Driving ergonomics for an elevated seat position in a light commercial vehicle

By

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ABSTRACT

With more legislation being enforced to achieve a reduction in road transport CO_2 emissions, automotive companies are having to research and develop technologies that deliver 'greener driving'. Whilst emissions from passenger vehicles have dropped over recent years, there has been an increase in emissions from light commercial vehicles (LCVs). The nature of LCV delivery work is a routine of ingress/egress of the vehicle, changing from a standing to a seated posture repetitively throughout the day. One research focus is packaging occupants in to a smaller vehicle space, in order to reduce the amount of vehicle emissions over its lifecycle. For LCVs, benefits from space saving technology could be an increase in overall loading space (with the same vehicle length) or a reduction in the overall length/weight of the vehicle. Furthermore, an elevated seat posture could reduce the strain on drivers during ingress/egress, as it is closer than that of a conventional seat to a standing posture. Whilst space saving technology has obvious benefits, current driving conventions and standards are not inclusive of new and novel seated postures when packaging a driver in to a vehicle.

The fundamental purpose of a vehicle driver's seat is to be comfortable and safe for the occupant and to facilitate driving. It has been shown that a seat needs both good static and dynamic factors to contribute to overall seat comfort. Additionally, comfortable body angles have been identified and ratified by studies investigating comfortable driving postures; however, this knowledge only applies to conventional driving postures. For an 'elevated posture', defined as having the driver's knee point below the hip point, there is little research or guidance.

The overall aim of this thesis is to identify the ergonomic requirements of a wide anthropometric range of drivers in an elevated driving posture for LCVs, which was investigated using a series of laboratory based experiments. An iterative fitting trial was designed to identify key seat parameters for static comfort in an elevated posture seat. The results showed that in comparison with a conventional seat: Seat base length was preferred to be shorter (380mm compared with 460mm); Seat base width was preferred to be wider (560mm compared with 480mm); Backrest height was preferred to be longer (690mm compared with 650mm). These findings provided a basis for a seat design specification for an elevated posture concept seat, which was tested in two subsequent laboratory studies. A long-term discomfort evaluation was conducted, using a driving simulator and a motion platform replicating real road vibration. Discomfort scores were collected at 10-minute intervals (50-minutes overall) using a body map and rating scale combination. The results indicated that in comparison with the conventional posture, the elevated posture performed as well, or better (significantly lower discomfort for right shoulder and lower back; $p<0.05$, two-tailed), in terms of long-term discomfort. Furthermore, the onset of discomfort (i.e. the time taken for localised discomfort ratings to be significantly higher than the baseline ratings reported before the trial) occurred after as little as 10 minutes (conventional posture) and 20 minutes (elevated posture) respectively. A lateral stability evaluation was conducted using low-frequency lateral motion on a motion platform (platform left and right rolls of 14.5°). Stability scores were reported after each sequence of rolls, comparing scores on a newly developed lateral stability scale between three seats: Conventional posture seat; Elevated posture concept seat (EPS1); Elevated posture concept seat with modifications aimed at improving stability (EPS2). Participants reported being more unstable in EPS1, compared with the conventional posture seat ($p<0.05$, Wilcoxon). However, the EPS2 seat performed equally to the conventional posture seat.

These findings suggest that the elevated posture seat developed in this research is a feasible and comfortable alternative to a conventional posture seat. Furthermore, the final elevated seating positions showed that real space saving can be achieved in this posture thus allowing for more compact and lighter vehicles and potentially reducing strain on drivers during ingress/egress.

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CHAPTER 1

GENERAL INTRODUCTION

The amount of CO_2 emitted in to the earth's atmosphere has become a huge concern, which has led to corporate carbon footprint requirements being instated and government legislation being enforced, in an effort to reduce this. It is estimated that 24% of CO_2 emissions in the UK will be contributed by transport (Department of Energy and Climate Change, 2013), with road transport being the most significant contributor. Whilst emissions from passenger vehicles have fallen in the last 20 years, emissions from light commercial vehicles (LCVs) have risen. With legislation and global pressures in place, automotive companies must shift their research and design to meet these quotas to remain competitive.

The primary purpose of a vehicle driver's seat is to allow them to complete the driving task comfortably and safely. Within each class of vehicle (e.g. passenger, commercial, industrial, agricultural), there is an expected driving position to which a vehicle cabin is designed. Whilst it is important that safety is explored fully for a respective seated driving position, driver comfort is integral in designing a seat suited to the driving task. With more and more vehicles on the road each year, inner city driving is becoming more prominent and more congested as a result. Consequently, it is essential that LCVs, vehicles commonly associated with inner city driving, are considered for research. It is important to effectively address every day issues that are associated with these types of vehicles, from ingress/egress and driver comfort, to the environmental impact of having more of these vehicles on the road.

The design of vehicles (e.g. rail vehicles, trams, buses, cars, delivery vehicles, vans) for city use requires a balance between the benefits of being light and compact, and the benefits of having a large load capacity. By making the vehicle light and compact, the fuel economy and manoeuvrability can increase. With loading considerations, if it is possible to reduce the space required to package a driver in to these vehicle types, then the vehicle can benefit in two ways: a more compact driver package can result in an increased overall loading space or can result in an overall reduction in the length of the vehicle itself. Both of these end results are potentially environmentally and economically positive, by reducing the carbon emissions over the lifecycle of the vehicle. In the first instance, with an increased overall loading space, fewer miles will need to be travelled in order to transport the same amount of cargo, resulting in reduced fuel usage and thus reduced carbon emissions. In the second instance, a reduction in the overall length of the vehicle will lead to a significant weight reduction of the vehicle. This, in turn, will lead to a reduction in carbon emissions.

By making the driving posture within a vehicle more upright, the space required to package a driver in to the vehicle cabin can be much less. Most current vehicle designs require the driver to sit in a low seat with a semi-recumbent posture with legs extended towards the front of the vehicle. By increasing the height of the seat from the ground (heel step), the driving posture changes to one where the distance between the pedal set and the driver hip point in X (pedal-hip (PH) gap) can be reduced (Figure 1.1), thus reducing the space required to package the driver.

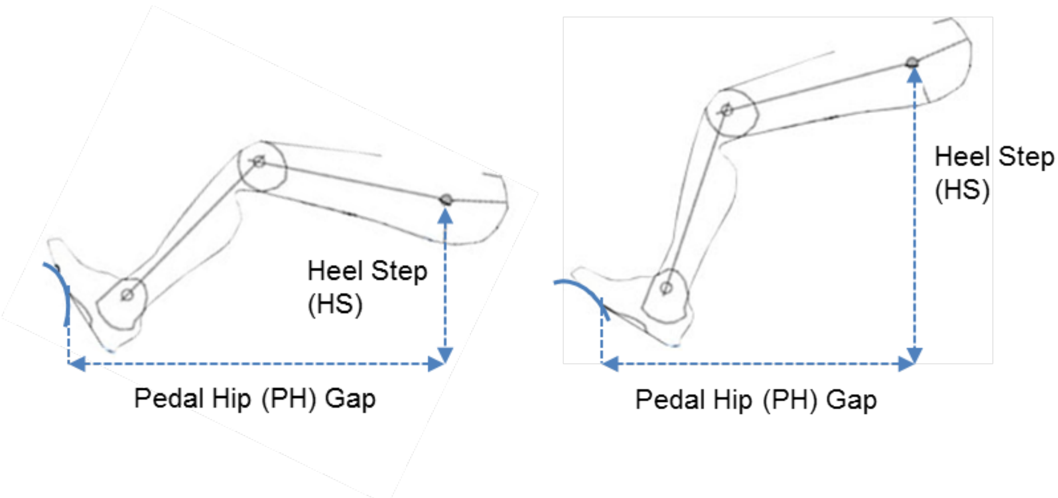

Figure 1.1. Heel step (HS) vs. Pedal-hip (PH) gap in a conventional (left) and proposed elevated (right) driving posture.

The elevated driving posture explored in this thesis has one notable change which differentiates it from a conventional driving posture, in that the driver hip point is positioned higher in the vehicle than the knee. This opens up the knee angle and the distance from the pedals to the hip point can be reduced. Whilst some vehicles use an elevated driving posture, there is little evidence to determine the impact of this posture on driver comfort and very little attention to the suitability for an anthropometrically diverse driving population.

1.1 Context of the research

The research reported in this thesis was government funded through the Technology Strategy Board (TSB) and was conducted in collaboration with Nissan Technical Centre Europe (NTCE). The research explored a new driving posture for LCVs, which could potentially lead to packaging benefits and in turn a potential reduction in CO_2 emissions over the lifecycle of the vehicle. Quarterly meetings were held with the automotive sponsor throughout, where detailed discussions would often help to steer the research.

1.2 Aims and objectives

The primary aim of the research presented in this thesis was to identify the ergonomic considerations and determine the requirements for a wide anthropometric range of drivers, in an elevated driving posture for LCVs. The following research questions were posed:

Q1: 'Are there specific seat parameters that need consideration when packaging a driver in an elevated driving posture?'

Q2: 'What are the long-term seat comfort considerations for drivers in an elevated driving posture compared with a conventional posture?'

Q3: 'When exposed to motion, what are the lateral support considerations for occupants in an elevated posture compared with a conventional posture?'

To address the research questions, the following research objectives were identified.

Objective 1: to identify key parameters (seat sub-component dimensions) for a seat design in the elevated driving posture.

Objective 2: to understand the effects of the seat design parameters on initial impressions of comfort in the elevated driving posture.

Objective 3: to understand the suitability of the chosen research methods in identifying key seat parameter for the elevated posture.

Objective 4: to understand the effects of a new seat design on long-term driver comfort, in comparison with a benchmark production seat.

Objective 5: to identify the onset of musculoskeletal fatigue in comparison with a benchmark posture and the literature.

Objective 6: to understand whether the increased height of the driver's hip point results in an increased sensitivity to and perception of vehicle motion.

Objective 7: to understand the suitability of the chosen research methods in assessing dynamic seat comfort in the elevated posture.

1.3 Methodology

The methodology comprised a systematic review of the literature to establish current knowledge and identify gaps for exploration, including research methods currently used in the assessment of seat comfort/discomfort and driving posture. Following this, three studies were designed to meet the main objectives of the study, leading to seat design considerations for an elevated posture, along with proposals for further investigation.

1.3.1 Literature review

A literature review was conducted using journals, books, theses, online databases and conference papers, selected for their relative importance to the topics in this research, for example: musculoskeletal system; driver posture; factors affecting seat comfort; driving conventions and standards; novel postures; CO_2 reduction.

1.3.2 Research methodologies

A review of current research methods used in automotive ergonomics research when investigating driving posture and dynamic seat comfort, for example: posture analysis; interface pressure mapping; fitting trials; driving simulations.

1.3.3 Seat design parameter study

A fitting trial study was conducted to identify key seat parameters for an elevated posture seat design (Objective 1), to understand the effects of seat design parameters on initial impressions of driver comfort (Objective 2) and to understand the suitability of chosen methods (Objective 3). Anthropometric data and final seat sub-component positions were taken from 20 participants (10 male and 10 female) with LCV experience, and final seat positions and verbatim were recorded (Chapter 4).

1.3.4 Long-term discomfort evaluation study

A long-term discomfort evaluation study was conducted to evaluate the effects of a specified elevated seat on long-term driver comfort (Objective 4) and to identify the onset of musculoskeletal fatigue (Objective 5) in the elevated posture. Twenty participants (10 males and 10 females) with LCV driving experience were recruited to take part in two 50-minute driving simulations, one for the elevated driving posture and one for the conventional driving posture. In both conditions, participants were exposed to whole-body vibration (WBV) replicating driving under normal road conditions and were asked to report their discomfort using body maps and rating scales at 10-minute intervals.

1.3.5 Lateral stability evaluation study

A lateral stability evaluation was conducted to explore the effects of the elevated driving position on sensitivity to perceived lateral motion in a vehicle (Objective 6) and to understand the suitability of the chosen methods (Objective 7). Twenty participants (10 male and 10 female) were recruited to take part in a lateral stability evaluation testing three seats (benchmark production seat; elevated posture seat; elevated posture seat with modifications aimed at improving lateral comfort) in three separate laboratory sessions. Lateral stability scores were reported after each sequence of seat rolls using a rating scale and the verbatim was recorded.

1.4 Structure of the thesis

The thesis is organised as follows. Chapter 2 presents a review of the literature, e.g. musculoskeletal system; driver posture; factors affecting seat comfort; driving conventions and standards; novel postures and CO_2 reduction. Chapter 3 presents the research methods commonly associated with identifying optimum seat positions, evaluating seat discomfort and driver posture and assessing lateral stability in automotive ergonomics. This identified a framework for the study designs for the seat design parameter study, the long-term discomfort evaluation study and lateral stability evaluation study. Chapter 4 reports on the seat design parameter study, Chapter 5 reports on the long-term discomfort study and Chapter 6 reports on the lateral stability evaluation. For Chapters 4-6, the results are discussed in context of each individual study and the current state of knowledge relevant to each study design. Chapter 7 summarises the findings, acknowledging the contribution to knowledge as well as considerations for future work and the application of the elevated driving posture. The structure of the thesis is detailed in Figure 1.2.

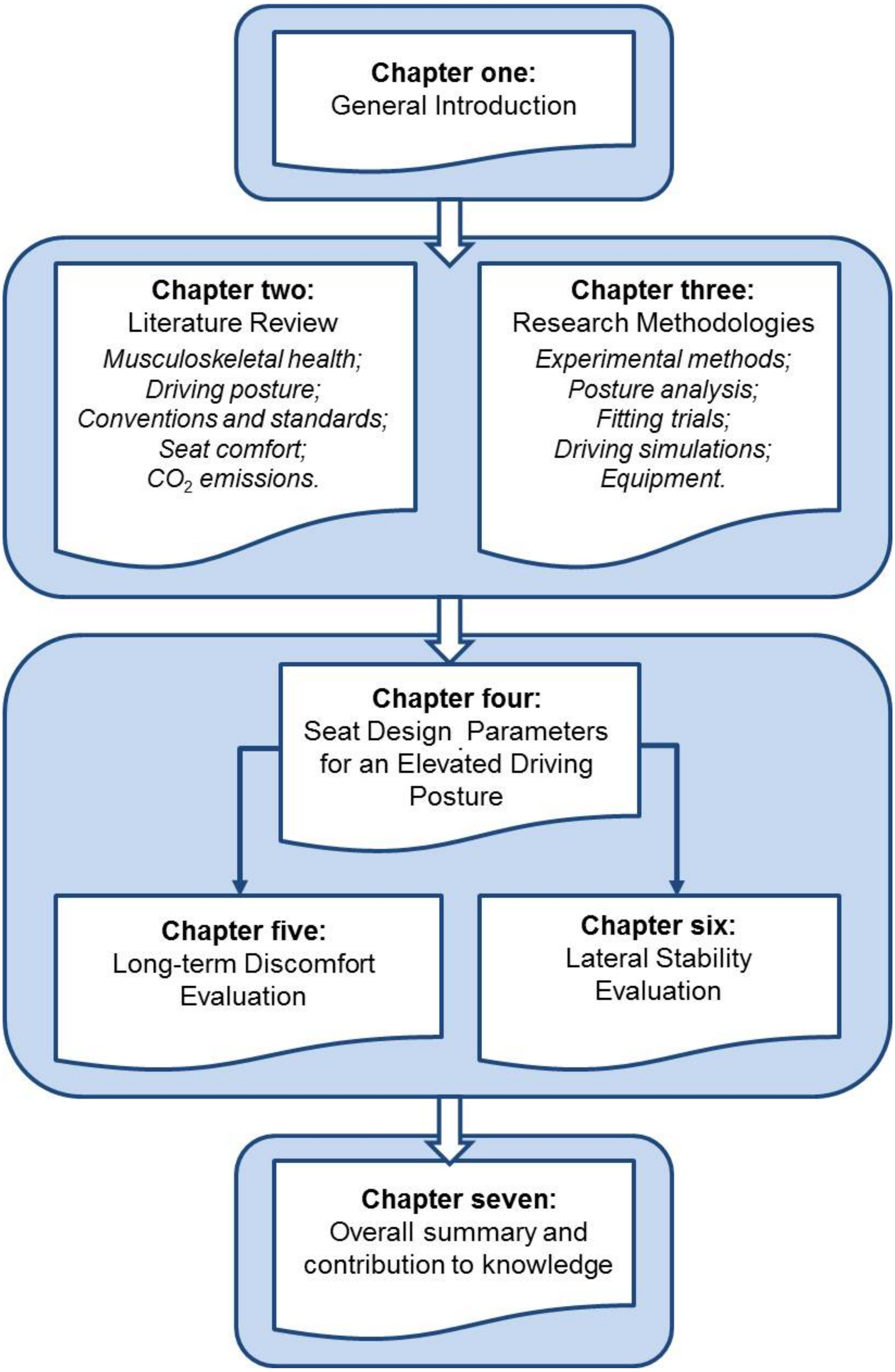

Figure 1.2. Structure of the thesis 'Driving ergonomics for an elevated seat position in a light commercial vehicle (LCV)'.

CHAPTER 2

LITERATURE REVIEW

A literature review was conducted from journals, reports, conferences and books. In order to understand the aims of the proposed research, these topics were explored:

- Musculoskeletal system
- Seated posture and driving
- Conventional driving postures and standards
- Novel seated postures
- Factors affecting seat comfort
- Lateral stability
- Crash pan profiling and anti-submarining
- Seat materials and weight reduction
- CO_2 emissions and the environmental impact

Various databases were accessed in the collection and analysis of the literature, including Google Scholar, Science Direct, Web of Science, Scopus and British Standards. Examples of key words used in these searches were: driving posture; posture analysis; musculoskeletal system; sitting AND low back pain; driver discomfort; driver comfort; seat comfort; seat discomfort; driving AND ergonomic AND seat; automotive ergonomic(s); novel posture(s); carbon emissions AND driving.

The strategy of searching and filtering papers was selected to gain a fuller understanding of the topics explored. The following inclusion criteria were used:

- English abstract and, where applicable, full paper
- Publication date >1970, with the exception of standalone papers or areas of little research

- Research relating to driving
- Original papers only (not applicable to books)

As a separate strategy, citations from relevant papers were followed to gather origins of research and relevance to the proposed research. Papers were reviewed primarily by abstract, to highlight key areas and key words relating to the proposed research. If papers proved to be of high relevance, full analysis of the paper would be conducted. For those papers with little or no relevance, they were discarded and noted. A critical appraisal approach was used for 'The Seated Posture and Driving' section, which enabled a focussed analysis and understanding of the research.

2.1. Driving and musculoskeletal health

The following section introduces the musculoskeletal system and the dynamics in changing from a standing to a sitting posture. This section also looks at the relationship between musculoskeletal injuries and work absences. The limitations in the literature for musculoskeletal health are the very few papers focussed on the impact of driving on the musculoskeletal system. The prevalence of research in the health sector, or aimed at disabled wheelchair users, is not directly applicable or useful to the proposed research.

2.1.1. Musculoskeletal system and sitting

This section introduces the definition of the musculoskeletal system and the importance of this when thinking about changing postures, especially from standing to sitting. The musculoskeletal system is the combined operation of the skeleton and skeletal muscles which provides core support and overall movement for the human body (Silverthorn, 1998). The skeletal muscles make up nearly half of the total weight of the human body and provide the forces that enable the body to move and maintain a posture (Baggaley, 2001). With this information, it is evident that an unnatural posture or a posture not 'fit for task', will give more strain to the muscular system and increase the likelihood of suffering injury from repeated exposure.

When changing from a standing to a seated posture, backwards rotation of the pelvis flattens the curve of the lumbar spine and changes its shape (Figure 2.1). This increases pressure in the posterior part of the inter-vertebral discs and within the nucleus itself, making it vulnerable to long-term damage (Gyi, 2013). This has specific implications to the scope of a high heel step (vertical distance between the heel point or cabin floor and the driver hip point) driving position, as the nature of light commercial vehicle (LCV) delivery work is a routine of ingress and egress of the vehicle, changing from a standing to a seated posture repetitively throughout the day. In addition, the literature indicates that the task of manual handling and carrying loads all day makes this group of workers more susceptible to musculoskeletal discomfort (Sang et al., 2010).

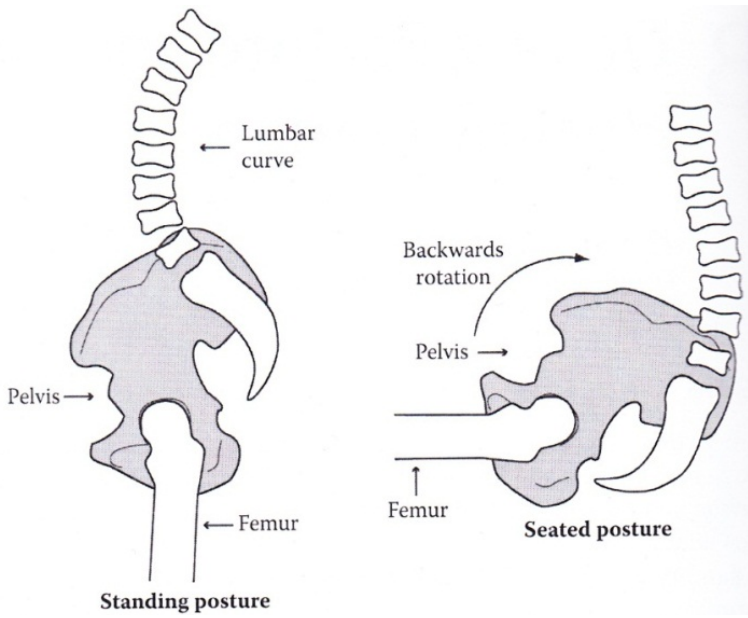

Figure 2.1. Rotation of the pelvis when changing from a standing to a seated posture - reproduced from ‘Automotive Ergonomics, Driver-Vehicle Interaction; Driving Posture and Healthy Design’ (Gyi, 2013).

Non-malignant musculoskeletal pain is the most common clinical symptom that causes patients to seek medical attention and is a major cause for disability in the world (Bove et al., 2009). This is validated by Sobeih et al. (2006) who states that every year more than 70 million physician office visits can be attributed to work-related musculoskeletal disorder (WRMSD) related complaints. Kuorinka et al. (1995) looked at the prevention of musculoskeletal disorders at work and found that it is possible to reduce sick leave due to low-back disorders by intervention measures directed toward both the work environment and the workers themselves.

2.1.2. Musculoskeletal system and driving exposure

Dedicated research into seat comfort and a healthy driving posture is well documented and is one of the most important ergonomics areas in vehicle development. Ergonomics is concerned with more than discomfort levels and investigates the effects that discomfort can have on the wellbeing of the driver, relating to health and safety (Andreoni et al., 2002). Zhang et al. (1996) indicate that whilst this is true, discomfort is mainly related to biomechanical factors involving muscular and skeletal systems.

Porter and Gyi (2002) conducted a questionnaire survey to explore the relationship between exposure to driving and musculoskeletal troubles. They found that there was a clear association between exposure to driving and sick absence due to low back symptoms, and that there was a correlation between annual mileage and reported discomfort. Additionally, drivers with a more adjustable driving package had fewer reported musculoskeletal problems from driving. The sample size was 600 and balanced fairly evenly between males and females, which indicate that this study has high validity in its results. However, a limitation is that 135 subjects were classed as non-drivers. As a driver, as opposed to a passenger, more factors are introduced such as the steering wheel and the pedals which in turn can affect discomfort, which is a consideration for future work. Sang et al. (2010) conducted a questionnaire study (n=205) with follow up interviews to assess the prevalence of musculoskeletal disorders (MSDs) in pharmaceutical representatives. The findings identified manual handling as a cause, along with prolonged driving, sitting and working in the car as factors contributing to MSDs in their field of work. Meyer et al. (1998) conducted a study looking at manual handling and summarise that exposure to intense whole-body vibration (which may occur in driving) is associated with musculoskeletal complaints and disorders, which tend to have grave repercussions in economic terms. This study showed that both male and female drivers in manual handling jobs had a higher frequency of lower back pain (LBP) than their reference population. However, the control sample for males and females (n=104) did not match the sample for those observed in manual handling jobs (84 females and 264 males), which skews the statistical power.

