female	Peugeot 107	4	N/A
65-79	Female	Mazda 5	5.5	6.5
65-79	Female	BMW 328	5.5	N/A
65-79	Female	Honda CRV	5	N/A
65-79	Male	Honda Jazz	4.5	N/A
65-79	Male	Volvo V70	3	9
65-79	Male	Nissan Qashqai	4.2	12.5
65-79	Male	Jaguar XJ8	N/A	N/A
65-79	Male	Citroen C4	5.4	N/A
65-79	Male	BMW 328	5.5	N/A
65-79	Male	Rover 400	4.5	10
65-79	Male	VW Passat	8	37
65-79	Male	Audi A6	6	N/A
65-79	Male	Mazda 5	5.5	6.5
65-79	Male	Renault Scenic	N/A	N/A
65-79	Male	Vauxhall Corsa	13	N/A
65-79	Male	Rover 75 Tourer	7.5	9
65-79	Male	Peugeot 207	11.5	N/A
Over 80s	Male	Vauxhall	6.5	8
Over 80s	Male	VW Passat	6.5	8
Over 80s	Male	Toyota Avensis	5	8
Over 80s	Male	Mini Cooper	15	11
Over 80s	Male	Jaguar X type Diesel	5	N/A
Over 80s	Male	Ford Docus	7.2	N/A
Over 80s	Male	Skoda Octavie	9	9
Over 80s	Male	Citroen C3	15	N/A
Over 80s	Male	BMW 318Ci	5	N/A
Over 80s	Male	Peugeot 107	13	N/A
Over 80s	Female	Toyota Corolla	5.5	N/A
Over 80s	Female	Ford KA	12	N/A
Over 80s	Female	Mini Cooper	15	11
Over 80s	Female	Mercedes W168	5	N/A
Over 80s	Female	Fiat Punto	13	12

Appendix 8: In-depth audit: seat set-up process (order of the tasks)

Order of the tasks carried out in participants own vehicle (1 of 2).

Own vehicle (Order of the tasks carried out)								
Participant (name)	Control Number							
	1	2	3	4	5	6	7	8
A. C.	50	0	25	75			100	
A. W.	33	85	66	66	58	17	100	25
B. G.	0	17	33	66	50	83	100	
B. D.	66	83	33	66			0	
C. B.	66	0	17	33		50	100	83
C. W.	0	50					100	
C. T.	0	25	50	75		100		
D. S.	33		33	83			100	
D. C.	0	40	20	80		60	100	
H. D.	25	0	75				100	50
H. T.	38		100				25	50
I. C.	25		63	75	88	25	100	
I. F.	33	0	50			50	83	
D. H.	33	67	0		100			
E. W.	30	57	11	44		89	100	
G. C.	0	66	17	50		33	100	83
G. T.	44		22	89	33	67	100	
H. B.	0	50	50	43		57	100	
J. C.	38	63	0	50		56	88	
J. D.	11	89	67		41	33	100	
J. G.	0		50				100	
J. R.	0	17	50		33	83	100	
J. W	20	40	30	100			80	
J. Wh.		33	0	67			100	
J. E.		33	0	67			100	
L. T.	0	36	86	72		29		
M. D.	40	60	20		40		100	
M. M.	25	63	38	25		75	100	
M. C.	0		50				100	
M. D.		21	14	86	57	29	86	
M. Ch.	0	83	33	50	67	17	100	
M. Ma.	0	20	40	60		80	100	
M. H.	60	0	20	80		40	100	
P. M.	25		25	75	100			
P. W.	0		50				100	
R. K.	20	0	40	60		80	100	
R. K.	38	25	38	100		50	88	
S. S.	0	80	20	60	40		100	
S. S.	0	40	20	60		80	100	
S. P.	40		40		40		100	
S. J.	50	70	0	20	30	60	100	
T. L.	40		40	60		20	100	
T. T.	29		14	57	86	21	100	72
Z. H.			0	50			100	

Order of the tasks carried out in the test vehicle (2 of 2).

Test vehicle (Order of the tasks carried out)								
Participant (name)	Control Number							
	1	2	3	4	5	6	7	8
A. C.	0	25	50		75		100	
A. W.	60	20	40	80		0	100	
B. G.	0	33	17	83	66	50	100	
B. D.	33		33	83	66	100	0	
C. B.	50	17	0		100	66	83	33
C. W.		20	40	80	60	0	100	
C. T.	57	57	57	71	0		100	
D. S.	0		17		83	33	50	83
D. C.	21	29	14	71	86	57	100	
H. D.	75	0	50	30	50	40	70	
H. T.	17	66	33	83			100	
I. C.	17	0		67	67	33	100	
I. F.	0	25			75	50	100	
D. H.	35	50	23	90	80	40	100	
E. W.	25		0		75	50	100	
G. C.	42	25	13	38	100	88		63
G. T.	0	14	50	86	43	57	100	
H. B.	47	89	39	71	30	53	100	42
J. C.	43	14	0	72	86	43	100	
J. D.	0	25	50		75		100	
J. G.	20		0	60	80	40	100	
J. R.	0	11	33	89	67	33	89	56
J. W	43	14	50	57		43	100	
J. Wh.		33	0	100		67		
J. E.		33	0	100		67		
L. T.	14	29	57		72	86	100	
M. D.	33	0	17	83	67	50	100	
M. M.	0		20	60	80	40	100	
M. C.	0	43	43		86	43	100	
M. D.		0	25	83	67	33	100	
M. Ch.	0	33	17	83	67	50	100	
M. Ma.	13	25	42	75	50	63	100	
M. H.	60	20	3	80		40	100	
P. M.	33	25	17	83	67		100	
P. W.	17		17	50	67	83	100	
R. K.	0	25	13	88	50	75	100	
R. K.	45	68	26	36		60	100	
S. S.	0	17	33	83	50	67	100	
S. S.	0	40	20	80		60	100	
S. P.	44	33	17	67			100	
S. J.	20	0		60	80	40	100	
T. L.	33	17	0	83	67	50	100	
T. T.		33	0	83	67	33	100	
Z. H.	0	31	63	88	75	25	100	