As a group, LCV drivers and the nature of their work leads to repetitive ingress and egress, awkward seated postures, and manual handling of loads (Okunribido et al., 2006). In addition, it has been identified that there is a strong correlation between lorry/truck driving and low-back pain (Hedberg, 1987; Magnusson et al., 1993; Miyamoto et al., 2000). Miyamoto et al. (2000) reports that in 1997, the proportion of low back pain (LBP) involved in illnesses which caused work absences was 83.5%. This research explored low back pain in truck drivers and identified three correlations with LBP, which were irregular duty time, short resting time and long driving time in a day. However there were no significant correlations between occupational factors and LBP, such as posture and manual handling. This study had a relatively large target sample (n=153) of which only 4 were female drivers. In addition to this, there were reported to be no significant differences between age, height, body weight etc. amongst drivers, which doesn't address how drivers of differing anthropometry will be affected by LBP in commercial driving conditions. It is identified that these results were based on self-reported measures, in a postal questionnaire. This reduces the validity of the results, because of the ambiguities of people's perceptions of LBP and not being evaluated in the environment in which they gave their responses.

There is no obtainable research and statistics for the number of female LCV drivers in the UK or global market; however the perceived observation is that the 'typical' LCV driver image is changing. With supermarkets employing their online delivery from existing staff, this is just one area where an increased number of female drivers are driving these types of vehicles. As the average age of the population rises, the impact of musculoskeletal conditions on society will increase in parallel (Bove et al., 2009). Relating this to driving, Bhise (2012) identifies that drivers aged 65 and older will represent 16.2% of the whole driving population of the USA and that drivers aged 75 and over are the fastest growing population. With people driving (and working in driving task jobs) to an older age, identifying and preventing musculoskeletal disorders is more crucial now than it ever has been.

2.1.3. The seated posture and driving

The efficiency of any posture from a biomechanics viewpoint can be determined by the degree to which it loads the skeleton and postural muscles (Gyi, 2013). Postural stress is a result of gravitational (and other) forces acting on the body and the forces required by muscle activity to maintain any particular posture (Troup, 1978). A study by Nachemson et al. (1984) showed that muscle efforts required for a sitting task are greater than those for standing tasks. This is ratified by Andersson and Örtengren (1974), who identified that intra-discal pressure in the spine was 40% higher in sitting than in standing. This study has limitations in that the study focused on an office chair, which as a seated posture differs from the conventional driving position. Nevertheless, these findings have relevant implications to modern driving tasks, such as inner city delivery jobs, where drivers are seated for a large proportion of their working day.

When thinking about the interaction between the driver and the seat in a vehicle, Gyi (2013) identifies that when a backrest is present, the pelvis will rotate until the drivers back comes in to contact with a support. In a car, a slouched posture could be exacerbated by design elements such as low headroom space or a seat cushion length which is too long. These are important considerations for an elevated driving position, as the driver will inherently require more headroom with an upright posture, thus taking the driver away from a slouched posture (Table 2.1). Judic et al. (1993) assume that humans search instinctively for the body posture allowing the lowest expenditure of energy within the limits of that which is physiologically and biomechanically possible, as well as that which allows an ease and efficiency in task execution. This assumption can be applied to both a conventional and an elevated driving posture, which is a fundamentally important consideration when researching this new area. Previous research (Gyi, 2013; Mansfield et al., 2007) identify that a factor contributing to comfort is the opportunity for changing postures (thus changing the muscle groups which are supporting the body weight). It has been identified that a good driving posture is best fit for task. With this in mind a task requiring long-duration sitting, such as LCV driving jobs, would benefit from a seat set up that would allow for adjustments in posture to reduce discomfort.

Table 2.1. Summary of a well-designed and a poorly-designed seat (adapted from Gyi, 2013).

Well-designed seat	Poorly-designed seat
• The weight of the trunk is taken by the backrest • The muscles in the back are relaxed • The curve of the lumbar spine is supported	• Flattened lumbar curve (loss of lordosis) • Increased pressure within the discs • Straining the spinal ligaments and gluteal muscles and increasing the thoracic c-shaped curve in the upper spine (increase in kyphosis).

2.1.4. Conventional driving postures and standards

There are numerous driving conventions and standards that have been developed and are utilised in the design and packaging of occupants in automotive vehicles. One such example of this based on the Anthropometry of Motor Vehicle Occupants (AMVO) study, which was a landmark study of driver posture and anthropometry for crash dummy design. The data from this study is currently used for the standard representations of small-female, midsize male and large-male vehicle occupants in the context of ‘normal vehicle sitting’. Tilley and Dreyfuss (2002) outline a standard driving posture, with optimum body angles for comfortable operation of the vehicle, for drivers. Tilley and Dreyfuss (2000) state that this standard driving posture is more or less the same for all vehicles, with only small variations in parameters such as the floor angle between different vehicle types (e.g. race cars, sports cars, sedans, trucks and vans). The standard posture diagram, representing a 1st percentile female and a 99th percentile male driver (Figure 2.2), illustrates the comfortable angle ranges for these drivers. The notable observation from this standard posture is that the knee point is located above the hip point in the vehicle cabin space (vehicle package). The elevated posture that is proposed to be investigated in this thesis has the driver knee point below the hip point in the vehicle cabin space and closer replicates the seated posture in an office chair. This, therefore, is the fundamental difference between the elevated posture and the conventional posture. As a result, the comfortable body angles that are referenced (e.g. knee angle, trunk angle, ankle angle) are likely to be less relevant for the proposed research.

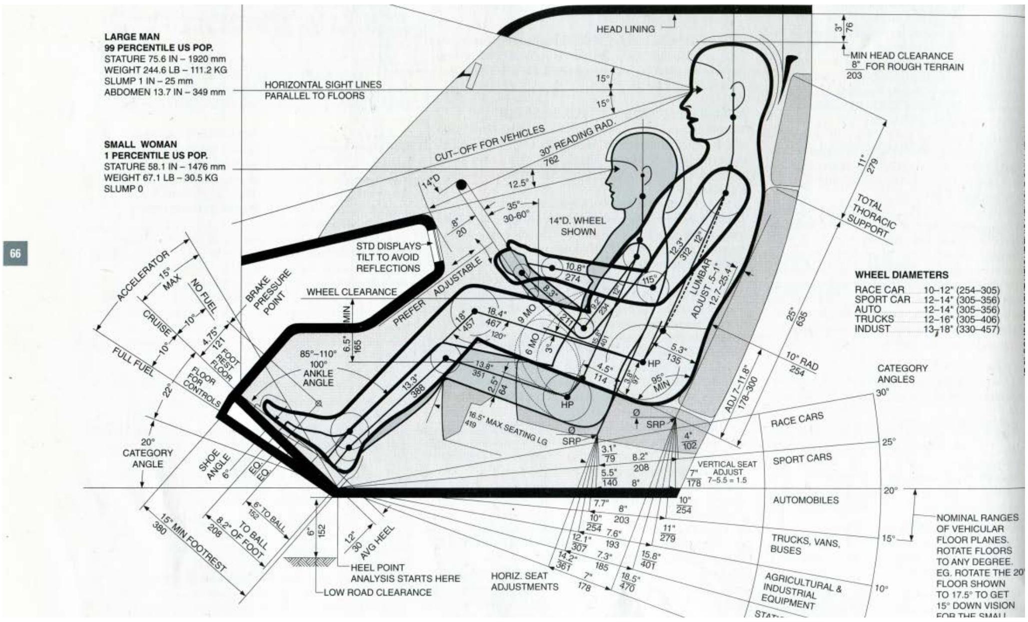

Figure 2.2. Standard driving posture with the driver knee point situated above the hip point in the vehicle (image taken from Tilley and Dreyfuss, 2002).

Another example of the standard driving posture is the OSCAR hip-point mannequin (used in conjunction with SAE J826, 2008), which provides the physical representation of the occupant hip point and can be adjusted to represent various driver percentiles (e.g. leg length). This is the required design and auditing tool for current production in the automotive industry (Figure 2.3).

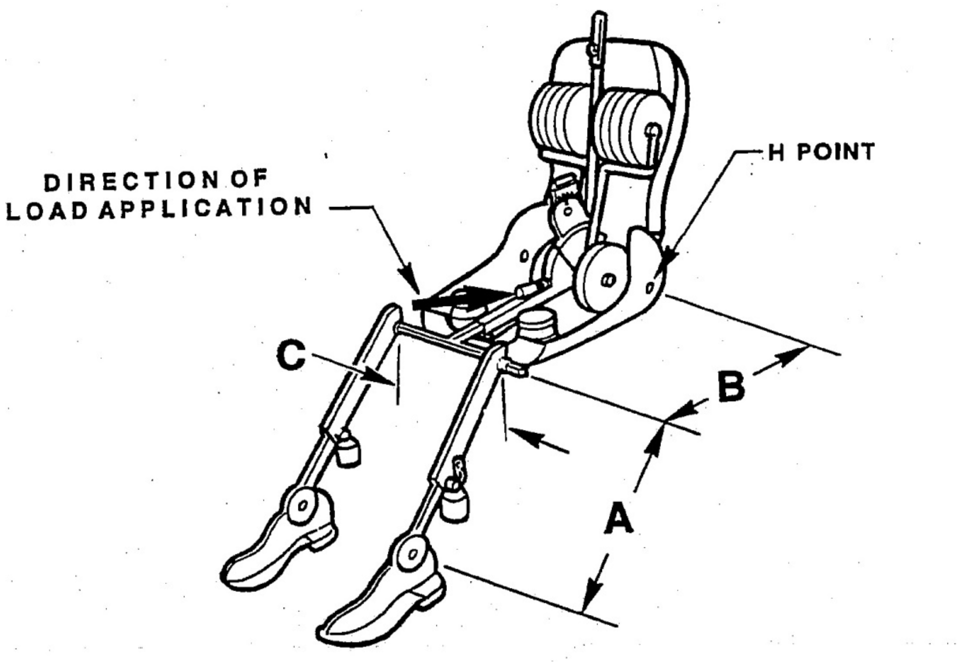

Figure 2.3. OSCAR hip-point mannequin used in the automotive industry for seating package configurations and crash test positioning (image taken from SAE J826, 1995).

The sitting posture standards that have been highlighted offer guidance for conventional vehicle seating. This literature is important because the concept elevated posture for LCVs that is proposed for exploration is far removed from the conventions of a ‘normal sitting posture’. Consequently, the standards that are adhered to in the current automotive industry are unsuitable for comparison and offer no guidance for an elevated seating position in LCVs moving forward.

2.1.5. Automotive seating in other vehicle types

Whilst it has been identified that the elevated posture explored in the proposed research is new for LCVs, it should also be acknowledged that there are several vehicle types that accommodate a seated posture closer to the one described here. Agricultural vehicles, buses and trucks all have higher seated positions than conventional vehicles (such as the LCV driving posture explored in the proposed research) where suspended seats are often mounted in the vehicle and as such have standards of testing which must be followed. One such standard describing and illustrating a similar posture for a suspended seat in these vehicle types is ISO10326-1 (1992) which details the laboratory method for evaluating vehicle seat vibration. The illustrated posture shows that the knee point of the driver is lower in the vehicle than the hip point and thus fits in to the definition of the elevated posture proposed for this research (Figure 2.4).

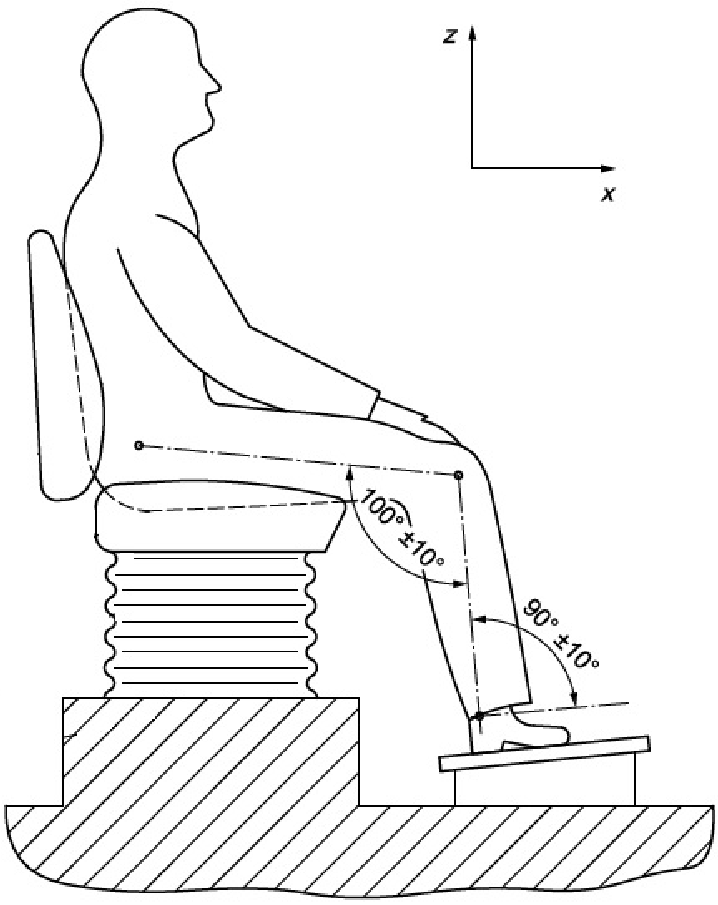

Figure 2.4. Suitable posture for testing suspension seats (image taken from ISO10326-1: 1992).

Whilst this is true, this standard states that when setting a driver in this posture there should be no contact between the seat and the thighs and furthermore that the upper leg should be approximately horizontal and the lower leg should be approximately vertical. As a result, the posture illustrated in this standard is almost impossible to achieve in application.

This section has identified that there are vehicle types (aside from LCVs and other conventional vehicles) that have seated driving postures closer to the one proposed for this research. However, in practice there are limitations in setting a driver in these postures with consideration of the thigh interacting with the front edge of the seat. This highlights that the key findings from the proposed research may also benefit vehicle types beyond LCVs with similar postures.

2.1.6. Novel seated postures

In the automotive sector driving postures differ between vehicle types, for example a sports car tends to package drivers with a more reclined posture with a lower hip point compared with a SUV, which tends to have a higher hip point and more upright posture. Nevertheless, both of these are still examples of conventional driving postures and there are standards in place to assess these with regard to occupant comfort and health. However, Paddan et al., (2012) identified that although there are National and International standards used for the assessment of WBV in respect to comfort and health (BS6841 and ISO 2631-1), these standards only consider upright (backrest angle of 90°) and recumbent (backrest angle of 0°) postures. Consequently, these standards do not consider the novel seated postures adopted by, for example, military vehicle drivers, ambulance patients, race car drivers and passenger transportation offering reclined seating for long-distance travel (e.g. air travel). Paddan et al. (2012) explored the influence of seat backrest angle on perceived discomfort, during vertical WBV exposure and identified that semi-recumbent positions of 67.5° and 45° were the least uncomfortable. This research highlights that there are novel seated postures in transport across many sectors, both for drivers/operators and for passengers. Additionally this represents the importance of constantly developing standards for assessment and guidance of comfortable seated postures.

Whilst it is important to gain an understanding of the theory behind healthy and comfortable sitting postures, applications in seating markets beyond the automotive market need to be explored to identify ‘novel seated postures’ that work towards the specified ideals. Table 2.2 provides an overview of current novel seating. The table identifies four options which have similar implications on the occupant’s posture, with the knee point falling below the hip point and the trunk-thigh angle opening up. This in turn leads to a straighter spine, closer to the natural S shape observed during a standing posture. There are numerous office seating options which are similar to the ‘Thatsit Balans’ and ‘HumanScale Saddle’ seats. A study by Gadge and Innes (2007) investigated the immediate effects on comfort and posture of a similar seat, comparing it with a standard office chair. The results identified that discomfort ratings increased in both seats; although the saddle seat style provided reduced levels of lower back discomfort. However, it was also noted that whilst the lower back discomfort was lower for the saddle seat, the reported discomfort of the hips and buttocks was higher. This is likely to be a cause of the weight distribution shift from the back of the seat and buttocks, to the front of the seat and lower limbs.

Table 2.2. Overview of selected existing novel seated postures (images taken from Thatsit balans, 2013; Ransome Mobility Stairlifts, 2012; Wired, 2010; Humanscale, 2013).

Novel seated posture	Thatsit balans® (kneeling seat) 	Perch Seat (stair lift) 	Aviointeriors SkyRider 	Humanscale Saddle Seat 
Industry	Home/office	Mobility assistance/home	Aviation	Home/office
Advantages	Dynamic seating maintains the natural curvature of the spine Allows for a more open posture. Improves breathing. Encourages movement and changes in posture.	Easier for those suffering from hip or back troubles. Better for those people suffering from restricted knee movement. Helps to maintain a more upright posture.	Space saving option for airlines. Open posture and more legroom for passengers. More passengers can fly in an aircraft in the same space.	Lowers the thigh position. Opens up the hip angle. Puts the spine in a healthy position (natural curvature). Specifically beneficial for short-term sitting/frequent movement.

It is evident from the market research that novel seating solutions exist, predominantly in the home/office industry. The underlying message is that for novel seating to be beneficial, it has to be fit for purpose, where solutions to the task and the wellbeing of the person are driving the design solutions. However, whilst it has been identified that there are novel seated postures, it is also true that there are no unique considerations for the driving seated posture. This is an area which is to be explored throughout the proposed research, by looking in to an elevated driving posture.

2.1.7. Synopsis: Avoiding a poor seated posture

The literature identifies the fundamental biomechanics of the spine and highlights the shape of the spine which will reduce the amount of pressure on the lumbar region, in turn reducing discomfort over time. From these studies, the key points that should be considered when designing a comfortable driving seat are summarised below:

- Maintaining lordosis of the spine (Gyi, 2013)
- Reduction in postural stress by distributing pressure over more than one muscle group (Troup, 1978)
- Comfortable body angles for ankle, knee and trunk-thigh (Porter and Gyi, 1998)

2.2. Vehicle seat comfort

The constant development in vehicle design is an area where ergonomics can successfully be applied to help define preferred postures for a large range of occupant sizes. This consideration is often influenced by fixed vehicle components and safety considerations, though driver comfort is crucial. This section introduces considerations for seat design which can affect the overall seat comfort, identifying factors that should be considered when designing a comfortable seat. This includes static and dynamic seat factors as well as the importance of the seat crash pan. The crash pan is the hard metal structure beneath the seat foam which is designed to stop the occupant from slipping off the seat in a crash (described in section 2.2.5).

2.2.1. Static seat comfort

For the proposed research, it is important to identify and understand the factors that are commonly associated with assessing seat comfort, both in static and dynamic conditions. Understanding the parameters for seat comfort in a conventional driving posture will give a benchmark for considerations in an elevated driving posture. Kolich (2008) created a breakdown diagram representing the factors affecting subjective perceptions of automobile seat comfort (Figure 2.5). This illustrates the diverse range of factors to be considered that go beyond the scope of seat design (e.g. transmission type, purchase price of vehicle) which holds a lot of focus in automotive research. It is important that this is noted for the wider context and evolution of the proposed research.

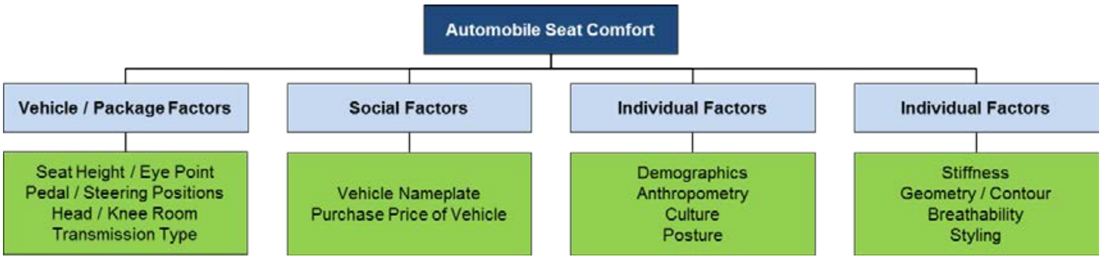

Figure 2.5. Factors affecting subjective perceptions of automobile seat comfort (Kolich, 2008).

Comfortable seating is no longer considered a luxury; it is a requirement (Kolich and Taboun, 2004). This is very evident in the automotive industry, with customer requirements driving further research into comfortable seats, but Thakurta et al. (1995) highlight the difficulty of this. With factors such as user subjectivity, occupant anthropometry, seat geometry and the exposure to the driving task all carrying weight, achieving these customer expectations is not a simple task. Defining 'seat comfort' is something which is not universally pinned down, which leads to research being based around investigators' subjective definitions. On the contrary, Hertzberg (1972) identified comfort as 'the absence of discomfort'. This further backs Branton (1969) who stated that it is unlikely an automobile seat will impart a positive feeling to the sitter. Hertzberg's theory takes away any ambiguity of labelling a seat as ‘comfortable’ and instead gives way to a scale of incremented levels of discomfort.

Comfort is considered to be one of the most important aspects of seat design. Specifically, ‘static comfort’ refers to the sitting impressions of seat occupants when there is no vibration (Ebe and Griffin, 2001). Ebe and Griffin (2001) conducted a paired comparisons test of four different seat cushions, made up of different polyurethane foams (dictating the cushion stiffness). The experimental design is very simple and repeatable, with a 7-point Likert scale rating one cushion in comparison with the previous cushion. There is ambiguity with the duration of sitting with the exposure reported to be 3-10 seconds, which indicates that this changed from participant to participant and perhaps even cushion to cushion. It is questionable as to how many seconds a driver needs to be able to rate a seat cushion for comfort and perhaps this should be a constant time for all exposures. The results showed that static seat factors seemed to affect the rate at which discomfort increased with increasing vibration magnitude. This summarises that both static and dynamic seat characteristics need to be considered with good seat design. Whilst this is true, the sample size was relatively low, with only 12 participants and also only male subjects were tested. With the distribution of weight on the seat surface differing for men and women, a balanced sample may provide different results. Lee et al. (1993) identified foam hardness and thickness as important parameters affecting the comfort in a static seated posture. Cunningham et al. (1994) and Tan et al. (1996) stated that deep-down firmness and a surface softness contribute in achieving a good static show-room feeling. The show-room feeling refers to a first impression when sitting in a seat for a short period of time. These findings show that a supportive feeling and stiffness from the seat is often preferred, with the added benefit of a softer cushioned surface. However, driver discomfort research has shown that showroom analysis is not sufficient as it does not take in to consideration the dynamic factors which are concerned with overall seat comfort, highlighted by Porter et al. (2003) who identified that short term recordings were inadequate. With long-duration driving, all factors of the seat need to be considered. This is a combination of the static and dynamic factors (affected by vibration) which will determine a comfortable seat over long periods of driving.