Appendix 9: Workshop (participant information sheet)

Controlling your car seat
Participant Information Sheet

Researcher: Sukru Karali	s.karali@lboro.ac.uk	01509228161
Supervisors: Dr Diane Gyi	d.e.gyi@lboro.ac.uk	01509223043
Prof Neil Mansfield	n.j.mansfield@lboro.ac.uk	01509228483

What is the purpose of the study?
This study is being conducted to understand older drivers' views of car seat controls. The aim is to specify solutions for good design by focusing on their optimum positioning and operation. This will be conducted in a form of fun and interactive workshop session.

Who is doing this research and why?
The research will be carried out by me, Sukru Karali; I am a PhD student in Loughborough Design School at Loughborough University.

Are there any exclusion criteria?
Yes, in order to participate you'll need to be 65 years and over.

Once I take part, can I change my mind?
Yes! After you have read this information and asked any questions you may have, I will ask you to sign an Informed Consent Form. If you wish to withdraw from the study at any time, all you have to do is say so. You can withdraw at any time, for any reason and you will not be asked to explain your reasons for withdrawing.

Will I be required to attend any sessions and where will these be?
If you live outside Loughborough, we will book a suitable place in your location for you to attend with other volunteers; if you live in Loughborough then you will visit Loughborough University to take part in our workshop.
How long will it take?
The session will last between 60-90 minutes.

Is there anything I need to do before the sessions?
Yes, please complete the pre-questionnaire before you attend the session and bring it along with you. Additionally, please have a look into your car seat controls listed in

the pre-questionnaire to familiarise yourselves with your own controls before you attend the session.

Is there anything I need to bring with me?
You should bring eyewear (glasses) if you need them.

What will I be asked to do?

- This will be a group workshop session with 4-5 participants in each. The session will focus on the optimum positioning and operation of the seat controls.
- You will be involved in discussion and have the opportunity to give your views on the likes/dislikes of your car seat controls.
- Some photographic images of seat controls based on ‘real world’ examples of design will be shown. You will be asked to evaluate these controls and give your opinions on re-designing each.
- Physical models of seat controls will be available; you will use these on a car seat located in our lab to label the optimum position, size, colour preference, shape and materials. Reasons for your choices will be captured.

What personal information will be required from me?
Your name will be required purely for our contact sheet. In the write up of this workshop you will be kept in anonymous.

Are there any risks in participating?
There is no driving involved and the workshop will be held indoors; therefore there are no risks in participating in this study.

Will my taking part in this study be kept confidential?
Information provided will be held by Loughborough University and will be stored against a reference number to ensure anonymity. Information will only be used for this research and will conform to the requirements of the Data Protection Act 1998. We will not share individual responses with third parties, and summary information will not be produced in any way that could reveal your identity.

What will happen to the results of the study?
The results of this study will be used for my PhD thesis and also for publication.

I have some more questions who should I contact?
Please feel free to contact me, or my supervisors.

What if I am not happy with how the research was conducted?
If you are not happy with how the research was conducted, please contact the Mrs Zoe Stockdale, the Secretary for the University’s Ethics Approvals (Human Participants) Sub-Committee:

- Mrs Z Stockdale, Research Office, Rutland Building, Loughborough University, Epinal Way, Loughborough, LE11 3TU. Tel: 01509 222423. Email: Z.C.Stockdale@lboro.ac.uk

- The University also has a policy relating to Research Misconduct and Whistle Blowing which is available online at: http://www.lboro.ac.uk/admin/committees/ethical/Whistleblowing(2).htm.

Appendix 10: Workshop (Consent form)

Loughborough University

Controlling your car seat

Informed consent form

The purpose and details of this study have been explained to me. I understand that this study is designed to further scientific knowledge and that all procedures have been approved by the Loughborough University Ethics Approvals (Human Participants) Sub-Committee.

I have read and understood the information sheet and this consent form.

I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that all the information I provide will be treated in strict confidence and will be kept anonymous and confidential to the researchers unless (under the statutory obligations of the agencies which the researchers are working with), it is judged that confidentiality will have to be breached for the safety of the participant or others.

I agree to participate in this study.

Your name…………………………………..

Your signature………………………………

Signature of investigator……………………

Date…………………………………………

Appendix 11: Workshop (NVivo analysis- word frequency example)

An example data - discussion on the dislikes of car seat controls. Word frequency example on mechanical type of controls resulted from discussions with Group 4.

An example data - suggestions based on the ideal locations of seat controls. Diagram below shows the word frequency resulted from the workshop discussions with Group