2.2.2. Seat comfort and vibration

Whilst static factors affecting seat comfort are usually the first impression point of reference for drivers in the 'show-room' experience, when researching overall seat comfort, dynamic factors including WBV need consideration. Dynamic comfort refers to the sitting impressions of seat occupants while being exposed to vibration (Ebe and Griffin, 2000a,b). As discussed above, defining seat comfort and applying a method to quantify comfort is challenging, leading to qualitative methods and models being explored and applied to this area of research. Ebe and Griffin produced a model which detailed the impact of both static and dynamic characteristics of the seat on seat comfort, under vibration, for two case studies (Figures 2.6 and 2.7).

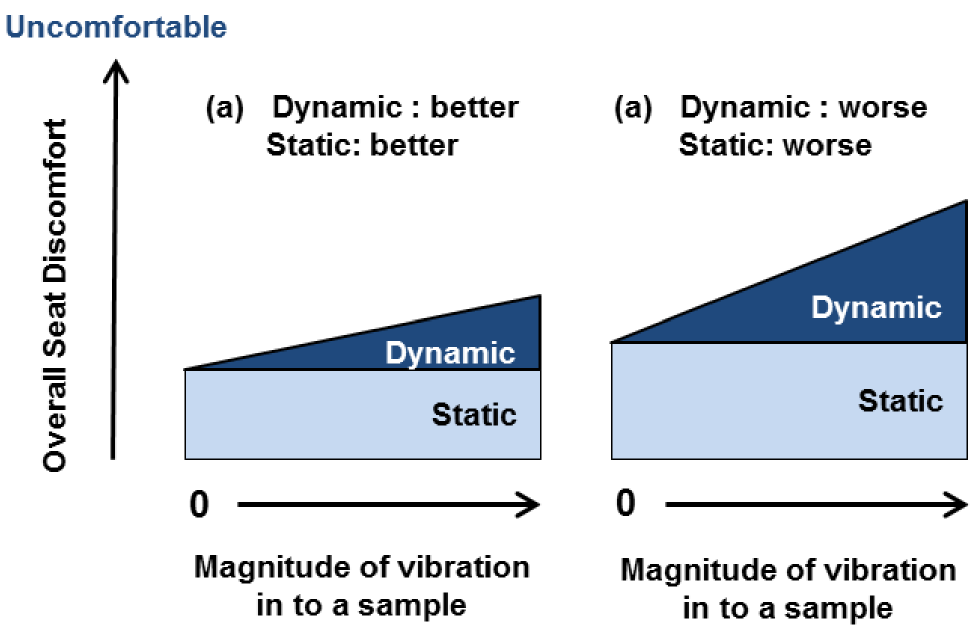

Figure 2.6. Comparison of overall discomfort models – (a) a seat with better static and dynamic characteristics vs. (b) a seat with worse static and dynamic characteristics (Ebe and Griffin, 2000a).

Case study 1 (Figure 2.6) shows that a seat with better static and dynamic characteristics should be judged as less uncomfortable than a seat with worse static and dynamic characteristics. Additionally, in this example, the difference in discomfort between the two seats should increase as the vibration magnitude increases.

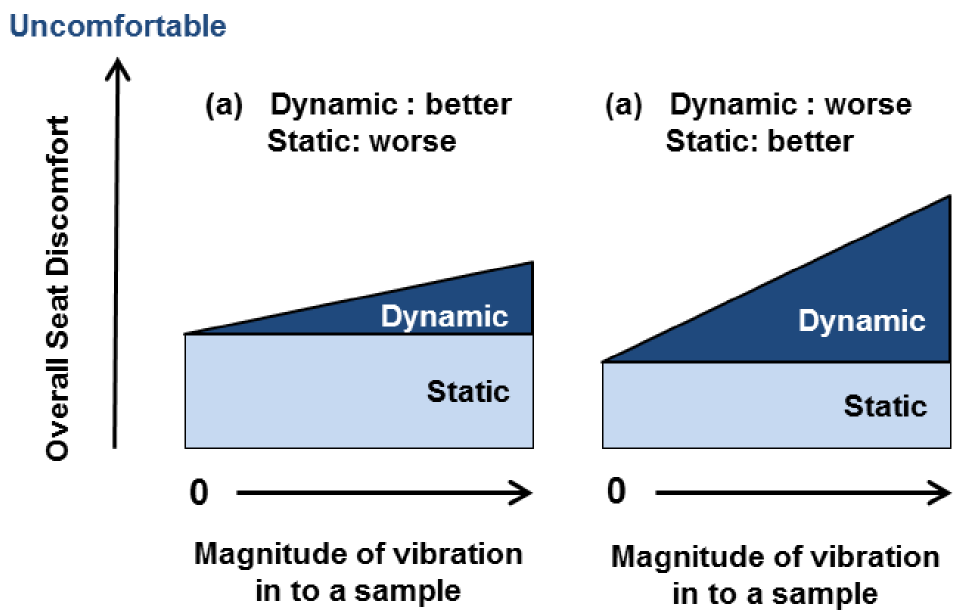

Figure 2.7. Comparison of overall discomfort models – (a) a seat with worse static and better dynamic characteristics vs. (b) a seat with better static and worse dynamic characteristics (Ebe and Griffin, 2000b).

Case study 2 (Figure 2.7) compares a seat that has poor static and good dynamic characteristics, with a seat that has better static and worse dynamic characteristics. With this example, the difference in discomfort between the seats should decrease as the vibration magnitude increases. This example highlights how dynamic factors affecting every day driving, are hugely important when considering overall seat comfort and must be considered in the context of the proposed research. Ebe and Griffin go on to conclude that considerations of both factors (e.g. stiffness of foam), dynamic factor and the vibration dose value (VDV) improves predictions of overall seat comfort compared with predictions based on either factor individually. Mansfield et al. (2007) investigated this model further with the addition of temporal factors. The study showed that discomfort accrues with time; however more discomfort is experienced when exposed to WBV. Mansfield et al. (2007) identifies that factors affecting discomfort could include the physical profile of the seat cushion, the fit of the seat to the occupant, the materials from which the seat is made (dictating stiffness), exposure to WBV and the length of time the occupant is sitting in the seat. This, again, highlights the complexity of assessing overall seat comfort whilst reiterating the importance and weight of dynamic characteristics of a seat when subjected to vibration.

Griffin et al. (1982) summarise that vibration in combination with a poor seated posture produces a measurable level of discomfort, especially during journeys of long duration. This study found significant correlations between subject characteristics (size and transmissibility) and subject relative discomfort, with a gender balanced sample of 18 males and 18 females. The vibration at the seat level affects the buttocks and is transmitted to the spine. In addition to this, cramp, numbness and postural instability can occur when exposed to long durations in a seated posture (El Falou et al., 2003). This physical degradation and fatigue, combined with the driving mental fatigue can also replicate a decrease in driving performance (Lamotte et al., 1996; Duchêne and Lamotte, 2001; El Falou et al., 2003). However, whilst it is clear from this literature that vibration will accelerate the onset of discomfort during driving over long periods of time, most of this research is laboratory based and so the real world applicability needs to be considered. Whilst vibration magnitudes can be matched for laboratory trials, they cannot be fully replicated and the addition of being in a real world environment with real driving tasks and risks may affect the perception of discomfort. This literature shows that consideration of the entire seat package is beneficial in reducing long-term driving discomfort. Whilst ensuring that seat sub-components (seat base length, seat width, seat base angle and upholstered foams etc.) offer drivers a comfortable seat in a static scenario, consideration of how they impact upon drivers' discomfort once vibration is present is crucial.

2.2.3. The onset of discomfort

Previous studies have shown that the perception of overall discomfort increases with the duration of exposure (El Falou et al., 2003; Porter et al., 2003; Kyung and Nussbaum, 2008; De Carvalho and Callaghan, 2011) and additionally that the presence of vibration will accelerate the onset of discomfort (Mansfield et al., 2014). A further study by Mansfield et al. (2015) investigating driver discomfort effects of seat foam composition was in agreement with these results. Significant differences in discomfort have been observed after only 30 minutes (Mansfield et al., 2014) and 40 minutes (Mansfield et al., 2015) respectively, when vibration has been implemented. This suggests that two individually configured and designed seat set-ups could be tested under the same conditions to collect reliable reported differences in driver discomfort.

2.2.4. Seat comfort and postural stability during lateral accelerations

It has been identified from the literature that WBV influences drivers' seat discomfort. Additionally, low-frequency accelerations (movement of the occupant in the seat) occur during accelerating, braking and cornering which contribute to the comfort and the stability of drivers (Mansfield and Whiting-Lewis, 2004). In a seated position, the postural stability of drivers is sustained by a number of factors, including the friction and contact with the seat backrest, the differential downward forces at the buttocks and feet, and muscle activity (Beard and Griffin, 2013; Porter et al., 2003; Farah et al., 2006). Predominantly, static seat comfort has been a focus for automotive companies; however in the current automotive market, the focus on human perception of the dynamic comfort of the seat is of increasing importance (van Niekerk et al., 2003). Previous studies have approached the field of lateral accelerations and the impact on driver comfort in automotive seats from an objective standpoint. Numerous studies have explored the frequency ranges where seat occupants have the maximum sensitivity to lateral accelerations (Yonekawa and Miwa, 1972; Griffin et al., 1982; Corbridge and Griffin, 1986) and in many cases, these have been compared with the same sensitivities for vertical accelerations. Farah et al. (2006) used surface electromyography to assess the physical responses of car passengers to lateral accelerations between two different seats. The study was designed to collect EMG signals bilaterally from five muscle groups, which identified differences in lateral support between the seats. Muscle activity was affected by turning direction (e.g. when turning left passengers were forced right and counteracted this by activating the left sided core muscles) showing that the greater the lateral acceleration, the more the muscles worked to maintain postural stability. This approach accurately identified a correlation between muscle activity and lateral acceleration intensity, however it should be noted that occupant comfort is not only defined by muscle activity and so these results do not necessarily conclude one seat as more comfortable than the other.

In real-world driving, drivers adjust their speed during cornering so that the maximum vehicle lateral accelerations decrease at high speeds (Reymond et al., 2001; Mansfield and Whiting-Lewis, 2004). This indicates that the vestibular system and the proprioceptive sensory channels have a large influence on driving behaviour and thus seat stability and comfort. There is also continued evidence that automotive manufacturers respond to these considerations, with the development of new electronic stability control/traction control functions, with the capability of stabilising the vehicle during cornering (van Zanten, 1994). Whilst dynamic seat comfort is becoming paramount to seat design, there is currently no literature examining lateral stability and comfort during low frequency lateral accelerations (i.e. the accelerations that are experienced whilst cornering, rather than lateral vibration due to road irregularities) from the occupant’s point of view. It is likely that drivers in an elevated posture seat will have an increased sensitivity to lateral accelerations in comparison to a conventional, lower-mounted seat position, as the centre of gravity is raised. The consideration of lateral stability therefore becomes a crucial consideration in the exploration of this posture.

2.2.5. Crash pan profile and anti-submarining

Whilst the seat-sub components and the foam/upholstery are important factors in determining a dynamic comfortable driving posture, an understanding of the structure beneath the seat foam and how this is perceived is also necessary. The term ‘submarining’ means the slipping forward of a vehicle occupant under the seat belt in an impact situation, such as a vehicle crash, in case the lap belt fails to restrain the pelvis of the vehicle occupant (Yamaguchi and Shimizu, 2005). This occurs most frequently when the vehicle occupant is sitting on an edge of the seat and/or the seat back is significantly reclined, and could impair the restraining capability of the seat belt because the seat belt fails to restrain the proper part of the vehicle occupant. For safety requirements, a robust anti-submarine system must be included in the structure of the seat (Figure 2.8): this, even if covered by foam of a suitable size and density, could potentially introduce zones of high pressure when a driver is seated (Andreoni et al., 2002), which highlights the impact the safety structure can have on seated comfort.

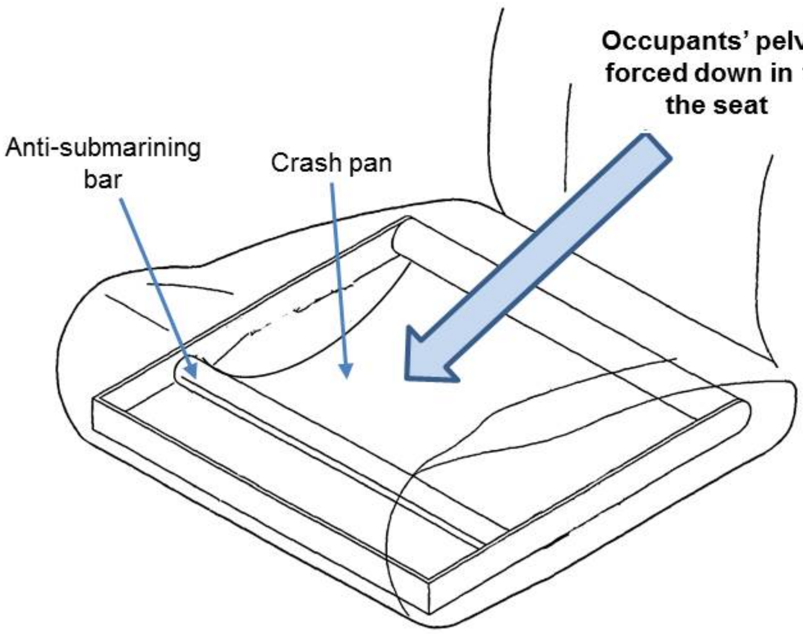

Figure 2.8. Diagram of an anti-submarining system (bar) fixed to the crash pan underneath the seat foam of a vehicle seat.

In a conventional driving posture with a conventional seat, the weight distribution of the occupant is towards the rear of the seat cushion (as a result of the knee point being above the hip point). It is theorised that an elevated posture changes the biomechanics of the occupant, in that the position of the knee point is located below the theoretical hip point and thus the weight distribution will shift further towards the middle and front of the seat. This potential change in the occupants' weight distribution across the seat surface consequently means that the positioning of the anti-submarining system needs to be considered, in terms of both comfort and safety. For the proposed research, understanding factors that influence overall seat comfort is an important consideration for concept elevated posture seat design compared with conventional seat design and the crash pan beneath the seat foam contributes to this.

2.2.6. Seat materials and weight reduction

In the automotive industry, as with most areas of transport, weight reduction is an on-going process throughout all parts of a given vehicle design. Having a lighter vehicle usually benefits other areas of performance, but from a manufacturers perspective it reduces the cost of production. Alongside this, with targets and legislation introduced set to lower carbon emissions, the lighter a vehicle can be made increases the likelihood of these targets being met. Seat weight reduction is currently an area very much a priority in the automotive industry, and with most cars having two independent (driver and passenger) seats, any weight reduction will be doubled in an average vehicle. A trend in the automotive seating industry is the implementation of full foam seating i.e. a seat design where the foam is placed on a 'dead pan' rigidly mounted to the vehicle floor pan (Kolich et al., 2005). Kolich expands on this and identifies that this is a change in seat design driven by weight and cost reduction and green considerations (recyclability). With a full foam seat, there would be no additional springs nor wires beneath to control the comfort and ride for the passenger.

Future aims of the industry surround eliminating foam from seating systems, in order to address the issues relating to recyclability. With both of these approaches, the aim is to remove weight from the seat which in turn equals better fuel economy. A smaller seat package will consequently result in more space in the vehicle, which in passenger vehicles could lead to more passenger room or more seats. This trend of using suspension fabrics is already being seen in seating beyond the automotive industry. This is already present in short-haul aviation and most commonly has been used for many years in office furniture. This movement in weight reduction will further benefit the space saving advantages that could be realised in the elevated posture explored in the proposed research; however the implication on occupant comfort needs exploration.

2.2.7. Synopsis: Factors affecting seat comfort

Seat comfort is a complex thing to define and is influenced by many factors, most noticeably static seat factors, dynamic seat factors and temporal factors. The literature has identified that a seat which considers all three of these will go further in minimising occupant discomfort from the seat during driving. Key points that should be considered when designing a comfortable driving seat are summarised below:

- Deep-down firmness and a surface softness contribute in achieving a good static show-room feeling (Cunningham et al., 1994; Tan et al., (1996).
- Good static and dynamic seat characteristics (Ebe and Griffin, 2001).
- Compromised foam composition with stiffness and soft cushion top (Cunningham et al., 1994; Tan et al., 1996).
- Comfortable position of vehicle cabin e.g. pedals, steering wheel etc. (Gyi, 2013).
- Seat that provides opportunity for adjusting postures (Mansfield et al., 2007).

2.3. CO_2 emissions and environmental impact

The context of the proposed research is that by elevating the seat position within a light commercial vehicle package, a space saving benefit can be realised. This space saving can be achieved in terms of a reduction in the overall length of the vehicle (and thus a reduction in the overall weight) or in terms of an increase in loading space (whilst maintaining the same overall length and weight of the vehicle). These space saving benefits could potentially reduce the CO_2 emissions and the environmental impact of the vehicle over its lifecycle. With this in mind, it is important to understand what is driving CO_2 reduction in the automotive industry, in terms of International and National legislation. This knowledge will provide a greater context by way of understanding the impact that this technology could have.

2.3.1 Global trends and the automotive industry

The following section describes the global trends in the automotive industry and the contribution of road transport to overall CO_2 emissions. It has been estimated that CO_2 (fossil fuel use) accounts for 57% of global emissions (United States Environmental Protection Agency, 2013). With more and more vehicles on the road each year, the global trends for the automotive industry are focussing on reducing CO_2 emissions. This has led to the more recent transitions towards greener energy such as hydrogen fuel cells and Electric Vehicles (EVs). For the UK, CO_2 accounted for 83% of total greenhouse gas emissions in 2011, which is estimated to increase by 4.5% in 2012 figures (Department of Energy and Climate Change, 2013). In the UK, it is estimated that 24% of CO_2 emissions will be contributed by transport, which is actually 1.2% down from the previous year. Of these transport figures, road transport is the most significant contributor and whilst there was a decrease in emissions from passenger cars from 1990-2011, there was an increase in emissions from LCVs. Globally, light-duty vehicles account for approximately 10% of the greenhouse gas emissions (Solomon, 2007). Furthermore, according to the World Business Council for Sustainable Development (2004), ownership of these types of vehicles is likely to increase from around 700 million to 2 billion, an increase nearly threefold, between 2000 and 2050.

This in turn will place an even heavier demand on fuel in an increasingly environmentally considerate age. For the context of the proposed research, being targeted at LCVs, this statistic is very important as it identifies the need for focus on these types of vehicles in today's transport market.

There are initial signs of this consideration with reference to the LCV market, as CO_2 emissions for the average new van fell by 4.9% in 2012 on the previous year, to 188.7g/km (SMMT, 2013), highlighting the trend identified above. The SMMT (Society of Motor Manufacturers and Traders) define vans as work tools bought to do a job and the specification of the vehicle is determined by the market need. They also highlight that operators will always look to minimise costs. With commercial vans, fleets will be bought and used by many companies and so any costs that can be saved over the life-cycle of one van, through lower CO_2 emissions, will be multiplied across a fleet.

In summary, it is evident that road transport has a large impact on the overall global CO_2 emissions. It has also been highlighted that in the LCV market, the production of new vans in the last few years has seen close to a 5% in CO_2 reduction year on year. This verifies the importance of the proposed research as it is contributing knowledge to a section of the automotive industry that is making observable changes to reduce vehicle emissions.

2.3.2. EU and UK government policy for LCV CO_2 reduction

There is a current EC New LCV CO_2 Regulation, which sets out targets for manufacturers to fulfil. SMMT report that the EU-wide target is to achieve 175g/km in 2014-2017, following the steps taken for car regulation. The details of this target are detailed in Table 2.3. When transferring this information and applying this to the UK market independently, the average LCV CO_2 emissions would need to reduce by 3% per annum, to meet this predicted EU target. With legislation coming in to effect, LCV manufacturers' trends are clearly following in the same direction. To assist the transition to lower carbon vehicles, the UK government made electric vans exempt from the 'van benefit charge' (£3,000 per annum) for 5 years from April 2010. In addition, in January 2012 the Plug-In Van Grant was brought in to provide buyers with 20% of the van's list price, up to £8,000, to qualifying vehicles emitting below 75g/km of CO_2 (SMMT, 2013).

Table 2.3. EU LCV CO_2 reduction target through to 2020.

Year	g/km CO_2 Target	Reduction
2007	203 (reported levels)	n/a
2014-2017 phase in	175 (70% compliance by 2014, 75% compliance in 2015, 80% compliance in 2016 and 100% from 2017 onwards)	n/a
2017	175	14% (based on 2007 levels)
2020	147	16% (based on 2017 target)
Overall reduction	56g/km	28%

In summary, these trends and statistics show the clear directive that both the EU and UK have towards LCVs and highlight the relevance of conducting research in to seating solutions aimed at reducing these emissions. This literature provides context for the proposed research and has identified where this research will fit in with the environmental trends and considerations for road transport and CO_2 emissions reduction.

2.4. Summary

The literature has identified that overall seat comfort is well researched and that a combination of static, dynamic and temporal seat factors have been proven to influence the comfort of occupants in a vehicle seat. There is, however, a gap in the state of knowledge on the applicability of these assumptions to an elevated seating posture. There is certainly a range of examples of novel seated postures in other markets which are comparable to the proposed elevated driving seat, most notably in the office and home seating markets where the occupant knee point is below the hip point. However, comfort in these seat types are solely concerned with static factors and do not take in to account long-duration sitting nor the transmissibility of vibration through the seat and to the occupant. Understanding drivers' comfort under replicated road conditions in an elevated posture is therefore of paramount importance for the proposed research.

The literature also highlights that whilst previous studies have identified the frequency ranges in which drivers are most sensitive to lateral vibration, there is very little in the way of assessing subjective lateral stability from the occupants' perspective. In addition, there is no research that explores how these accelerations would impact upon a seat mounted higher in the vehicle. It is likely that a higher centre of gravity would expose the occupant to an increased sensitivity; however to the extent that this would be observed is unknown and crucial in the exploration of the elevated driving posture. The automotive market is being driven by global targets and government legislation to reduce carbon emissions and provides a wider context for the proposed research. The aims and objectives of the proposed research are set out to understand the feasibility of an elevated posture in a LCV driving package for occupant comfort, which will provide a platform for further research with a greater scope.

CHAPTER 3

RESEARCH METHODOLOGIES

This chapter outlines and discusses the possible approaches for the proposed research and details the selected methods. Additionally, an outline is provided of the principal equipment used, the test configurations and calibration procedures for each study. In depth details relating to the equipment and analysis techniques specific to each study are provided in the relevant chapters.

3.1. Research approach

Researchers design research studies to address a gap in the knowledge or address a specific question; however selecting techniques to obtain and analyse the data represents only the final stages of an effective research design (Saunders et al., 2012). From a philosophical standpoint and for both reliability and validity, it is important to understand the research approach as a whole. Saunders et al. (2012) created the ‘research onion’ paradigm which illustrated layers of the process when designing a piece of research. This onion paradigm was adopted to understand the research philosophy, which helped to characterise the proposed research and to put it in to context in the field of vehicle ergonomics. The outer layer of the onion is the identification of the ‘research philosophy’ (Figure 3.1). The philosophy for the proposed research falls in line with positivism, where the role of the investigator is to collect data to further understanding of the research area. The reason for this approach is because it has been acknowledged that the elevated driving posture concept studied in this thesis is an unknown quantity in research. The literature outlined in Chapter 2 has identified extensive research in occupant seat discomfort during driving; however these studies have been conducted using a conventional driving set-up. It is therefore important that the new elevated posture is explored and compared to a conventional set-up and that the quantifiable data leads to an identification of optimising the driving ergonomics for this posture.

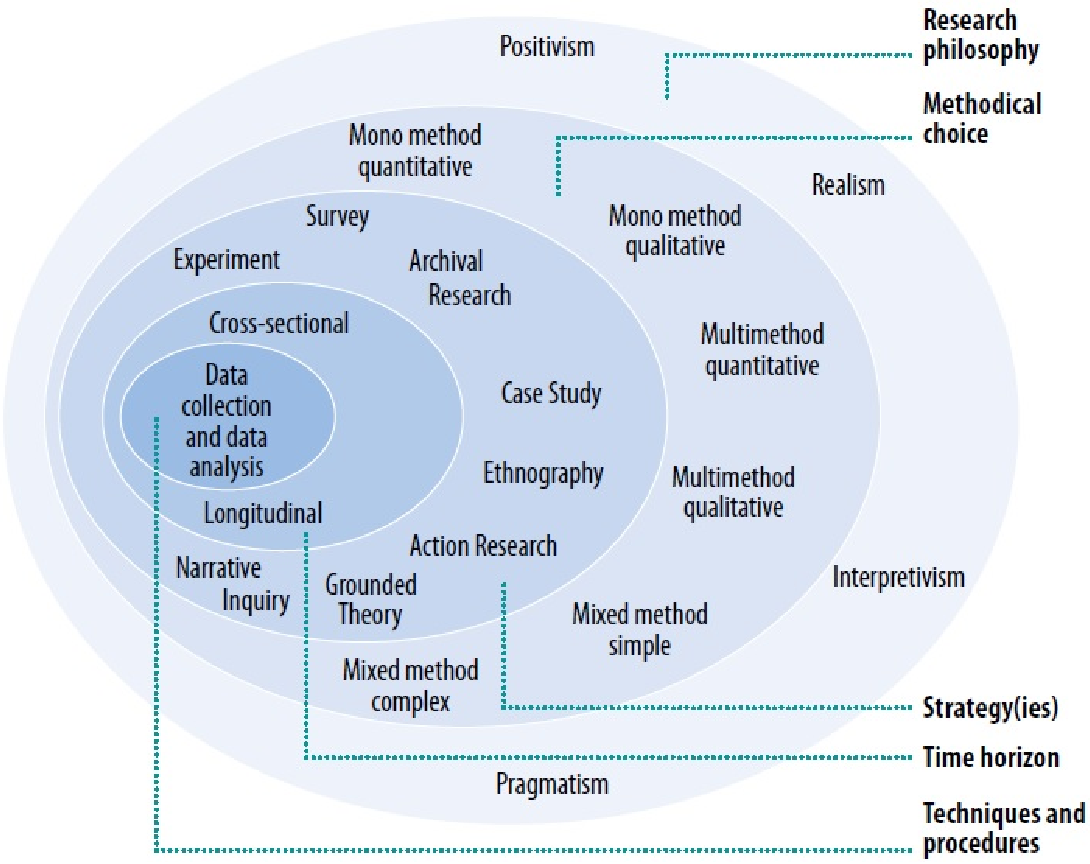

Figure 3.1. The research onion paradigm (Saunders et al., 2012).

3.2. Research strategy

The proposed research was in collaboration with an automotive sponsor, investigating a new elevated driving posture in an early stage of its development. During the time frame of the proposed research the development of the elevated posture had not progressed to a stage, nor was there scope within the funding, to incorporate it in to a road vehicle. This meant that the studies reported in this thesis were laboratory studies by design.

Typically, experimental research is the deliberate manipulation of factors under highly controlled conditions to ascertain how and why an event or phenomenon occurs (Allison et al., 1996). This work is often conducted to study the probability of a change in an independent variable causing a change in another, dependent variable (Hakim, 2000). It is noted by Bhise (2012) that for experimental validity, the research design needs to include all the critical factors related to the performance of the product that is being tested. In addition to an experimental approach, Bhise identified observation as a commonly used ergonomic evaluation technique during vehicle development. These two approaches may be used separately but used in combination is good for triangulation of results. The addition of communication as an evaluative method provides the researcher with information about participants' impressions or experiences, before during or after an experiment (Table 3.1).

Table 3.1. Ergonomic evaluation methodological approaches for vehicle development (adapted from Bhise, 2012).

Evaluation method	Summary of approach
Experimental	• Allows the investigator to control the research situation (laboratory testing) • Allows relationships between the response variable and the independent variable to be evaluated • For validity the research design needs to include all critical factors related to the performance of the product
Communication	• Asking participants to provide information about his or her impressions and experiences • Questions can be asked prior to, during or after • Participants can be asked to categorise the product e.g. rating using a nominal scale • Participants can be asked to compare products in pairs based on a given attribute e.g. comfort

The studies reported in this thesis were experimental with the addition of communication in the form of semi-structured questions after each experiment, relating to their seat comfort. This provided a degree of context to the quantitative data that was collected and a greater degree of understanding about the elevated posture.

3.3. Experimental methods

There are a number of experimental methods in the literature which have been adopted to explore sitting comfort and driver posture. Although these methods have not been applied to investigating an elevated driving posture, many of these methods are still relevant. This section discusses the experimental methods and techniques that were considered to answer the research questions, including: posture analysis, interface pressure mapping, comfort/discomfort rating scales, anthropometry, fitting trials and driving simulations. These experimental methods will be evaluated for their suitability to answer the objectives of the research conducted in this thesis

3.3.1. Posture analysis

Posture analysis is a method that can be used to measure a driver's posture whilst sat in a given automotive driving position. There are several ways in which it can be conducted, with both manual measurement and body scanning techniques historically being used. The literature identified that body angle measurement and the calculation of theoretical joint angles, with both 2D and 3D techniques, is a common approach in posture analysis. Consequently, seven papers were selected to critique the methods, findings and strengths/limitations of the research and to highlight any trends between studies (Table 3.2).

The reported studies used posture analysis as a technique to investigate comfortable/optimum driving postures in conventional vehicle set-ups, most commonly for cars. These studies were laboratory based and incorporated adjustment of specified seat sub-components for participants to explore and select their driving position. The sample sizes ranged from 4 to 68 participants and with the exception of two studies (Andersson and Örtengren, 1974; Andreoni et al., 2002) the studies were balanced by gender.

Rebiffe (1969) explored the posture and position of the driver to best fit the requirements of the driving task and was able to propose theoretical joint angles of the body for comfort and a correct posture. Numerous studies

(Andersson and Örtengren, 1974; Porter and Gyi, 1998: Park et al., 2000; Reed et al., 2000; Andreoni et al., 2002) augmented this theoretical framework with observed driving postures, with the resulting recommendation of ‘comfortable body angles’. Porter and Gyi (1998) conducted a study exploring the optimum posture for driver comfort and set out to measure seven body angles to compare with angles observed in prior research. The method of measurement was to place markers on the seven joint angles (7th cervical vertebrae, acromium, lateral epicondyle, ulnar styloid, greater trochanter, lateral condyle and lateral malleolus) and when in their optimum driving posture set-up, to measure the participant’s right-hand side with a goniometer. The measurement was taken three times. Manual measurements (Porter and Gyi, 1998) of comfortable body angles for the most part replicated those in the literature. However, for increased reliability, this measure was alluded to as needing care with the placement of the markers and that measuring through clothing can produce some variance in recordings.

Manual measurements come with a higher margin for error than some 3D digital scanning techniques such as sonic digitizer probe and ELITE (Reed et al., 2000; Park et al., 2000; Andreoni et al., 2002; Hanson et al., 2006; Kyung and Nussbaum, 2009). One example of a 3D method of posture analysis is the ELITE system, which is an optoelectronic system that can reconstruct (with a claimed accuracy of 0.8mm) the three-dimensional trajectories of passive markers placed on the participant’s skin. This allows for a 3D simulation to be mocked up and the body angles of the drivers to be recorded in a given posture, which can then be compared with documented comfortable body angle ranges in the literature. Whilst this method is an accurate measure, and is indicated that it can be applied to both dynamic and static driving conditions, the equipment cost and set-up are significantly more time consuming compared with Porter and Gyi’s goniometer measurement approach. Some studies recorded only one side of the body, which makes an assumption on a symmetrical driving posture. However, two studies reported that there were significant variations between the left and right side of the body (Hanson et al., 2006; Kyung and Nussbaum, 2009). In addition, Schmidt et al. (2014) states that the complexity and interdependence of joint angles in a driving posture, means that the results of driving posture studies are influenced by the heterogeneity of the experimental set-up and protocol. In practice, an example of this is that the positioning of participants’ hands on the steering wheel can affect the wrist, elbow and shoulder angles being assessed (Schmidt et al., 2014).

Table 3.2. Driving posture and joint angle measurement critique of seven studies.

Topic	Author	Year	Title	Aim of Study	Method	Sample	Main Findings	Strengths and Limitations
The Seated Posture and Driving: Critical appraisal of research investigating driving posture by means of posture analysis and theorising comfortable body angles.	Reed et al.,	2000	Effects of Vehicle Interior Geometry and Anthropometric Variables on Automobile Driving Posture	To provide an understanding of the individual and interactive effects of seat height, steering wheel position and seat cushion angle on all of the major posture characteristics of interest for vehicle interior design.	Participants self-selected their optimum driving position by adjusting the backrest angle and the fore-aft of the seat. Variables included differing cushion angles and steering wheel positions. Body landmarks were placed and body angles were measured.	68 (34 males, 34 females)	1. Seat height, steering wheel position, and seat cushion angle each have different, largely independent effects on posture. 2. The effects of these three variables are independent of body size, proportion and gender. 3. Overall body size (stature) is the primary determinant of fore-aft hip position with respect to the pedals, but seat height, steering wheel position and seat cushion angle all have significant effects. 4. The ratio of sitting height to stature is an important predictor of hip-to-eye angle and elbow angle. 5. Knee and elbow angles, the primary measures of limb posture, are strongly influenced by seat height and steering wheel position. Over the range studied, steering wheel position has the stronger effect. 6. Seat cushion angle has a highly significant effect on both lumbar flexion and overall torso recline. But the importance of the effect is diminished by the restricted range of this variable in vehicle designs.	Laboratory based experiment, rather than field work (real-world applicability). There were no spatial or visual cues in the buck to aid a participant self-selecting their optimum driving posture, which exist in vehicles. Good sample size and evenly balanced a very repeatable method, experimental design.
	Porter and Gyi	1998	Exploring the Optimum Posture for Driver Comfort	Investigate the observed optimum driving postures and positions of the main driving controls for comparison with available data.	The pedals and steering wheel were fully adjustable. The floor and controls were moved around the seat with the seat having its own adjustment in tilt, backrest angle and lumbar support. The trial followed an iterative process of adjustment - each dimensions being adjusted across its full range of travel and back again until an optimum position was selected by the driver. Body angle measurement was taken using a goniometer joining fixed body landmarks.	55 (27 males, 28 females)	Generally, participants preferred to sit with a smaller trunk-thigh angle than previously recommended. Neck inclination, arm flexion and elbow angle were greater than the ranges of any previous recommendations. Results identified significant correlations between trunk-thigh angle and knee angle ($p<0.01$) and between arm flexion and elbow angle ($p<0.001$) respectively. A more 'open posture' was generally preferred by males with differences in arm flexion, elbow angle and trunk-thigh angle approaching significance	Large and balanced sample. The rig used for the trials was highly adjustable, which allowed for optimum selection of driver posture. The measurement of body angles was achieved manually using a goniometer, which is a crude measure and lacks the accuracy of 3D scanning or digital photographs for such data.

Topic	Author	Year	Title	Aim of Study	Method	Sample	Main Findings	Strengths and Limitations
The Seated Posture and Driving: Critical appraisal of research investigating driving posture by means of posture analysis and theorising comfortable body angles.	Andersson and Örtengren	1974	Lumbar disc pressure & myoelectric back muscle activity during sitting IV studies on a car drivers seat	Investigate the myoelectric activity of several muscles of the back and the lumbar disc pressure whilst sitting in a driving posture.	Three support parameters were explored: backrest inclination, lumbar support and seat inclination. Two driving manoeuvres were tested: depression of the clutch pedal and shifting gear.	4 (3 males, 1 female)	The disc pressure and myoelectric activity both decreased when the backrest was inclined backwards and when the lumbar support was increased. The seat inclination had a minor influence only. The disc pressure increased both when the gear was shifted and when the clutch pedal was depressed.	A very small sample size of 4 is not representative of the population of drivers and also very little detail on the seat that was used, other than 'Volvo drivers'. This was a simple study and the trunk-thigh angle was measured based on the inclination of the backrest, rather than body landmark measurement with either 2D or 3D methods.
	Park et al.,	2000	Comfortable driving postures for Koreans	Identify the relationships between preferred driving postures obtained by DPMS as well as the VICON 140 analysis system, seat adjustment level and anthropometric characteristics of participants. The obtained results can be applied to seat designs for better driving work and comfort.	A questionnaire was given to the participants to determine the 'important features' of a car seat considered for adjustment and obtaining a comfortable driving posture. 7 body landmark positions were placed on drivers and the posture and joint angles were recorded using a three-dimensional measurement system.	43 (24 males, 19 females)	Actual observed driving postures were compared with recommendations in the literature. Both the trunk-thigh angle and knee angle were greater than the ranges in the literature. There was a difference in the arm posture during driving according to gender, but not much difference in the trunk posture. These results indicated that there was a difference in preferred driving postures between Koreans and Caucasians.	Balanced sample and good sample size shows a good representation of the population. The study does not specify what inclusion criteria was outlined for participants other than they were healthy individuals with a good range of anthropometry. The experience of driving ranged from 2-242 months, which highlights the vast difference in time spent in a vehicle across the sample.
	Andreoni et al.,	2002	Method for the analysis of posture and interface pressure of car drivers	To develop a multi-factor method for the study of the car driver posture.	Based on an Alfa Romeo 155 mock up with seat fore-aft adjustment and backrest angle inclination. ELITE system, which is an optoelectronic system which can reconstruct (with an accuracy of 0.8mm) the three-dimensional trajectories of passive markers (21 for this study) placed on the participant's skin. This allowed for a 3D simulation to be mocked up and the body angles of the drivers to be recorded in a given posture, which can then be compared with documented comfortable body angle ranges in the literature	8 (7 males, 1 female)	Different and characteristic pressure maps were found among the participants for both cushion and for backrest. When assuming his/her own most comfortable steering posture, it is hypothesised that lumbar flexion angle could be an indicator of comfortable driving posture.	Small sample size, which is not evenly balanced, perhaps representative of the LCV driving population but this study did not specify only commercial drivers. Additionally, the study purposefully used participants with bigger percentiles. Digital measurement of body angles ensures a high level of accuracy when predicting theoretical joint angles to achieve a comfortable driving posture.

Topic	Author	Year	Title	Aim of Study	Method	Sample	Main Findings	Strengths and Limitations
The Seated Posture and Driving: Critical appraisal of research investigating driving posture by means of posture analysis and theorising comfortable body angles.	Hanson et al.,	2006	Preferred car driving posture using 3-D information.	Investigate drivers' preferred postures, preferred interior dimensions and how they characterise their postures.	3D study, using a laboratory mock-up on a driving simulator and a PCMan questionnaire. Mock-up had adjustable steering wheel, seat (in x and x), backrest inclination, footrest angle and depth of seat.	38 (17 males and 21 females).	Minimum-maximum intervals of preferred angles correspond well with other experimental studies. No preferred posture differences were found between males and females: nor were differences found when comparing posture after 5 and 25 minutes of driving. Significant differences were found between the left and right side. Postures described as comfortable, relaxing and restful. Found no difference in posture between small drivers (<170cm) and large drivers (>190cm).	A good sample size to investigate driver posture, not a balanced sample but a good number of both male and female participants. Laboratory mock-up not specified, can't relate to posture. Reported as perhaps not being representative of posture when driving a real vehicle in traffic.
	Kyung and Nussbaum	2009	Specifying comfortable driving postures for ergonomic design and evaluation of the driver workspace using digital human models.	To enhance and expand upon several existing recommendations for comfortable driving postures.	Participants were tasked to drive in six sessions that differed by; vehicle class (sedan and SUV), venue (laboratory and field) or seat (vehicle seats rated high or low for comfort). Sixteen joint angles measured in preferred postures using FARO and 3D stick figures were generated using DHM software.	38 (18 males and 20 females).	Driving postures were found to be asymmetric and different between age, gender, venue and vehicle class. Comfortable driving angles obtained for two different vehicle classes (Sudan and SUV).	Good sample size which is fairly balanced. Anthropometric spread is good for stature; however no other body dimensions are reported that are deemed important to selecting a comfortable driving posture.

The application of posture analysis in automotive seat comfort is evident from the literature. However, this method has a lack of reliability and the theoretical issue of ‘accuracy’ is imprecise. Pheasant and Haslegrave (2006) make reference to the ‘anthropometric inch’ (25mm) which is an expected level of accuracy in posture measurement, and note that it is virtually impossible to measure to a precision of better than 5mm. This in some part is due to the requirement of participants to be clothed and wearing shoes, which lead to differences between and within participants. Furthermore and most notably, this method has been used to explore conventional driving postures, predominantly in cars. As a result the comfortable body angles, optimum driving postures and theoretical models of comfort that have been identified using this method are specifically tailored for these vehicle types. The elevated posture is far removed from a conventional driving set-up and as such has different ergonomics considerations. The first objective of the proposed research is to ‘identify key parameters (seat sub-component dimensions) for a seat design in the elevated driving posture’. It is likely that there will be a wide range of comfortable body angles and subsequent driving positions as a result of developing a new seat with so many variables. Consequently, it is acknowledged that this method will not help to answer the objectives of the proposed research and therefore is not a suitable method choice.

3.3.2. Interface pressure mapping

Interface pressure mapping is used to identify the seat pressure distribution, commonly for automotive seating, and has been considered effective in predicting automobile seat comfort (Hertzberg, 1972; Kamijo et al., 1982). This section discusses papers found relating to interface pressure distribution and summarises their suitability for the proposed research.

Static seat pressure distributions have been investigated comprehensively to understand driver discomfort (Gyi and Porter, 1999; Kolich and Tabourn, 2004; Na et al., 2005; Kyung et al., 2008; Nag et al., 2008) and pressure mats have been used to provide visual and quantifiable data of seat pressure per unit area during driving. Generally speaking, it is assumed that a more even pressure distribution across the seat will result in lower ratings of discomfort from seat occupants (Yun et al., 1992; Kamijo et al., 1982; De Looze et al., 2003). Interface pressure measurement, it was hoped, would provide designers with easily quantifiable data which would indicate areas of the seat which were contributing to seat comfort/discomfort at an early stage in the design process. Whilst this is the case, there are few studies which report significant correlations between pressure measurements at the seat back and/or pan and reported discomfort (Yun et al., 1992; Thakurta et al., 1995; Vergara and Page, 2000; Kyung et al., 2008). Furthermore, there are a number of critiques of the studies mentioned above. Vergara and Page (2000) conducted their study with only six participants, and the study was exploring seated comfort in office chairs, which have different considerations compared with automobile seats in terms of comfort over extended periods of time e.g. dynamic and temporal seat factors. The study by Thakurta et al. (1995) does not report the statistical methodology, or the level of significance which is required to understand this conclusion in context. Kyung et al. (2008) investigated the relationship between driver comfort/discomfort and interface pressure and found that several types of pressure variables were linked with subjective responses. However, it was also acknowledged that there are many confounding influences, due to the practical limitations of pressure mapping, making this method more appropriate for short-term discomfort assessment rather than long-term. This is supported by the findings presented by Nag et al. (2008), investigating the human-seat interface weight distribution of the upper and lower body on office chairs. They found that the specified components in the set-up i.e. incline of seat backrest, presence or absence of armrest, armrest height, slope of seat pan and foot support, have a combined influence on the distribution of weight across a seat. This highlights the difficulty of using interface pressure mapping to reliably collect data for a wide range of drivers with different seat set-ups in the same vehicle set-up and also to reliably compare results between different seats/driving postures.

Some studies have identified a relationship between changes in pressure variables or postural movements and reported discomfort during simulated driving in a laboratory experiment (Na et al., 2005; Jin et al., 2009). This finding suggests that pressure mapping is a suitable method in identifying how occupants adapt their posture and move more frequently in the seat when they are experiencing higher levels of discomfort. Additionally, Gross et al. (1994), investigating the perceived comfort of 12 separate aspects of 50 different car seats, concluded that their pressure data were strongly related to perceived comfort and therefore perceived comfort could be predicted from a study. However, this study was based on a relatively short time exposure (5-10 minutes) which does not necessarily correspond with long-term sitting/driving conditions. This supports the conclusions of Kyung et al. (2008), in that this method is more suited to short-term sitting in identifying seat discomfort.

Despite some of these findings, there are studies which are conflicting in the use of interface pressure mapping to predict driver seat comfort/discomfort. Lee et al. (1993) conducted a study with a sample of 100 participants to evaluate 16 visually similar car seats. The seats had varying parameters of foam thickness and hardness, back contour and angle, cushion angle, spring suspension rates and side support to make them structurally different from each other. Each participant was asked to sit in each seat for a minimum of two minutes and then their perceived comfort was recorded in 10 body areas. Despite the large sample size, the results showed no significant correlations between subjective comfort and the pressure recordings taken. Gyi and Porter (1999) conducted two experiments, reported in the same paper, to evaluate the practical application of pressure mapping, varying the foam density and the posture to create levels of discomfort. The sample for both studies had a good anthropometric spread, with particular focus on recruiting six tall males and six short females. The results were in agreement with Lee et al. (1993) and indicated that there was not a clear, simple and consistent relationship between interface pressure and driving discomfort.

The literature has conflicting conclusions regarding how effective pressure mapping is in identifying occupant seat discomfort. However, the studies that have found a relationship come with critique. These studies tend to have a smaller sample size, unbalanced in both gender and anthropometry (Na et al., 2005; Jin et al., 2009), and also shorter exposure times (Gross et al., 1994). The studies that had a larger sample size and a larger anthropometric range of participants found no relationship between interface pressure and seat discomfort. It is therefore acknowledged that this method is not reliable in predicting seat discomfort and as a result will not help to address the objectives of the proposed research. Furthermore, it has been identified that several problems can occur when using pressure mats for extended periods of time relating to the calibration of the equipment (Kyung and Nussbaum, 2008). One of these problems is ‘creep’, which is a measurement drift under a constant load and another is ‘hysteresis’ which is defined as a force-displacement pattern between loading and unloading. It is acknowledged therefore that this method is not suitable for identifying seat discomfort in long-term sitting. An objective of the proposed research is ‘to understand the effects of a new seat design on long-term driver comfort, in comparison with a benchmark production seat’. It is important that long-term sitting is explored for this posture as the literature has identified that discomfort increases over time (Chapter 2, section 2.2). Therefore, this objective cannot be met reliably using this method and is deemed unsuitable for the studies in this thesis.

3.2.3. Electromyography

Electromyography (EMG) is a method that is widely adopted to explore muscular response to a given stimuli. This is an objective method that is often used in combination with a subjective approach, to explore driver discomfort over time. EMG can be used to either measure muscle activity under a certain load or to measure muscular fatigue; the muscle activity measure providing a more descriptive analysis of the effect of the activation. Surface electromyography (SEMG) is a commonly used tool in the automotive industry as it provides a non-evasive index of muscle activation

(Duchene and Goubel, 1993) rather than the alternative more invasive method of using fine wire electrodes to measure EMG intra-muscularly.

Predominantly, observed effects using EMG have occurred when exploring more extreme vehicle environments and thus more extreme occupant postures. For example, there is significantly more postural stress and often a combination of both trunk and neck rotation in extreme environments such as agricultural work (Kumar et al., 2001), weight lifting tasks using forklifts (Taoda et al., 2002) and even piloting helicopters (de Oliveira and Nadal, 2004). With this 'occupational exposure' (Mansfield, 2005) in these instances, EMG is a suitable method to identify muscle activity as the occupational task is repetitive and puts strain on core muscles. These postures are usually connected with WBV driving tasks (agricultural vehicles) which increase muscular fatigue over time and studies investigating this are often aimed at reducing injuries through occupational exposure.

A disadvantage of using EMG is that the processing methods and analysis of the data can often cause ambiguity when interpreting the results based on muscle activity. The power spectrum, also referred to as the power spectral density function (PSD), is often referenced when identifying muscle fatigue. Physiologically, fatigue increases as the tension and force of the muscles decreases as a result of insufficient oxygen, use of energy stores and a build-up of lactic acid. More lactic acid causes a decrease in the conduction velocity of muscle fibres, which in turn leads to a decrease in peak contraction values and an increase in contraction times. The result of this is an EMG spectrum shift to lower frequencies (Kumar et al., 2001). Frequency domain features have been shown to perform better than other domain features at predicting muscle fatigue (Al-Mulla et al., 2011), with median power frequency (MPF) being the most commonly used indicator (Cifrek et al., 2009). This is because it is not so susceptible to extremes in the range and therefore more sensitive; so a decrease in the MPF is therefore an indicator of fatigue.

Using time domain processing methods, the main indicators of EMG amplitude are the average rectified value (ARV), also known as the mean absolute value (MAV) and the root-mean-square value (RMS). These indicators are calculated by rectifying raw EMG data and an increase in electrical activity (EA) is a widely-used method of fatigue identification (Van Dieén, 1996; Ng et al., 1997). However, it has been found that using amplitude as a measure of fatigue can jeopardize the estimation and the calibration of muscle load, obscuring assessment of fatigue (Oberg, 1995). This is because the level of electrical activity and a shift in the frequency towards the lower end of the spectrum are both used as indicators of fatigue and as indicators of muscle activity. Therefore, muscle fatigue over time may be falsely suggested by the presence of muscle activity. In concurrence, it has been suggested that task-specific physiological disturbances (EMG) generally appear before cognition, meaning that muscle activity reaches a level at which it is perceived by the occupant before it could be associated with fatigue or indeed, discomfort (Mehta and Tiwari, 2000).

There is very little literature which identifies a clear correlation between muscle activity and subjective discomfort reporting. Whilst positive relationships have been observed (Lee et al., 1993; Graf et al., 1993; Udo et al., 1999; Salewytsch and Callaghan, 1999), there have been few cases of statistical relationships between measures of muscle activity and ratings of comfort or discomfort (De Looze et al., 2003; El Falou et al., 2003). A study by Lee et al. (1988) did identify that an increase in back and shoulder muscle activation was significantly related to an increase in discomfort over time; however there are no recent studies that have observed similar findings. This corroborates the primary use of EMG being to investigate muscle activity in more strained postures in extreme working environments.

In summary, previous studies where EMG has been an effective method for identifying occupant discomfort in a seated posture, the tasks have involved significant amounts of postural stress and, consequently, the muscles are working hard. In a task where the muscles are not being made to actively work, it is more difficult to observe changes. The proposed research is focussed on non-extreme environments (i.e. cars, LCVs) and the aim of a comfortable driving seat is to minimise muscle fatigue, therefore it is likely that EMG signals will be very small. A previously mentioned objective of the proposed research is ‘to understand the effects of a new seat design on long-term driver comfort, in comparison with a benchmark production seat’. Based on the findings, it is acknowledged that EMG is unsuitable as a method to identify differences in long-term discomfort between driving postures, as they are both primarily concerned with minimising muscle fatigue.

3.3.4. Comfort/discomfort rating scales

A fundamental aim of automotive seating design is for occupants to ‘feel’ comfortable. Comfort/discomfort rating scales provide occupants with the platform to report exactly how they are feeling during a driving task, relative to their normal experiences. Comfort or discomfort ratings are often reported as an alternative to objective measures (posture analysis, interface pressure mapping, EMG) as they are easier to obtain in experimental research. Additionally, if suitable objective measures do not exist for an area of research, subjective measures can provide a valuable insight from the user (Bhise, 2012). The following section identifies comfort and discomfort rating scales previously used in vehicle ergonomics research.

De Looze et al. (2003) treated both comfort and discomfort as a continuous scale, ranging from extreme discomfort through to extreme comfort. However the term ‘comfort’ can be regarded as an ambiguous term, and is certainly not something that is thought of as being anything other than ‘normal or ‘expected’. A continuous scale is advantageous in that it provides participants with a recognisable format and has often been applied to this area of research (Richards, 1980). Karthikeyan and Sztandera (2010) used a comfort affective labelled magnitude (CALM) scale when measuring perceptive scores of comfort and discomfort with different sets of fabrics (Figure 3.2). This has the advantage of being a large numerical scale (-100 to +100) and so occupants can make acute adjustments to their reported discomfort over time. However, a disadvantage is that this scale can encourage more prolonged thought and judgement and does not evoke a quick decision, making it harder to record whilst participants are conducting a task such as driving.

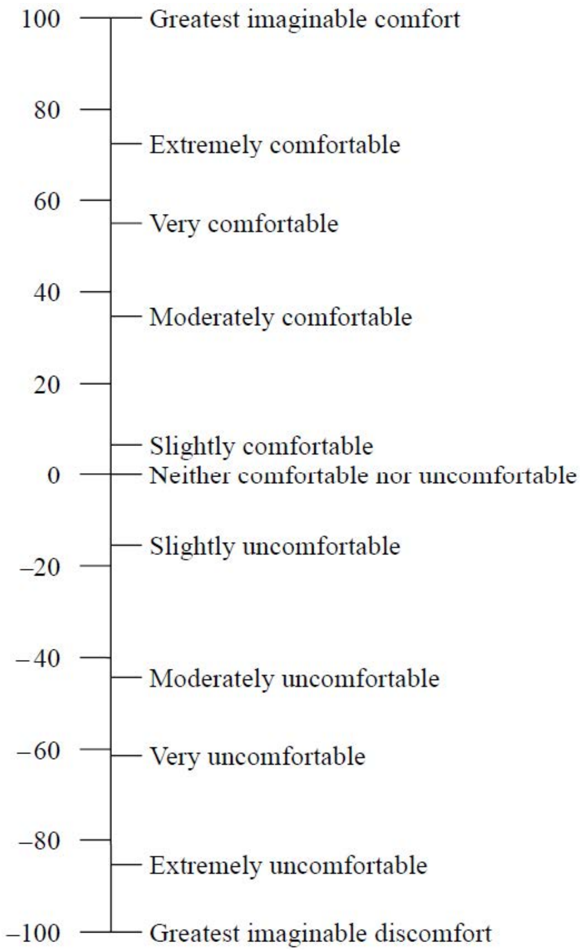

Figure 3.2. Comfort affective labelled magnitude (CALM) continuous subjective rating scale (Karthikeyan and Sztandera, 2010).

Alternatively, Gyi and Porter (1999) used a local discomfort questionnaire, which had a 7-point continuous scale (Figure 3.3) which provided a recognisable format for participants (Richards, 1980). This allowed participants to quickly identify which descriptor best fit their perception and the simplicity allowed participants to rate discomfort efficiently, whilst performing a task such as driving. A practical problem with this method is that there is ambiguity between ‘comfortable’ and ‘neutral’ where participants do not know what to state. An additional disadvantage is that it is hard to quantify discomfort, especially when considering how acutely perception of discomfort can increase/decrease, creating a grey area between two numerical discomfort ratings.

1	Very Comfortable
2	Moderately Comfortable
3	Fairly Comfortable
4	Neutral
5	Slightly Uncomfortable
6	Moderately Uncomfortable
7	Very Uncomfortable

Figure 3.3. 7-point continuous rating scale (Gyi and Porter, 1999).

Corlett and Bishop (1976) produced a body map for a standing individual, from which body parts could be assessed in isolation as opposed to overall discomfort. This map provided participants with a ranking system, where they would report which area of the body was the most uncomfortable, then the next most uncomfortable and so on. Gyi and Porter (1999) developed this body map for a seated individual for assessing occupant seat discomfort in a vehicle (Figure 3.4). Using this map, participants were asked to rate each body part from 1-7, using the verbal anchors identified in Figure 3.3 (very uncomfortable to very comfortable). Many laboratory based studies investigating seat discomfort have used a discomfort body map as a tool, specifically to collect data on localised discomfort (Kyung et al., 2008; Morgan and Mansfield, 2011; Mansfield et al., 2014; Mansfield et al., 2015). Of these studies, Kyung et al. (2008), imitated the standing rear-view diagrammatic (as created by Corlett and Bishop) which gives a clear image of the body areas represented. However it is more appropriate for a seated experiment to have the diagram representing this posture for participants to understand the context of the study. This type of seated body map has also been utilised to isolate areas of discomfort, to understand where on the body occupants feel uncomfortable during low-frequency lateral roll and oscillation (Beard and Griffin, 2013). Furthermore, body maps have also been used in different vehicle industries, for example Delleman et al. (2008) investigated sustained operation in confined-space military vehicles, asking participants to rate local discomfort in 40 regions of the body. This highlights the versatility of body maps to be used with different vehicle types and subsequent driving/workload tasks.

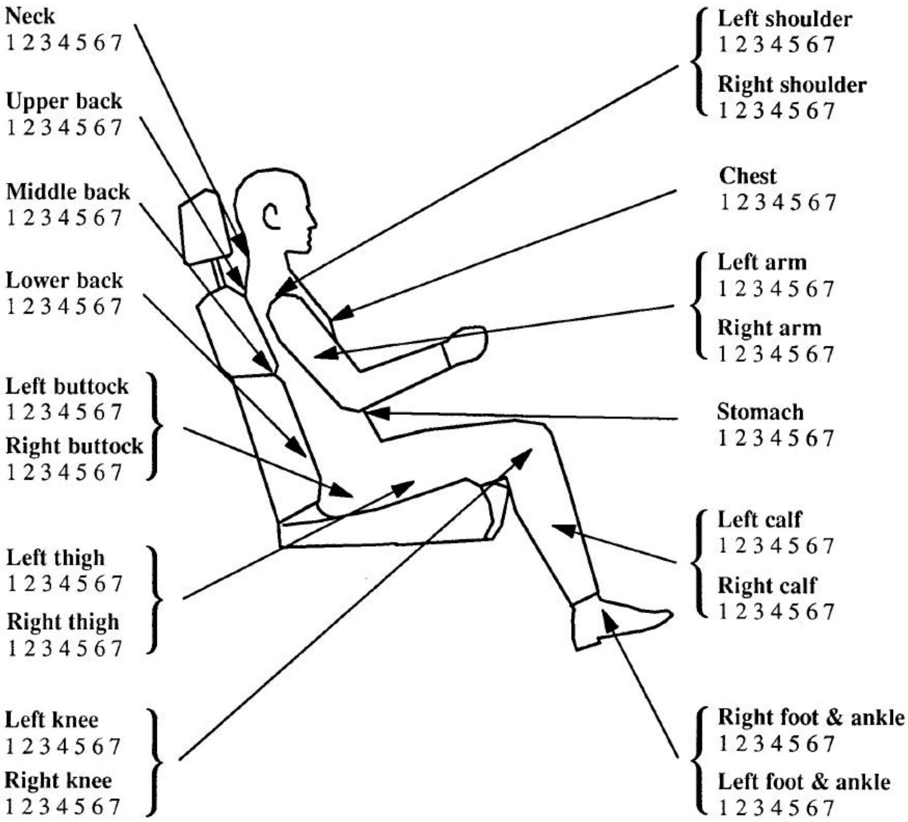

Figure 3.4. Body map: 1. very comfortable; 2. moderately comfortable; 3. fairly comfortable; 4. neutral; 5. slightly uncomfortable; 6. moderately uncomfortable; 7. very uncomfortable (Gyi and Porter, 1999).

Many studies (Zhang et al., 1996; Shen and Parsons, 1997; De Looze et al., 2003) report that comfort and discomfort are based on different variables and therefore have to be treated differently. In light of this, different verbal anchors have been used in laboratory testing of vehicle seat comfort. Morgan and Mansfield (2011) replaced the verbal anchors used in Gyi and Porter's (1999) study with verbal descriptions of the levels of discomfort expected from increasing levels of vibration, taken from ISO 2631-1 (1997); these verbal anchors spanned a scale of 'discomfort' only (Figure 3.5). This scale with verbal anchors has successfully been used in laboratory settings investigating driver comfort, making it a suitable choice for the proposed research (Mansfield et al., 2015). Additionally, Morgan and Mansfield (2011) focussed on the areas of the body that were relevant to the research and reported that participants did not struggle to apply discomfort ratings to the body regions specified.

Finally, to ensure that no additional effort aside from the task is required by participants, it is identified that sufficient instruction of using rating scales should be provided to the participant prior to the trial (Shen and Parsons, 1997). This can be a combination of allowing participants to familiarise themselves with the ratings, making the rating scale intuitive for participants and having visual aids to act as a reference should participants require.

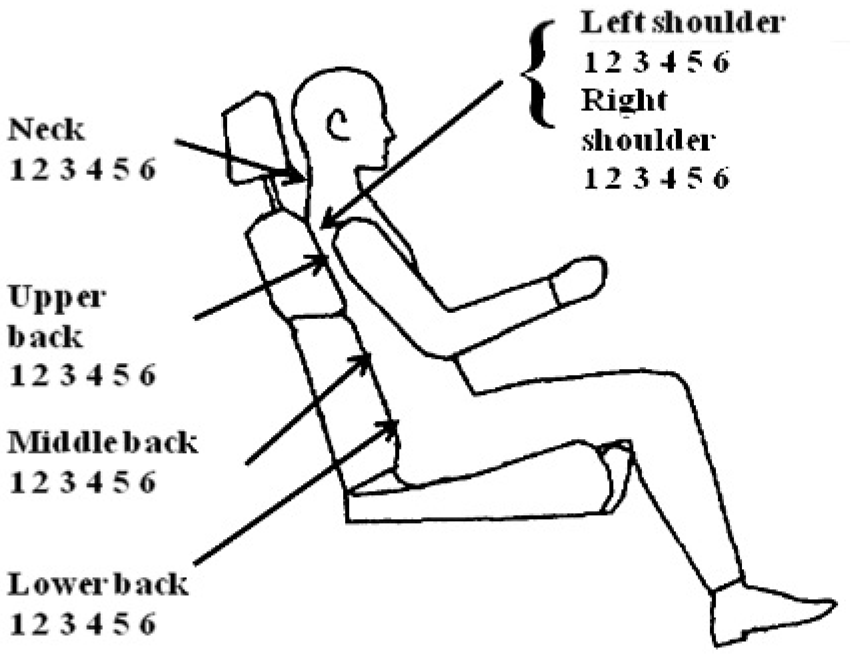

Figure 3.5. Modified body map (with ISO 2631-1, 1997 verbal anchors):
1. not uncomfortable; 2. a little uncomfortable; 3. fairly uncomfortable; 4. uncomfortable; 5. very uncomfortable; 6. extremely uncomfortable.

This section has identified that comfort/discomfort ratings are widely used in automotive ergonomics when exploring seat discomfort from an occupant's perspective. Additionally, there is evidence that body maps and discomfort rating scales work well together to collect data on many different vehicles. It has also been highlighted that comfort and discomfort should be treated as independent measures, with verbal anchors reflecting this. Based on these findings, a body map/discomfort rating scale combination with appropriate verbal anchors is a suitable method for exploring seat discomfort and lateral stability for an elevated driving posture, in comparison with a benchmark driving posture.

3.3.5. Anthropometry

Anthropometry is the measurement of human body dimensions, which can then be applied to help design and develop a product to accommodate a given user population (Bhise, 2012). User anthropometry is necessary to define many fundamental parameters of the vehicle, such as the position of the pedals, the location and size of the mirrors, the steering wheel position and the position of secondary controls.

A number of studies have collected anthropometric data when investigating driver comfort, often by investigating correlations between seat pressure or driver posture and subject anthropometry (Porter and Gyi, 1998; Reed et al., 2000; Kolich, 2003). Kolich (2003) identified that anthropometry should be considered a key aspect of comfortable seating and that designers must ensure that a diverse range of drivers can fit in to a vehicle seat. This is corroborated by Porter and Gyi (1998) who explored the optimum posture for driver comfort by designing an experimental rig capable of accommodating a wide range of participants from 1st percentile females to 99th percentile males. However, it is acknowledged that those at the extreme ends of anthropometric dimensions often have to compromise their comfort based on the target population of a given vehicle design, specified by the automotive company. Porter and Gyi (1998) analysed their data by comparing key participant anthropometry with postural angles and found significant correlations e.g. hip breadth was significantly correlated with trunk thigh angle ($p<0.001$). This does not concur with the findings of Reed et al., (2000) who found that large postural differences in the trunk-thigh angle were not well predicted by anthropometric differences. The latter reflects the complexity of driving posture and anthropometry, as occupants with similar anthropometric characteristics may sit in completely different positions (Kolich, 2008).

The measurement of body dimensions is usually taken using skeletal reference points, where there are fewer margins for error than using softer tissue or reference points on the skin. There are many anthropometry sources in human factors and ergonomics (Pheasant, 1996; Peebles and Norris, 1998; Tilley and Dreyfuss, 2002; Pheasant and Haslegrave, 2006; ISO 7250-1, 2008). These often outline terminologies and equipment used for data collection, provide pictorial and verbal definitions of anthropometric dimensions and provide tables detailing the percentile values and standard deviations for specific user populations. Additionally, there are multiple anthropometry surveys and databases that are available, which provide data for specific populations and are often used in digital human modelling and vehicle packaging (Army Anthropometric Survey (ANSUR); Civil American and European Surface Anthropometry Resource (CAESAR); Peoplesize).

In summary, anthropometric data is extensively used in vehicle ergonomics in order to understand the considerations and to accommodate a diverse driving population. This is of paramount importance in understanding a new driving posture and its seat requirements and so anthropometric data collection is a suitable method for the proposed research. Bhise (2012) highlights that automotive companies gather internal data by measuring the dimensions of participants who are invited to market research clinics, and evaluations of vehicle prototypes. This is also true of the automotive sponsor of the proposed research, who have their own internal engineering manual outlining the measurement methods and percentile values for their anthropometric data. After consultation with the sponsor, the decision was taken to use their internal methods to collect anthropometric data. It should be noted that they are very similar to those of Pheasant, 1996; Peebles and Norris, 1998; Tilley and Dreyfuss, 2002; Pheasant and Haslegrave, 2006 and BS EN ISO 7250-1, 2008, to allow for better transferability. The anthropometry measurement definitions and methodology are detailed in full in Appendix A1. The details of the body dimensions that were measured are specified for each study in the relevant chapters (Chapter 4, Chapter 5 and Chapter 6).

3.3.6. Seat fitting trials

It is important to identify what are believed to be the critical dimensions of a seat or workspace and then to design a mock-up in which each dimension can be adjusted independently over a wide range (Jones, 1969). The fitting trial process that Jones (1969) described was one where each parameter could be adjusted quickly, so that participants could experience a new setting before they forget the feeling of the last. Additionally, the dimensions were adjusted in set increments over a range which is far beyond the expected comfort zones for the occupant. The fitting trial method is potentially an accurate and systematic way of identifying the optimum location for the seat and driver package components, which contribute to achieving a comfortable driving position. The fitting trial process was adopted by Porter and Gyi (1998) when exploring the optimum posture for driver comfort whereby they designed an adjustable rig with adjustment of the steering wheel, pedals, workstation and floor around a fixed seat position, with additional adjustment of the seat tilt, backrest angle and lumbar support. Similarly, Kyung et al. (2008) modified this method to set up a participants' driving position before testing, by adjusting the seat fore/aft position, seat back angle, seat cushion angle, steering wheel angle and steering wheel fore/aft position. Unlike Jones (1969), who proposed the adjustment of each component separately (with the other components fixed in their initial position), Porter and Gyi (1998) and Kyung et al. (2008) adjusted components sequentially. This meant that each component was in a preferred position as the trial progressed, with the knowledge that each component's position will affect the position of the next, and final small adjustments were then made iteratively to fine-tune the preferred positions.

The advantage of a laboratory based fitting trial is that the researcher has a high level of control, in both the design and the reliability of the experiment. In support of this, Mansfield and Hazlett (2015) conducted a study to compare occupants' self-selected driving posture between a production vehicle and a rig replicating an identical seat, pedal and steering geometry with actual seat slide adjustment. The findings showed that there were no differences between the two set-ups. This suggests that drivers can relate to a driving posture that is removed from its natural environment (inside a vehicle). However, the validity of fitting trials must be considered at this early stage of seat development, because it is likely that in real-world set-up, factors such as visibility will affect the postures that are adopted during driving. Furthermore, experimental fitting trials provide a static assessment of comfort which is susceptible to change under the influence of both vibration and time, as identified in Chapter 2. Therefore, the findings from a fitting trial should be combined with further exploration of long-term discomfort to validate comfortable dimensions and this has been included in the objectives of the proposed research.

3.3.7. Driving trials

There are a number of methods in which driving trials can be conducted, depending on the aims and objectives of the research. There are three main methods of driving trials in vehicle ergonomics (Table 3.3). Road trials are advantageous in that they represent real roadway driving experiences and vehicle dynamics and so the method has validity. However, they are harder to control in respect to driver speed, progress and road traffic, making them less repeatable. Test-track methodology has the benefits of real vehicle dynamics and there is a greater level of control in terms of exposing each participant to a similar set of conditions. However, the lack of changing environment and road conditions (rural, motorway or town driving) means that this method lacks validity. These two methods offer driving research a higher level of validity in comparison with a driving simulator.

Table 3.3. Experimental studies; identification and exploration of on-road trials, test track trials and simulator trials.

Study type	Description
On-road trials	• Driving on real roadways, often in own vehicle • High degree of validity • Can be expensive to set-up • Can take a long time to collect data and analyse
Test track trials	• Studies can be conducted with minimal risk to participant and other road users • Representative of real vehicle dynamics • Hard to recreate dynamic driving environments (Regan et al., 2009) • Lacks validity compared to road trials
Simulator driving trials	• Dynamic driving environments (motorway, rural, urban) • High level of control • Low equipment costs (Reed et al., 1999) • Less immersive as a driving task than road trials • Vehicle dynamics not as accurate as a real car • Side effects such as simulator sickness (SS)

3.3.7.1. Driving simulator studies

Simulator based studies have the advantage of being in a safe environment for the participant to complete the driving task, whilst generally speaking (dependent on the fidelity of the simulator) offering participants a more varied driving environment (motorway, town or rural driving). In addition to an interchangeable roadway classification, high fidelity simulators can also replicate different time and weather conditions, which in turn affect the complexity of the driving task e.g. day driving, night driving, rain and fog. Furthermore, these conditions are highly controlled so that each participant is exposed to the same set of conditions irrespective of the day of testing, making it very reliable as an experimental methodology. The main disadvantage of simulator studies is that they lack ecological validity. The safety aspect of simulated driving leads to a potential behavioural change, where participants drive unrealistically when the risk of real driving is removed. Additionally, the simulated vehicle dynamics may not replicate those of a real vehicle which in turn affect the way in which participants control the vehicle (Reed et al., 1999; Engström et al., 2005). Whilst this is true, these disadvantages are more applicable to experiments that focus on assessing driving performance (headway, reaction times, and lane keeping).

Mayhew et al. (2011) found that on-road performance and simulator driving performance are significantly related, when looking at overall driving experience and the validity of simulated driving. An example of a low-fidelity simulator is the ‘Lane Change Task (LCT), which combines primitive driving simulation with a reaction time test (Mattes et al., 2009). The driving task requires participants to give a steering input, when instructed, around a test track with the speed kept at a constant. The output can then identify how well participants maintain their lane positioning by predicting participants’ mean deviation from the pre-set ideal path. This simulation has significant learning effects (Petzoldt et al., 2011) and is an example of a non-immersive task, with no traffic present, driving on a test-track and using only the steering wheel. However, the low-cost set-up and running of this simulator is the main advantage.

A potential side effect of using driving simulators is ‘simulator sickness’ (SS). Even when fixed-base simulators are used and thus no vibration is present, virtual environments can induce many of the same symptoms experienced when suffering from motion sickness and is often referred to as visually induced motion sickness (VIMS) (Lee et al., 1997; Kennedy et al., 2010). These symptoms, such as nausea and disorientation, arise as a conflict in sensory information which induces the illusion of self-motion (Treisman, 1977; Lee et al., 1997). This is further explained by the vestibular system’s effect on postural maintenance and the dependence on visual information. Whilst simulator sickness is reported in simulator studies, it is also possible to minimise the effect by conducting trials with a high fidelity simulator. This includes the presence of accurate WBV which reduces the effects of SS by giving a more consistent and ‘real’ feedback to the ocular and vestibular systems. Concurrently, Harms (1996) proposes that a lack of SS is a way to classify the fidelity of simulators, whilst Drexler (2006) identifies a general consistency of symptoms within simulators as opposed to between simulators.

In summary, the main advantage of simulator based studies for the proposed research is that a crash-safe seat was not required and it was unnecessary to incorporate the elevated posture on to a road vehicle. With this in mind, simulators were selected as being the only feasible method. The findings identify that whilst simulator studies lack ecological validity in comparison to on-road trials, this can be improved with a high fidelity simulator with a realistic and immersive driving experience. The presence of WBV and the development of a high fidelity simulator can reduce the effects of SS, by balancing the sensory inputs. The reliability of this method, with a high level of control, makes it a sensible methodology choice when comparing two different driving postures for a seat discomfort effect. It was therefore decided to use a driving simulator in the proposed research with rigs replicating both the elevated and conventional driving postures (Chapter 4).

3.4. Summarising the selected methodologies

This chapter has identified that a positivist approach was taken in designing the proposed research. The context of the proposed research, developing a new seat for a concept elevated driving posture, led to the identification of experimental methods for laboratory based trials. Current vehicle ergonomics methodologies have been explored and this section summarises the methods that have been selected and is presented by linking it to the research questions and the objectives of the proposed research. Where the methods are unique to a specific chapter, these methods have been described in more detail there. Additionally, this section details the sampling strategies that are available and their suitability for the proposed research.

3.4.1. Seat design parameters

The first research question was ‘Are there specific seat parameters that need consideration when packaging a driver in an elevated driving posture?’ As previously identified, it was not feasible to incorporate the elevated posture on to an actual vehicle platform which meant that the experimental study was directed towards a laboratory based trial. The literature has identified fitting trials as being the most suitable method to address this research question. This method is an accurate and systematic way of identifying seat design parameters (Porter and Gyi, 1998; Kyung et al., 2008) and it has been shown that seat positions identified in experimental mock-ups and real road vehicles are comparable (Mansfield and Hazlett, 2015). A fitting trial has the advantage of identifying individual seat parameters, whereby seat sub-components are moved one by one across a range of travel. For example, the length and the width of the seat base can be moved individually, following the hypothesis that the dimension of one parameter will directly influence the dimension of another. This is important because the elevated driving posture has not previously been explored and so all knowledge of comfortable seat parameters for a standard driving posture is far removed from the aims of for the proposed research

Additionally, driver anthropometry directly affects a comfortable driving set-up, and is deemed to be very important in vehicle ergonomics and is used extensively in vehicle packaging. There are many anthropometric references and the sponsor have their own methods, which are notably similar to those observed in the literature and are appropriate for the studies reported in this thesis. The full experimental design is described in more detail in Chapter 4.

3.4.2. Long-term discomfort evaluation

The second research question was ‘What are the long-term seat comfort considerations for drivers in an elevated driving posture compared with a conventional posture?’ As previously identified, it was not feasible to incorporate the elevated posture on to an actual vehicle platform, nor was the seat ‘crash safe’ which meant that the experimental study was directed towards a laboratory based trial. As discussed, anthropometry is extensively used in vehicle ergonomics and is once again a suitable method choice here. This is because a diverse range of occupants (in terms of body dimensions) will have differing comfort considerations during a long-term sitting trial based on the static and dynamic factors of the seat design (Kolich, 2008). The literature identified that body maps combined with comfort/discomfort ratings have been used effectively in occupant comfort assessment for many vehicle types (Morgan and Mansfield, 2011; Mansfield et al., 2014). This is important because the research question is concerned with comparing a new elevated posture with a conventional driving posture. Furthermore comfort and discomfort should be treated as different measures and studies have followed this approach by tailoring the verbal anchors to reflect levels of discomfort.

It was also identified that developing a high fidelity driving simulator provides an immersive task for participants to engage with. Simulators have the advantage of being very reliable, as the investigator has a high level of control in terms of exposing participants to the same driving experience during a trial (e.g. road type, weather conditions, time of day). These findings make a high fidelity simulator a suitable method when assessing long-term driving discomfort. It has been discussed (Chapter 2) that vibration increases the onset of discomfort and so the presence of whole body vibration is an appropriate addition to the selected methodology, to be able to answer the research question. The full experimental design for this study is described in more detail in Chapter 5.

3.4.3. Lateral stability evaluations

The third research question was 'When exposed to motion, what are the lateral support considerations for occupants in an elevated posture compared with a conventional posture?' As previously identified, it was not feasible to incorporate the elevated posture on to an actual vehicle platform which meant that the experimental study was directed towards a laboratory based trial. As discussed, anthropometry is extensively used in vehicle ergonomics and is once again a suitable method choice here. For example, occupants with a smaller hip width may be more susceptible to lateral motion if they are getting less lateral support from the seat compared with a driver with a larger hip width. Rating scales have been used extensively in vehicle ergonomics research. The use of this method is appropriate to answer this research question, as it is aiming to explore how stable occupant's 'feel' during lateral motion in a new elevated posture. Furthermore, the use of a motion platform is essential in answering this research question, as occupants need to be exposed to real levels of motion in order to rate their relative feeling of stability.

With this being said, there is a gap in the literature for experimental trials reporting perception to lateral stability from an occupant's perspective. The full approach, therefore, needs detailed exploration and piloting in order to select a reliable and valid methodology in order to meet the aims and objectives of the proposed research. The full experimental design for this study is described in more detail in Chapter 6.

3.4.4. Sampling strategy

The sampling strategy in research is associated with the external validity of research findings, which allows results to be generalised from the sample to the population (Robson, 2002). There are a number of different sampling strategies that are used in research, selected based on their appropriateness to, and the limitations of, the study (Table 3.4). For the studies reported in this thesis, stratified sampling was chosen as the most appropriate method to recruit participants. It is important for the proposed research that a balanced sample of male and female drivers was obtained and stratified sampling allows sub-groups to be specified in this way. To understand the driving ergonomics for an elevated seat position for the population, it was important to obtain a good anthropometric spread. Additionally, for the seat design parameters study (Chapter 4) and the long-term discomfort study (Chapter 5), it was important to recruit drivers with LCV experience, as a representative sample from the target population of drivers. With the time limitations of the proposed research, it was not always possible to get a sample of drivers which fitted with these criteria and so 'quota sampling' was also utilised, so that participants were selected based on their immediate availability.

Table 3.4. Summary of sampling strategies used in research (adapted from Allison et al., 1996).

Strategy	Summary
Simple random sampling	• Obtain a sample frame, number each participant in the frame and choose numbers at random • Every participant has an equal chance of being selected • Good chance of getting a representative sample
Systematic sampling	• First participant selected at random; further participants selected at equal intervals thereafter e.g. every tenth participant
Stratified sampling	• Used to split the population in to a number of smaller sub-groups e.g. male/female • Used when it is thought that the characteristics of the sub-groups will have an effect on the data being collected • Once strata identified, a simple random sample is taken from each sub-group
Quota sampling	• Similar to stratified sampling but accepting whatever participants are available from sub-groups
Cluster sampling	• Splitting the population in to sub-groups called clusters • Each cluster represents the various characteristics that the population might contain
Judgemental sampling	• Participants included that are thought to be representative of the population
Convenience sampling	• Includes participants that are immediately to hand

3.5. Equipment

This chapter has explored experimental methods used in vehicle ergonomics and appropriate methods have been identified and summarised to meet the objectives of the proposed research. This section describes the equipment that was selected to be used, in combination with the selected methodologies, in order to meet these objectives.

3.5.1. Motion platform (Multi-axis vibration simulator)

The literature has identified that the onset of discomfort increases with vibration and that a seat's dynamic characteristics must be considered when assessing overall seat discomfort. Building on this, a motion platform was needed to combine with the body map/discomfort rating scale and driving simulation methodologies. This section describes the motion platform at Loughborough University, as selected to meet the objectives of the proposed research, detailing the technical specification, experimental protocol and calibration methods.

The platform is a Rexroth Hydraudyne B.V. Micro Motion 600-6DOF-200-MK5 multi-axis vibration simulator which allows six degrees of movement to replicate a vibration condition (Figure 3.6). The non-simultaneous excursions have a range of:

- 323 mm movement in X
- 292 mm movement in Y
- 184 mm movement in Z
- 34 degrees roll
- 34 degrees pitch
- 54 degrees yaw

The following procedures would be followed for normal operation of the vibration platform:

- Participant seated on seat fixed to the platform with safety belt fastened.
- Area around the platform is cordoned off with a safety barrier.
- Platform is pressurised and set to neutral position (from -0.15 to 0.0m in z).
- Vibration exposure set and controlled by the operator for the duration of the experimental trial.
- Platform is set to settled position and depressurised.
- Participant instructed to egress the seat and platform.

Figure 3.6. The vibration simulator system used at Loughborough University.

3.5.1.1. Experimental protocol

Trials conducted on the vibration platform were in accordance with ISO 13090-1 (1998) 'Mechanical Vibration and Shock – Guidance on safety aspects of tests and experiments with people'. Safety barriers and tape marked off an 'inner zone', which is designed to avoid any contact by personnel with the motion base or any parts fixed to it. For safety, this zone was not entered whilst the motion was ongoing and the emergency stop button was in reach of the experimenter at all times. However in the case of a participant requesting a stop to the trial, the system is brought to a settled state by the experimenter. The platform is controlled by a dedicated computer to ensure sole control. A mechanical end-stop cushioning system is built into the actuators to avoid end-stop shocks, and additional accumulators were added to the hydraulic system to dampen motion during depressurisation in the event of a power or mechanical failure.

3.5.2. Accelerometers on the motion platform

The vehicle environment laboratory at Loughborough University has a motion platform (MAViS) with eight fixed accelerometers; the specifications of which are detailed in Table 3.5. Gravitation forces act on the seismic mass, secured inside the accelerometer casing. Consequently, the output for a vertically aligned accelerometer provides a measure of +1g (9.81 ms^{-2}) acceleration and an inverted accelerometer provides a measure of -1g (-9.81 ms^{-2}) acceleration (Mansfield, 2005).

Table 3.5. Manufacturer specifications for 8305A10 K-Beam accelerometers (Kistler Instrument Corporation).

Technical data	Units	Specification
Acceleration range	g	±10 (98.1ms^{-2})
Sensitivity (±5%)	mV/g	100/ms^{-2}
Resonant frequency (nom.)	kHz	2.7
Frequency response (±5%)	Hz	≥180
Operating environment	°C	-40 - 85

3.5.2.1. Calibration of motion platform accelerometers

The eight accelerometers are attached to the underside of the motion platform plate and, as already indicated, are a permanent fixture of the laboratory set-up. Using gravity as a known acceleration source, the accelerometers were calibrated as part of the laboratory set-up, using an ‘inversion test’. The inversion test is used to establish an agreement between the accelerometers. The process is to align the accelerometers vertically, on a horizontal surface, and then to turn the accelerometers through 180° for a few seconds before returning them to their original orientation (Mansfield, 2005). For convenience on set-up, the offset control can be used on a strain-gauge amplifier to set the vertically aligned output to ‘0’, with the resulting inverted accelerometer measuring -2g (-19.62 ms^{-2}). Figure 3.7 illustrates a typical output from an inversion test with a piezo-resistive accelerometer.

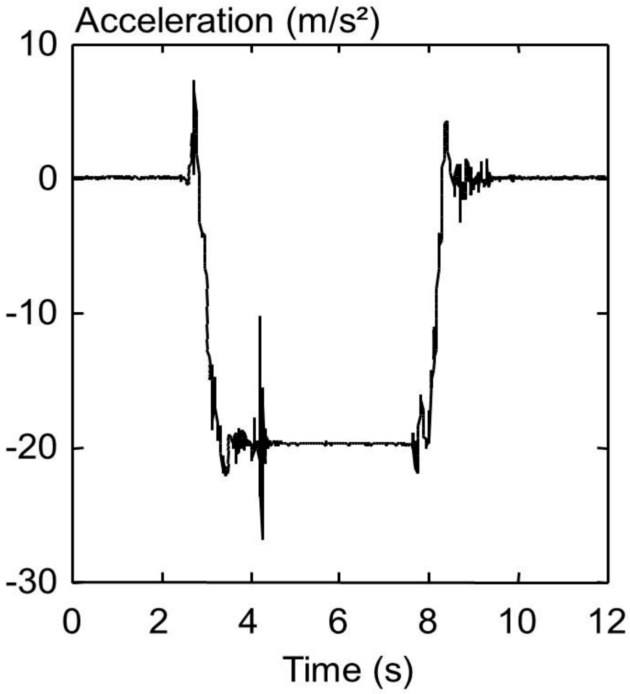

Figure 3.7. Typical signal from a piezo-resistive accelerometer undergoing an inversion test (set for upright measure of 0 ms^{-2} and an inverted measure of -19.62 ms^{-2}). Impulses in the signal correspond to impacts with the horizontal surface (image taken from Mansfield, 2005).

3.5.3. System characteristics

Participant characteristics (stature, weight) and preferred seat position have an effect on the vibration levels measured at the seat surface, which was an important consideration for the long-term driving study. Prior to each trial, the system characteristics can be calibrated using a Larson Davis Human Vibration Meter HVM-100 (Figure 3.8) with a tri-axial seat pad accelerometer. If measures are to be made on the seat surface, then the accelerometers should be mounted in a flexible disc, often referred to as an ‘SAE pad’ (Mansfield, 2005) (Figure 3.9).

Figure 3.8. Human Vibration Meter HVM-100 (Larson Davis).

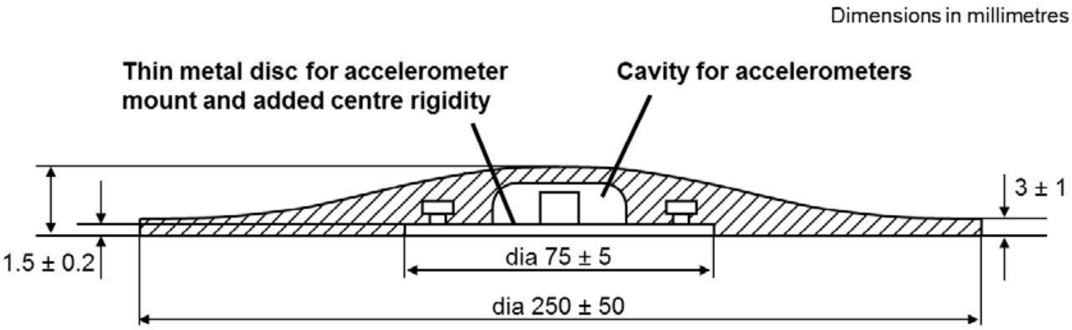

Figure 3.9. Design of flexible disc for mounting seat accelerometers as defined in ISO 10326-1 (1992), taken from Mansfield (2005).

The tri-axial seat pad accelerometer is placed on to the seat surface once participants have finalised their preferred seating position (Figure 3.10). A weighted equivalent metric is used on the HVM100, which provides the following frequency weighted outputs:

- W_dX (whole-body vibration of the seat in the x-direction)
- W_dY (whole-body vibration of the seat in the y-direction)

- W_kZ (whole-body vibration of the seat in the z-direction)
- ∑. (r.s.s. sum of the values W_dX, W_dY and W_kZ with a multiplication factor of 1.4 for X and Y values)

The calculation method uses the root-mean-square (r.m.s.) which squares every value in the signal, taking the mean and taking the square root of this final value. Mansfield (2005) highlights that, in theory, the mean value of a vibration signal will always be zero (positive values cancelling out the negative values) and so the r.m.s. method compensates for this and is a better indication of the magnitude of the signal. The system settings are adjusted to compensate for the dynamics of the seat-person system so that seat surface vibration (sum) is set at the target level. Once the systems characteristics have been calibrated, the seat pad is removed to ensure that it does not influence the seat comfort ratings during the driving trial. For the rest of the trial the vibration level at the seat base is kept constant and continually monitored. Previous pilot work showed negligible changes in vibration on the seat surface over time.

Figure 3.10. Adjusting seat-system characteristics using the Larson Davis HVM-100 with tri-axial seat pad accelerometer (image taken from Mansfield, 2005).

3.5.3.1. Calibration of Larson Davis HVM-100 accelerometer

The calibration of the Larson Davis HVM-100 accelerometer is checked using a Brüel and Kjær type 4294 calibrator at 125 Hz. This calibrator permits accurate adjustment of measuring g instrumentation at a standard acceleration level of 10 ms^{-2} (0-70g load).

3.5.4. Driving simulator

The simulator that was used for the reported studies was the 'XP Driving Simulator, XPDS 2.0.1', a product of XPI Simulation. The software was originally designed to help learner drivers, with a variety of capabilities including emergency stops and differing weather conditions. As part of the piloting and development of the proposed research, Loughborough University worked with XPI Simulation to tailor a driving simulation package to meet the task requirements. As part of this process, some of the physical parameters were removed from the driving scenarios so that the simulation did not stop running as a result of unsafe or erratic driving. This was important to compensate for the time taken for participants to familiarise themselves with the simulator. Additionally, the time of each driving scenario was extended to allow for more free-flowing driving. A full specification of the driving scenarios is detailed in Chapter 5. Furthermore, the simulator was updated from a one-screen to a three-screen system, to give the occupant a wider field of view and a more immersive driving experience (Figure 3.11).

Figure 3.11. Three-screen XPDS driving simulator set-up in the vehicle laboratory environment in front of the vibration platform and mounted driving rig.

3.6. Summary

This chapter has identified and summarised commonly used methodologies in vehicle ergonomics and it has been explained why specific methods have been selected for the proposed research. The diagrammatic (Figure 3.12) shows which methods have been identified for each study in order to meet the objectives of the research. The ethics for the experimental studies have not been discussed here; however this is detailed in the chapters relevant to each study (Chapter 4, Chapter 5 and Chapter 6).

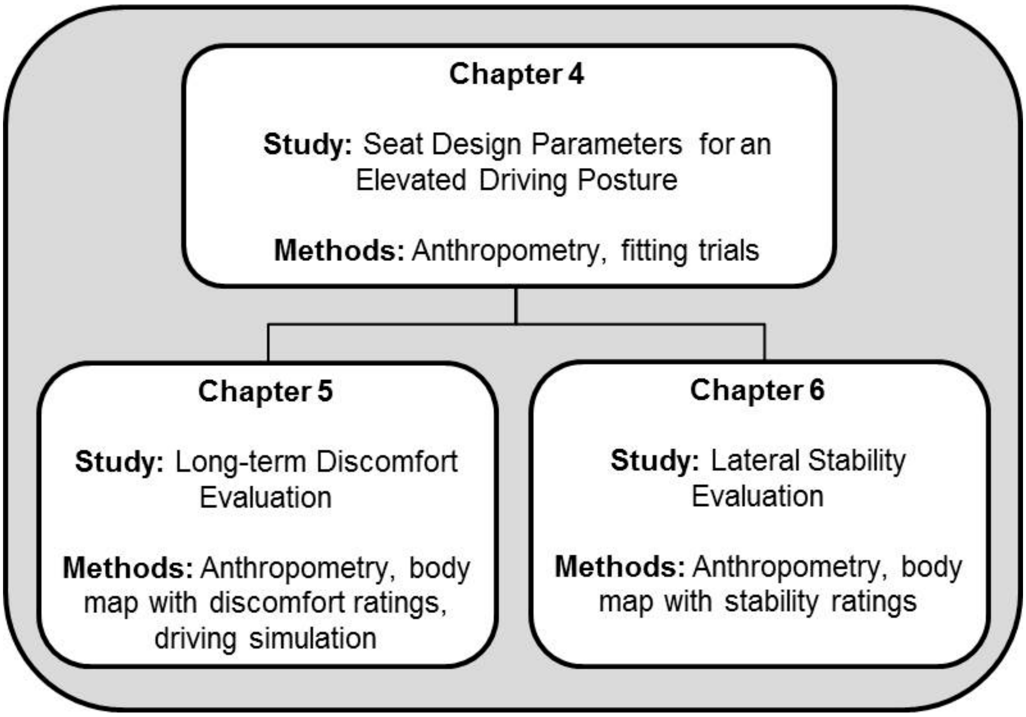

Figure 3.12. Diagrammatic of the methods selected for experimental studies and interactions (linking lines indicate information flow).

CHAPTER 4

SEAT DESIGN PARAMETERS FOR AN ELEVATED DRIVING POSTURE

4.1. Introduction

The interactions between the human body and the seat (musculoskeletal system and the biomechanics of sitting) have been reviewed in Chapter 2 to identify fundamental considerations when exploring a seated posture. Methodological approaches for research of driving posture have also been reviewed in Chapter 3 (seat fitting trials and anthropometry) to provide a basis for a repeatable experimental design. Factors contributing to 'seat comfort' (static and dynamic seat properties, foam thickness/hardness and opportunity for posture adjustment) along with ways of capturing seat comfort have also been identified. It has been determined from the literature that although there is a significant amount of research concerning the theory behind good sitting practice and tools for assessing seat comfort, there are no known studies investigating the concept of an 'elevated driving posture' and the ergonomics requirements of the driving workstation for drivers in this posture. The plan for the study presented in this chapter was to create a driving rig with a seat offering multiple adjustments of key design parameters, allowing a sample of drivers (with a large anthropometric range) to optimise their elevated posture set-up by way of a fitting trial. The output will provide an understanding of the seat design requirements for drivers in this posture whilst providing specific dimension requirements which could then be developed in to a seat design specification. A seat design lead by driver requirements will provide a platform for further investigation in to the comfort and suitability of the seat during dynamic testing (long-term discomfort and lateral stability). Being a new area of research, this study will seek new insights, ask questions and generate new ideas and hypotheses for future research.

4.2. Aims and objectives

The focus of this chapter is to identify the ergonomics considerations and determine the requirements of drivers in an elevated driving posture. A study was therefore conducted with the following objectives:

- Identify the key seat design parameters for the elevated driving posture.
- Understand the effect of seat design parameters on initial impressions of comfort in the elevated driving posture.
- Understand the suitability of the chosen research methods in identifying key seat parameters for the elevated posture.

4.3. Research method

4.3.1. Sampling strategy

The sample size was defined by the following criteria: large enough to perform statistical testing, practical limitations (e.g. time constraints), and driving experience. Twenty participants were recruited using a stratified random sampling technique, with the following inclusion criteria:

- 18 to 65 years old
  Rationale: younger (<18 years) or older (> 65 years) individuals were considered vulnerable population groups by the Loughborough University Ethical Advisory Committee (LUEAC) at the time of the study.
- Hold a full UK driving licence for a minimum of 2 years
  Rationale: the minimum of 2-years driving experience ensures that drivers will be at least 19 years old. Additionally, it allows a time period to gain experience of driving.
- Driving experience with light commercial vehicles (LCVs)
  Rationale: vehicles specified as vans, trucks, horse boxes, minibuses, and campervans. The importance of this was to ensure that drivers had knowledge of and reference points within a LCV driving set-up. The focus of the thesis is to explore an elevated posture for LCVs.

- Balanced sample by gender (10 males and 10 females)
  Rationale: a weakness highlighted from laboratory driving trials in the literature is that the sample is often not balanced by gender. As a new area of research, it is critical to understand the parameters for the elevated posture for both male and female drivers.
- Large anthropometric coverage
  Rationale: to fully understand the parameters for the elevated posture, for a physically diverse driving population.

Ethical approval was granted by the Loughborough University Ethical Advisory Committee (LUEAC) from Loughborough University in January 2012.

4.3.2. Elevated posture rig design and specification

For the purposes of this study it was necessary to design and construct a driving rig to replicate the elevated driving posture. The driving rig was specified by the researcher working closely with a Loughborough Design School technician. The design and construction of the rig was planned out in four stages (Table 4.1).

Table 4.1. Development and construction stages of the elevated posture driving rig.

Stage	Stage description	Equipment	Rationale
1.	Identify areas of the seat which need to be made adjustable for the trial.	Nissan NV200 seat	To gain as much understanding as possible as to which areas of the seat need adjustment in an elevated posture.
2.	Identify the type of adjustment required and how much adjustment would be needed.	Nissan NV200 seat	To understand exactly what that area of the seat did to support the driver. Once this was established, a range and type (lateral, vertical, prominence) of adjustment could be designed.
3.	Logistically plan how each adjustment can be engineered in to one driving rig.	Nissan NV200 seat	To logistically engineer how adjustments could be easily made by the researcher (without the need for tools).
4.	Build the driving rig on one platform.	Nissan NV200 seat (x2), MDF, galvanised steel	Materials chosen for strength and resistance to wear.

The aim was to design a rig that would allow multiple adjustments of the seat sub-components deemed important for seat comfort. The seat for the rig was developed from a current production Nissan NV200 seat, which was selected because of the application to the LCV market, the simple construction and the ease to which they could be modified. This NV200 seat is referred to as the reference set. Many of the existing dimensions of this 'conventional' seat were used as reference positions and defined some of the limitations for the adjustment ranges identified for the seat design of the elevated posture rig (Table 4.2) e.g. the seat height was tested upwards of 400mm as this exceeds the height for conventional postures. By testing seat heights >400mm, the gap in knowledge will be explored for the first time in this context and the requirements for the elevated posture will be identified for further research.

Table 4.2. Description of the seat sub-component adjustment ranges and rationale.

Seat sub-component	Adjustment range	Rationale
Seat height (distance in Z from the floor to the hip point).	400mm (400mm – 800mm)	A seat height of 400mm is currently observed in the LCV market and there is data available to support this driving posture. This study aimed at exploring seat heights upwards of this, where there was a gap in the knowledge.
Pedal-hip (PH) gap (distance in X from the hip point to the leading edge of the B pedal).	350mm (450mm – 800mm)	This study explored an elevated posture, with an increased seat height and a PH gap reduction. This adjustment range was defined by leg length dimensions for a JF05 and an AM99 driver.
Seat base length (distance in X from where the backrest intersects with the seat base to the front edge of the seat).	160mm (300mm - 460mm)	The current seat base length for the NV200 seat is 460mm. In the elevated posture it was hypothesised that the seat base will likely be shorter. The minimum was based on the limitations of the rig.
Seat width (distance in Y between the widest points of the seat base, including bolsters).	200mm (480mm – 680mm)	The minimum width dimension was determined by the NV200 seat and the way the rig was constructed. The adjustment of seat widths beyond this was explored for this posture, with the expectation that most drivers wouldn't need a narrower seat (than NV200).
Seat bolster height (dimension in Z added to the starting and reference position from the NV200 seat).	200mm (reference position - 1000mm)	It was anticipated that the higher seated posture would require additional lateral support. Therefore the adjustment tested the preferred bolster height upwards of that of the NV200 seat (standard posture).

Seat sub-component	Adjustment range	Rationale
Seat bolster angle (dimension in degrees iterating away from starting and reference position).	45° (reference position to 45°)	The minimum angle was defined by the contours of the NV200 seat, which was 80mm narrower at the back of the pad compared to the widest portion. Beyond 45°, the gap between the seat base and bolster would become prominent and the design was to give the driver the sensation of one seat base.
Lumbar height (dimension in Z from the seat base to the centre of the lumbar pad).	180mm (100mm – 280mm)	The lumbar pad itself was 150mm in height, which provided enough support for the lumbar portion of the back. The minimum dimension was determined by the bottom of the lumbar pad being in contact with the seat base. The maximum dimension was determined by the lowest edge of the upper backrest.
Lumbar prominence (dimension in X away from the line of the backrest with the lumbar pad).	100mm (reference position – 100mm)	The minimum dimension was determined by the rig and the NV200 seat. The maximum dimension was capped at 100mm as being suffice protrusion of the lumbar support.
Backrest height (dimension in Z from the seat base to the top of the backrest).	180mm (580mm – 760mm)	The minimum dimension was set 20mm lower than the NV200 seat and adjusted to 150mm beyond this height – the maximum was based on sitting height anthropometry with considerations of upper back support.
Backrest width (dimension in Y from the widest parts of the backrest, including bolsters).	200mm (510mm – 710mm)	The minimum dimension was determined by the NV200 seat contours (current width) and 200mm of adjustment was enough additional width to support larger drivers, based on shoulder breadth.
Backrest bolster height (dimension in Z away from the reference position – top edge of bolster).	100mm (reference position – 100mm)	The minimum dimension was determined by the NV200 seat contours and 100mm of adjustment was hypothesised to be enough for a seat component which was likely to be adjusted in small increments to reach its optimised position.
Backrest bolster fore-aft (dimension in X away from the reference position, from the backrest surface to the leading edge of bolster).	100mm (reference position – 100mm)	The minimum dimension was determined by the NV200 seat contours and 100mm of adjustment was hypothesised to be enough for a seat component which was likely to be adjusted in small increments to reach its optimised position.
Armrest height (dimension in Z from the seat base surface to the armrest surface).	200mm (100mm – 300mm)	The adjustment range was determined by sitting elbow height anthropometry for JF05 to AM99 drivers.
Armrest lateral position (dimension in Y from the centre of the seat base to the inside edge of the armrest).	200mm (In line with seat base bolster – 200mm outbound)	The minimum dimension was determined by the design limitations of the rig and the adjustment range covered the spread of shoulder breadth anthropometry for JF05 to AM99 drivers.

*Reference position – this refers to the Nissan NV200 seat with its original seat contours and dimensions.

4.3.2.1. NV200 seat dimensions: The reference seat

The NV200 seat was a reference seat for a standard LCV driving posture and had the following seat design parameters:

- Seat base length of 460mm.
- Seat base width of 480mm (400mm at rear of seat pad).
- Seat bolster height of 35mm (above seat pad surface).
- Backrest height of 650mm.
- Backrest width of 510mm.

These dimensions provided data for a comparison of key seat design parameters between a standard posture and an elevated posture and a starting point from which to design an adjustable rig for the fitting trial.

4.3.2.2. Identification of elevated rig seat sub-components

As an area of research with no supporting literature regarding seat design parameters in an elevated driving posture, the focus was to explore as many areas of the seat as feasibly possible. Details of the sub-components identified for adjustment and the rationale are shown in Table 4.3 e.g. the seat base length may need to be shorter as the biomechanics of the posture and the interaction of the drivers' legs with the pedals differ from a conventional posture.

Table 4.3. Identification of seat-sub components for adjustment in the fitting trial.

Sub-component	Rationale
Heel step (HS) Pedal-hip (PH) gap	These two dimensions are integral to the project. By increasing the heel step, the PH gap can be reduced, which has the benefits of lower vehicle mass and lower CO_2 emissions over the vehicle's lifecycle.
Seat base length	An increased heel step leads to a more upright posture and the direction from which the leg moves to operate the pedals differs to a conventional driving posture. A shorter seat base length may be required for movement in the upper legs, so that they can maintain pedal operation.
Seat width	An elevated driving posture could impact upon the seat base width requirement as with seat base length. With drivers sat higher in the vehicle cabin, lateral stability became an area of consideration and a static seat width adjustment provided the first insight in to this.
Seat bolster height	An elevated driving posture was expected to have an impact upon the amount of support, which is given and needed, for the buttocks and upper legs of the occupant.
Seat bolster angle	An elevated driving posture was not only expected to have an impact on the amount of support needed for the buttocks and upper thighs, but the specific area that this support was needed e.g. back of buttocks.
Lumbar height	The final position of the lumbar support was considered a crucial seat sub-component, as back pain experienced in long term sitting has been associated with inadequate lumbar support. With a large anthropometric range in a given population, the height of the lumbar zone on the spine differs, which is hard to accommodate in vehicle cabin design. Additionally, an elevated driving posture places the driver in a more upright posture, with the spine closer to its natural 'S' curve compared with a standard driving posture.
Lumbar prominence	It was important to not only know the required position for comfort and support, but also how much support is needed in that area. This is currently not known for a higher driving posture (Heel Step >400mm). This fitting trial will investigate how much support is needed in the lumbar zone to achieve a comfortable posture for a range of occupants.
Backrest height	It was imperative that the support offered for the upper back and shoulders was explored. The consideration lay with the length of the backrest itself and how much that would support larger occupants.
Backrest width Backrest bolster height Backrest bolster fore-aft	With a more upright driving posture, it was expected that the upper body would require more lateral support as a higher centre of gravity amplifies roll motion and cornering. This was explored through adjusting the width of the backrest, the height and fore-aft of the backrest bolsters.
Armrest height Armrest lateral position	Many LCVs have the option of an armrest whilst driving. Due to the nature of being higher up on the road a resting platform for the arm was expected to help in achieving a comfortable driving posture.

4.3.2.3. *Elevated posture rig specification*

A driving rig was built to the following specification in order to conduct a set of fitting trials for the elevated driving posture seat:

- A platform capable of incorporating and supporting an automotive driver seat.
- Have the capacity for independent adjustment of 14 seat sub-components.
- Have more mechanical adjustment than the specified ranges where safely possible.
- Have easily accessible and safe seat sub-component adjustment, with wing nuts and easy to use fixings for a quick and responsive adjustment.
- Must have fixings adequate of firmly locking each seat sub-component in place once locked.
- Assembly of seat sub-components and respective fixings must be done so in a way which allows the adjustment of one without having to adjust another.
- The seat sub-components must be upholstered to give the appearance of an automotive seat.
- All bolsters must be able to match up with the existing contours of the seat and backrest cushion as a minimum dimension.
- The shape of the lumbar pad must have a radius of 10” (Tilley and Dreyfuss, 2002). This matched the recommendation for office seating, which as a seated posture is close to the elevated driving posture.

The final rig was mounted to a frame built with a combination of MDF, steel and aluminium, to create a platform for the adjustable seat to be fixed upon (Figure 4.1). The seat sub-components themselves were made from current Nissan NV200 seats, giving a reference seat contour, foam composition and fabric. Additionally, the hard points and structure beneath the foam contours of the seat were all used from the Nissan NV200 seat, in order to have a reference seat to work back to. The adjustable rig offered a wide range of adjustment for all seat sub-components, allowing a comprehensive fitting trial to take place. Further details of the physical adjustment methods for each sub-component are illustrated in Appendix A2.

Figure 4.1. Assembled adjustable driving rig for fitting trials.

4.3.3. Study design and rationale

From the literature, it is evident that there are various techniques available to explore the interaction and comfort/discomfort between the occupant, the seat and thus the adopted driving posture. Posture analysis was considered as a method to identify a comfortable driving posture. Whether using manual goniometer measurement (Porter and Gyi, 1998) or optoelectronic scanning and digital photographing (Andreoni et al., 2002), posture analysis has proved to be an effective measure of determining a comfortable range of body angles (Chapter 3; section 3.3.1). However, the literature identified that posture analysis has a lack of reliability and the theoretical issue of 'accuracy' is imprecise. The elevated driving position changes the dynamics of the posture and so a range of comfortable angles becomes less relevant, in that there are currently no direct comparisons to make with the literature.

This research is aimed at identifying the seat design parameters for an elevated driving posture and so quantitative data relating to the position and dimensions of seat sub-components is required. This data will also provide knowledge on how drivers interact with this posture, in comparison to the conventional driving posture. The fitting trial process utilised by Porter and Gyi (1998) and Kyung et al. (2008) is an accurate and systematic way of identifying the optimum location for the seat and driver package components, which contribute to achieving a comfortable driving position. This method realises that changing one dimension will have an impact on the positioning of another and this premise was taken and applied to this research. The relationship between seat sub-components and driver comfort is currently unknown and so this approach was viewed as suitable. As an additional communicative tool, semi-structured questions asked after the main body of the trial were utilised in this research to help validate the quantitative data (anthropometry and seat positions).

4.3.3.1. Recruitment

Two methods of recruitment advertising were adopted; contact was made with the Facilities Management Department on the University campus and that led to an internal department circular for LCV drivers; adverts were placed on the intranet staff noticeboard, detailing the nature of the study in a digital recruitment poster. The first contact with the 20 participants (10 male and 10 female) was via e-mail, telephone or in person, with a brief explanation of the research and the nature of the fitting trial. Following that, interested parties were sent participant information sheets (Appendix A3) and asked for some basic body dimensions (e.g. stature) to monitor the anthropometric spread. If the individual agreed to take part they were asked to attend the fitting trial. They were instructed to wear flat shoes (e.g. trainers or a shoe with a heel of <4cm) to help standardise footwear.

4.3.3.2. Step 1: Anthropometric data collection

On arrival, participants were asked to re-read the information sheet, sign a consent from (Appendix A4) and fill in the health screen questionnaire provided (Appendix A5). Following this, anthropometric data was collected using a stadiometer, a sitting height table and an anthropometer. The set of anthropometric data taken was chosen based on its relevance to seat design and driving posture e.g. popliteal length is likely to influence how long a driver requires the seat base length to provide sufficient support beneath the thighs whilst allowing the legs to freely operate the pedals (Table 4.4). The definition of these measurements and the method of measurement are detailed in Appendix A1.

Table 4.4. Anthropometric data measurements selected for collection.

Dimension number	Anthropometric description
1.	Sitting height
2.	Shoulder width
3.	Sitting hip width
4.	Knee height
5.	Popliteal length
6.	Seat height
7.	Leg length
8.	Foot length
9.	Sitting elbow height
10.	Shoe size

4.3.3.3. Step 2: Fitting Trial

The experimental design for the fitting trial was based on a tried and tested method for laboratory based fitting trials. Porter and Gyi (1998) adapted the fitting trial process developed by Jones (1969). This involved iterative adjustment, moving each component incrementally through its travel, until a comfortable range was identified. This iterative process with fine increments of adjustment provided an accurate measurement and a realistic range of optimum driving positions.

The fitting trial was designed to move one seat sub-component at a time (for example, backrest height) and set it in an optimum position for the driver. The investigator adjusted each sub-component one by one, and if after any of the adjustments a sub-component position was compromised, the process would start again from that point (Appendix A6). The final seat sub-component positions were measured using a tape measure, an anthropometer and a 'seat stadiometer' built for purpose. The seat stadiometer was designed for the specific measurement of the 'heel step (HS)' and the 'pedal-hip (PH) gap'. The full definitions of how the sub-components were measured are presented in Appendix A7.

4.3.3.4. Step 3: Participant verbatim

After each participant had been set up in their optimum seating position, they were asked questions about their final seat set-up, relating it to own experience in a conventional driving posture. The investigator used a semi-structured interview approach to understand the reasoning behind their adjustment choices and common problems that occur for drivers in their day-to-day driving with regard to finding a comfortable driving posture (e.g. having long legs and large feet and forced to drive with an uncomfortably acute ankle angle).

4.3.4. Data Analysis

Statistical Package for the Social Sciences (SPSS) software for Windows (Release 21.0. SPSS©, Inc., 2014) was used for analyses. Correlations are useful to describe the strength and direction of the linear relationship between two variables (Tabachnick and Fidell, 2007). Pearson's product-moment correlation coefficient was used to identify relationships between the anthropometric data and the seat sub-component final positions. It is designed for interval level (continuous) variables making it applicable for this analysis. Multiple regression analysis was used to test 2 independent variables from step 1 testing (anthropometric data and seat sub-component position) as it has been shown to be statistically sound at predicting a dependant variable. It is an effective statistical method of assessing the relationship between a dependent variable and several independent variables (Tabachnick and Fidell, 2007) and in this context was a method employed to predict the contribution of certain independent variables (anthropometry and seat sub-components) in the outcome of the dependent variable (seat sub-component). Microsoft Excel for Windows 7 (Microsoft© Office, 2013) was used to run root-mean-square (r.m.s.) analysis on the self-selected seat sub-component positions.

The data analysis was conducted in a four-step approach:

Step 1. Correlation analysis between anthropometric data and seat sub-component position.

Step 2. Correlation analysis between individual seat sub-components positions.

Step 3. Multiple regression analysis between variables identified as being statistically significant predictors from step 1 and 2 testing (p=< 0.05).

Step 4. Root means squared (r.m.s.) analysis on final seat sub-component positions.

4.3.4.1. Step 1: Correlation analysis between anthropometric data and seat sub-component position

The first action was to identify which anthropometric dimensions and seat sub-components should be analysed together. These were chosen logically based on which dimension would be likely to have a relevant impact upon where participants adjusted certain areas of the seat. Table 4.5 shows which anthropometric dimensions were chosen to be paired with specific seat sub-components and why (e.g. leg length is likely to be a good predictor of where drivers set themselves up in the vehicle).

Table 4.5. Seat sub-component vs. driver anthropometry for correlation analysis.

Seat Adjustment	Anthropometry	Rationale
Heel step	Leg length	The position of the hip point relative to the floor is likely to be determined by the length of drivers' leg.
PH gap	Leg length	The position of the hip point relative to the pedals is likely to be determined by the length of drivers' leg.
Seat length	Popliteal length	The popliteal length (measured from the back of the buttocks to the back of the knee) is the specific area that is usually seated on a seat pad whilst driving.
Seat width (including bolsters)	Sitting hip width	The amount of lateral support required from the pad, including bolsters, is likely to be influenced by the dimension representing the widest point of the hips/thighs when seated.
Seat pad bolster angle	Sitting hip width	The angle of the bolster may be in some way affected by the width of the driver's hips.
Lumbar height	Sitting height	The height of the lumbar may be affected by a driver's sitting height (the dimension from the buttocks to the top of the head in Z).
Upper backrest height	Sitting height	The selected height of the backrest is directly linked to the sitting height dimension, with the backs of drivers in contact with backrest in the elevated posture.
Backrest width (including bolsters)	Shoulder width	The width of the backrest may be directly influenced by the width of a participants shoulders and how much support they require.
Backrest bolster height	Sitting height	The height of the backrest bolsters and exactly where that support is required laterally could be directly influenced by the sitting height of the driver.
Armrest height	Sitting elbow height	How high drivers select the armrest to be may be influenced by the natural sitting elbow height.
Armrest width	Shoulder width	How far from the centre point drivers position armrests may be directly influenced by the shoulder width and thus natural arm position of the driver.

*NB – Seat bolster height, lumbar prominence and backrest bolster fore-aft not tested due to no logical driver anthropometry to correlate with.

4.3.4.2. Step 2: Correlation analysis between individual seat sub-components positions

The first action was to identify which seat sub-components should be tested with one another. These were chosen logically based on which adjustments were likely to have an impact upon where participants adjusted other parts of the seat. Table 4.6 shows which seat sub-components were chosen to be paired with one another and why (e.g. the preferred width of the seat is likely to influence the preferred lateral position of the armrests).

Table 4.6. Seat sub-component vs. seat sub-component for correlation analysis.

Seat adjustment 1.	Seat adjustment 2.	Rationale
1. Heel step (HS)	Pedal-hip (PH) gap	Both have a strong correlation with leg length and the higher the driver is in the vehicle, the further away they need to be from the pedals in this posture.
2. Seat length	Seat width	Those drivers requiring more support from the seat base length, are likely to have a larger popliteal length and thus be a larger percentile driver, requiring more seat width.
3. Seat width	Seat base bolster height	Requiring more width from the seat indicates a larger percentile driver and thus perhaps more lateral support up the thigh is required.
4. Lumbar height	Upper backrest height	A higher lumbar pad placement is likely to be replicated with a higher positioning of the upper backrest, everything shifted up.
5. Upper backrest Height	Backrest bolster height	The position at which drivers require lateral support from the backrest is likely to be affected by the height at which the backrest is selected.
6. Armrest width	Seat width	The width of the seat is likely to have an impact on where drivers want their arm to rest – for a larger seat width; drivers are more probable to have a further outbound resting position for their arm.
7. Lumbar prominence	Backrest bolster fore-aft	With more lumbar prominence, the torso of drivers is likely to be further forward/more upright, meaning that bolsters may need to be more forward from the seat in order to provide adequate lateral support for the upper torso.

4.3.4.3. Step 3: Multiple regression analysis

Following the correlation analysis in steps 1 and 2, significant variables with a minimum threshold (Pearson correlation coefficient) r value of >0.3 are advised as having a strong enough correlation (according to Tabachnick and Fidell, 2007) for consideration for multiple regression testing. A similar process to step 1 and 2 was followed, with a logical and relevant combination of variables for each test (Table 4.7). No more than two independent variables were used per multiple regression test, due to the small sample size and the appropriateness of variables available per test.

Table 4.7. Dependent and independent variables identified for multiple regression analysis.

Dependent variable	Independent variable 1	Independent variable 2
Seat base length	Popliteal length	Seat width
Seat base width	Sitting hip width	Seat base length
Backrest height	Sitting height	Backrest bolster height

4.3.4.4. Step 4: Root-mean-square (r.m.s.)

R.m.s. analysis was conducted to establish the 'best-fit for sample' dimensions for each of the seat sub-components. The r.m.s. error is the square root of the mean of the square of the difference between the model and the observed value (Tabachnick and Fidell, 2007). This calculation was used to identify the seat sub-component dimension (from the fitting trial) which had the lowest difference (error) between that and the model.

$$\sqrt{(average((model - observed)^2))}$$

The r.m.s. analysis was only conducted on those seat sub-components that had a larger range of observed adjustment across the sample and/or they were deemed to have more relevance to achieving a comfortable elevated driving posture.

4.4. Results

In this section, the results of the fitting trial are reported, detailing the final seat sub-component positions and the results of the correlation analysis with driver anthropometry. The r.m.s. analyses together with verbatim from participants in their self-selected elevated driving posture are also reported. The anthropometric data and driver characteristics of the 20 participants recruited for the fitting trial (10 male and 10 female) were collected (Appendix A8). Participants were 19-65 years of age (*M* = 39; *SD* = 12), with differing levels of driving experience, ranging from (estimated) 250 to 100,000+ miles (*M* = 25,975; *SD* = 33,069) driven in LCVs. The anthropometric percentile ranges were calculated (Table 4.8) and showed that there was a good anthropometric spread, from Japanese female 7th percentile to American male 87th percentile in leg length (Figure 4.2 and Figure 4.3). The rationale behind using the Japanese and American percentiles is that these are common reference points for automotive companies such as Nissan when packaging occupants within a vehicle as they represent some of the smallest (JF) and largest (AM) populations in the world.

Table 4.8. Anthropometric data percentile range (n=20).

Dimension	Min (mm)	Max (mm)	Range (mm)	Percentile Range
Sitting height	818	1004	185	JF21 – AM97
Shoulder width	382	480	106	JF19 – AM81
Sitting hip width	329	439	110	JF04 – AM83
Knee height	439	608	169	JF37 – AM98
Popliteal length	385	500	123	JF02 – AM65
Seat height	350	470	120	JF43 – AM92
Leg length	843	1131	288	JF07 – AM87

*JF = Japanese female; *AM = American male (Nissan Engineering Manual percentile calculation)

Figure 4.2. JF07 female participant in their optimised elevated driving posture; left to right, side profile without armrest and with armrest.

Figure 4.3. AM87 male participant in their optimised elevated driving posture; left to right, side profile without armrest and with armrest.

The final seat sub-component positions were recorded by the investigator once the fitting trial had run through the iterative process and participants had optimised their elevated driving posture set up (Appendix A9).

The descriptive analysis (Table 4.9) shows that the PH gap had the biggest range of adjustment (180mm) whilst the lumbar prominence had the smallest range of adjustment (27mm). The PH gap and the heel step were expected to have the largest ranges of adjustment as they determined the position of the driver in the rig. Interestingly, the seat base length dimension reflects one of the smaller ranges of adjustment across the sample tested, however it was found that this dimension had the biggest impact upon the self-selected heel step and PH gap of the participant. The lumbar height adjustment range (157mm) reflects the diversity of participant requirements for this dimension and its importance of this for the elevated driving posture.

Table 4.9. Full range of adjustments for seat sub-component dimensions.

Seat sub-component	Min Adjustment (mm)	Max Adjustment (mm)	Range of Adjustment (mm)	Mean Adjustment (mm)
Heel step	550	681	131	605
PH gap	626	806	180	692
Seat length	332	409	77	378
Seat width	500	634	134	562
Lumbar height	60	217	157	177
Lumbar prominence	0	27	27	9
Upper backrest height	615	738	123	689
Backrest lateral support	442	539	97	483
Armrest height	190	260	70	230

4.4.1. Elevated posture observations

As a new area of research, this fitting trial study gave an opportunity to observe and understand key design and user considerations which in turn helped to develop knowledge regarding an elevated driving posture. The change in biomechanics for this posture has previously been described as the knee point being positioned lower in the vehicle than the hip point of the driver, which differs from a standard posture where the opposite is typically true. This study helped to visualise that posture change (Figure 4.4) and to understand the potential space saving and reduction in the overall length of the vehicle benefits for this concept.

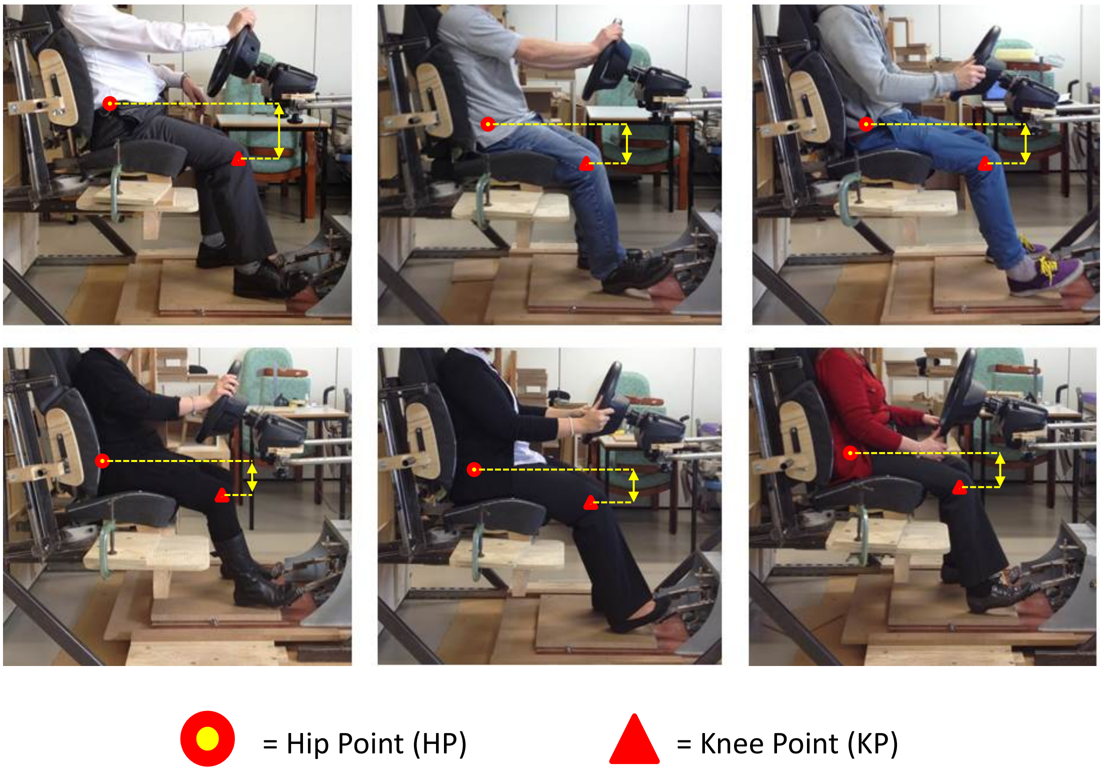

Figure 4.4. 6 participants (3 male and 3 female) in differing optimised seat set-ups demonstrating the 'knee-point below hip-point' concept.

An additional observation regarding this posture is that drivers appear to be sat upright, comparable to the seated posture on an office chair. The back is straighter with less recline in the backrest compared to the conventional posture. However, the knee being positioned lower than the hip point opens the trunk-thigh angle up and based on photographic observation, is comparable to the comfortable angle ranges identified for a conventional posture (Porter and Gyi, 1998; Reed et al., 2000; Kyung and Nussbaum, 2009). Furthermore, drivers were aware of sitting more upright in their driving position, which did not feel unnatural or distinctively different to a standard LCV driving posture (section 4.4.6).

4.4.1.1. Key seat design parameters

Of the 14 seat sub-components that were tested in this fitting trial, there were four that were highlighted by analysis (Seat base length; seat width; backrest height; lumbar pad position) as being key seat design parameters for this posture. The first of these was the length of the seat base which was considerably shorter than that of the reference NV200 seat. It was hypothesised that logistically a shorter seat base would be required, to meet the changes in the biomechanics and the angle of the leg. It was observed that with the leg intercepting the pedals from a steeper angle, drivers needed more of their leg free to manoeuvre between the A and B pedals. Reoccurring feedback during the trial was that initially the shorter seat base felt ‘unusual’ or ‘odd’ but also that this feeling dissipated as the trial progressed and was acknowledged as being different as opposed to uncomfortable. Over the duration of the trials, it was observed that participants would look for a balance of comfort, between a seat base length which offered enough support under the thigh and enough freedom to move the legs for operation of the pedals. As anticipated, drivers with a longer popliteal length would require more length to the seat in order to offer enough support beneath the thighs.

The width of the seat base was generally preferred to be wider, especially by larger drivers. An issue which was raised was that of losing lateral support from the bolsters for large drivers when they become part of the seat surface beneath the buttocks, as the seat isn’t wide enough. This is something which is of particular importance as lateral stability in an elevated posture is an important consideration for this research. There was a similar finding for the backrest width, with larger drivers requiring a wider surface to receive the benefits of the lateral support (bolsters). Conversely, smaller drivers wanted to be able to feel that support without too much of a gap between themselves and the bolsters.

Larger drivers generally preferred the backrest to be fixed higher than that in the reference seat. This was reported as being needed for sufficient support of the upper back and shoulders for the elevated posture. With a more upright posture, it was noted that support and contact with the backrest became more noticeable for the majority of the back, especially the upper back and shoulders of participants. This was also true for the positioning of the lumbar pad. Participants felt that they required noticeable support in the lumbar area of their back due to having a straighter and more upright back and wanting to remain supported in that way. Drivers reported that they rarely had the opportunity or advantage of being able to allocate support to this specific area of their back and one which was beneficial in achieving a comfortable posture. This is contrary to a standard driving posture, in which the lumbar portion of the spine is often not in such direct contact with the backrest.

4.4.2. Correlation between anthropometry and seat sub-component

After participants had decided their optimum driving position, the final sub-component positions were measured by the investigator. The relationship between the final positions of seat sub-components in the elevated driving posture (as measured in mm) and selected driver anthropometry (as measured in mm) was investigated using Pearson product-moment correlation coefficient. Table 4.10 details the results of the correlation tests as outlined in Table 4.5.

Table 4.10. Pearson correlation coefficients for anthropometry vs. seat sub-components.

Correlation Test	Pearson correlation coefficient (r value)	R squared value
Heel step vs. Leg length	.700**	.489
PH gap vs. Leg length	.717**	.514
Seat length vs. Popliteal length	.412	.170
Seat width vs. Sitting hip width	.389	.151
Seat pad bolster angle vs. Sitting hip width	.042	.002
Lumbar height vs. Sitting height	.069	.005
Upper backrest height vs. Sitting height	.631**	.399
Backrest width vs. Shoulder width	.326	.106
Backrest bolster height vs. Sitting height	.063	.004
Armrest height vs. Sitting elbow height	.340	.116
Armrest width vs. Shoulder width	.212	.045

**. Correlation is significant at the 0.01 level (2-tailed).

Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity. There was a strong, positive and significant correlation between three pairs of variables: driver leg length and heel step (Figure 4.5), $r = 0.70$, $n = 20$, $p = <0 .01$, with a longer leg length predicting a higher heel step (percentage of variance = 49%); driver leg length and pedal-hip gap (Figure 4.6), r =0 .72, n = 20, p = <0 .01, with a longer leg length predicting a larger pedal-hip gap (percentage of variance = 52%); driver sitting height and upper backrest height (Figure 4.7), r = 0.63, n = 20, p = <0.01, with a larger sitting height dimension predicting a high upper backrest position (percentage of variance = 40%).

For all other correlation tests between seat sub-components and driver anthropometry, the strength of the relationships was small and the correlations were not statistically significant.

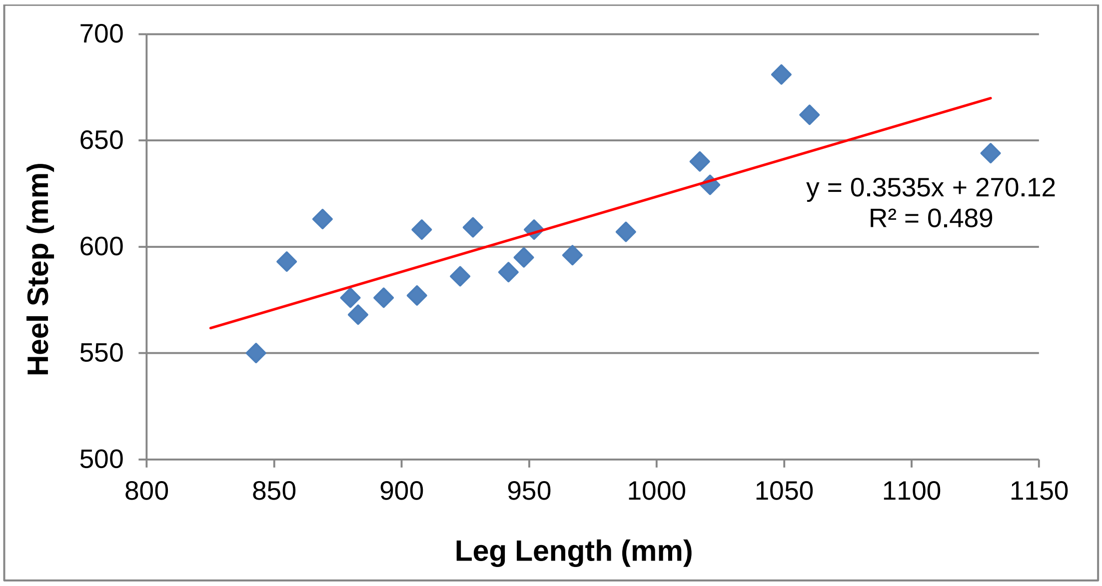

Figure 4.5. Heel step (mm) vs. Leg length (mm) – positive correlation plot (p < 0.01).

The plot (Figure 4.5) shows that leg length is a strong predictor of heel step, with a longer leg length predicting a higher heel step position. Additionally, the plot shows that the range of adjustment for the sample was 131mm, between 550mm – 681mm.

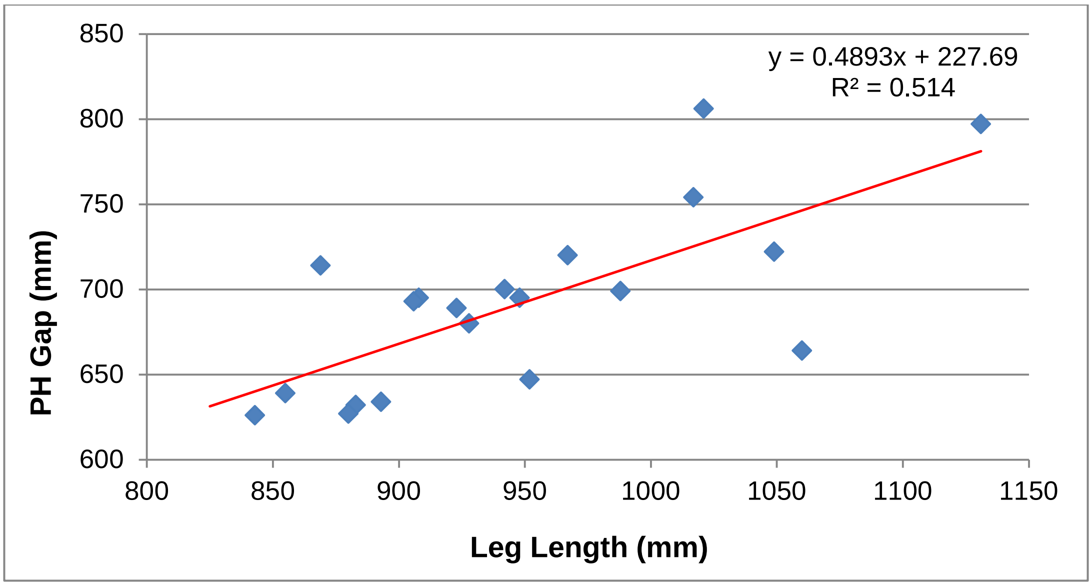

Figure 4.6. PH gap (mm) vs. Leg length (mm) – positive correlation plot ($p < 0.01$).

The plot (Figure 4.6) shows that leg length is a strong predictor of PH gap, with a longer leg length predicting a larger PH gap dimension. Additionally, the plot shows that the range of adjustment for the sample was 180mm, between 625mm – 805mm.

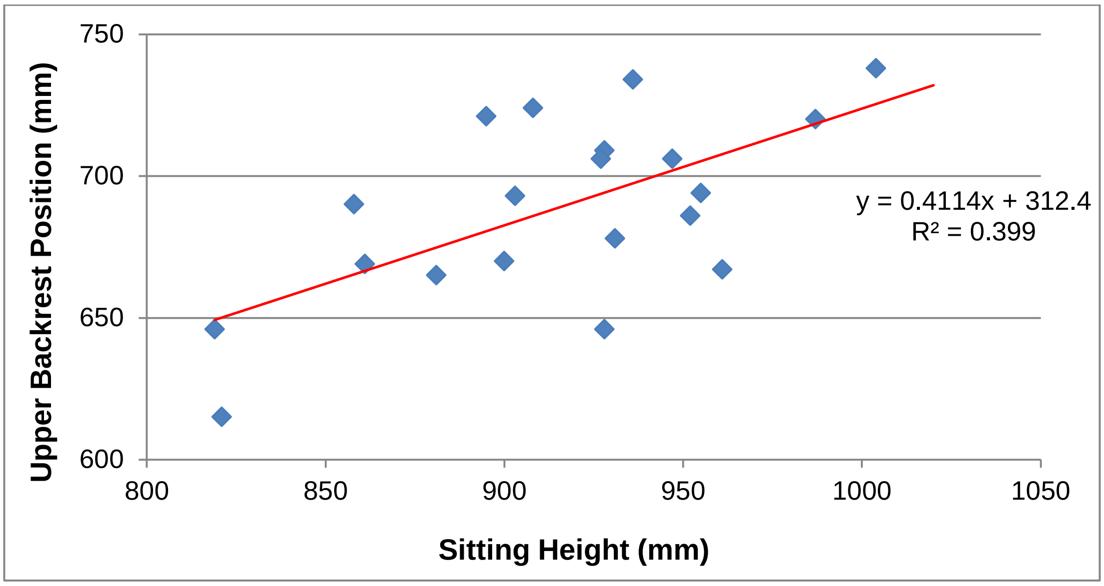

Figure 4.7. Upper backrest position (mm) vs. sitting height (mm) – positive correlation plot ($p < 0.01$).

The plot (Figure 4.7) shows that sitting height is a strong predictor of the upper backrest position, with a taller sitting height predicting a higher upper backrest position. Additionally, the plot shows that the range of adjustment for the sample was 125mm, between 615mm – 740mm.

4.4.3. Correlation between seat sub-components

The relationship between the final positions of seat sub-components' in the elevated driving posture (measured in mm) was investigated using Pearson product-moment correlation coefficient. Table 4.11 details the results of the correlation tests as outlined in Table 4.6.

Table 4.11. Pearson correlation coefficients for seat sub-components.

Correlation Test	Pearson correlation coefficient (r value)	R squared value
Heel step vs. PH gap	.592**	.350
Seat length vs. Seat width	.578**	.335
Seat width vs. Seat base bolster height	.224	.050
Lumbar height vs. Upper backrest height	.252	.063
Upper backrest height vs. Backrest bolster height	.651**	.424
Seat width vs. Armrest lateral position	.578**	.334
Lumbar prominence vs. Backrest bolster fore-aft	.400	.160

**. Correlation is significant at the 0.01 level (2-tailed).

Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homoscedasticity. There was a strong positive correlation between 4 pairs of variables: heel step and pedal-hip gap (Figure 4.8), r = 0.59, n = 20, p = < 0.01, with a higher heel step predicting a bigger pedal-hip gap (percentage of variance = 48%); seat base length and seat base width (Figure 4.9), r = 0.58, n = 20, p = < 0.01, with a longer seat base length predicting a wider seat width (percentage of variance = 40%); upper backrest height and backrest bolster height (Figure 4.10), r = 0.65, n = 20, p = < 0.01, with a higher backrest predicting a higher backrest bolster height (percentage of variance = 46%); Seat width and armrest lateral position (Figure 4.11), r = 0.58, n = 20, p = < 0.01, with a wider seat width predicting a wider position of the armrest (percentage of variance = 34%).

For all other correlation tests, the strength of the relationships was small and the correlations were not statistically significant (Appendix A7 details the dimension definitions of all seat sub-components).

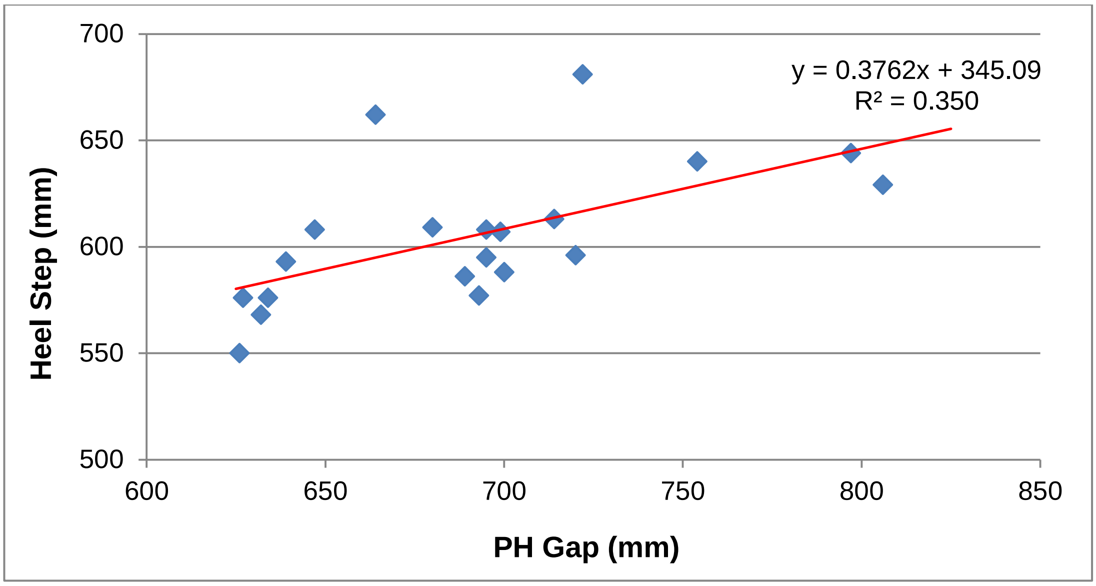

Figure 4.8. Heel step (mm) vs. PH gap (mm) – positive correlation plot ($p < 0.01$).

The plot (Figure 4.8) shows that heel step and PH gap have a strong positive correlation, with a larger PH gap resulting in a higher predicted heel step dimension.

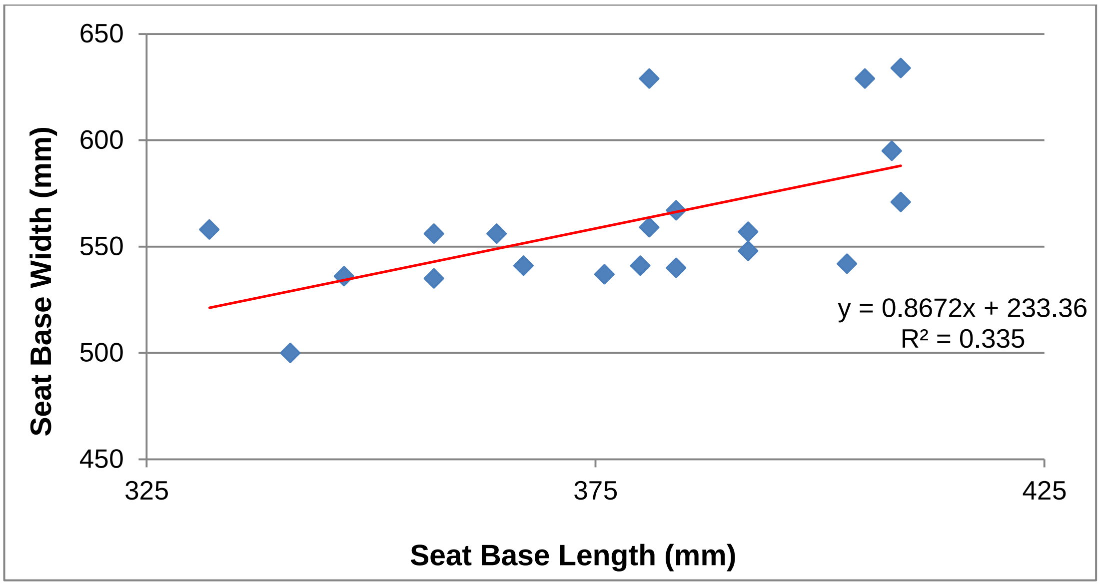

Figure 4.9. Seat base length (mm) vs. Seat base width (mm) – positive correlation plot ($p < 0.01$).

The plot (Figure 4.9) shows that seat base length and the seat base width dimensions have a strong positive correlation, with a wider seat resulting in a longer predicted seat base.

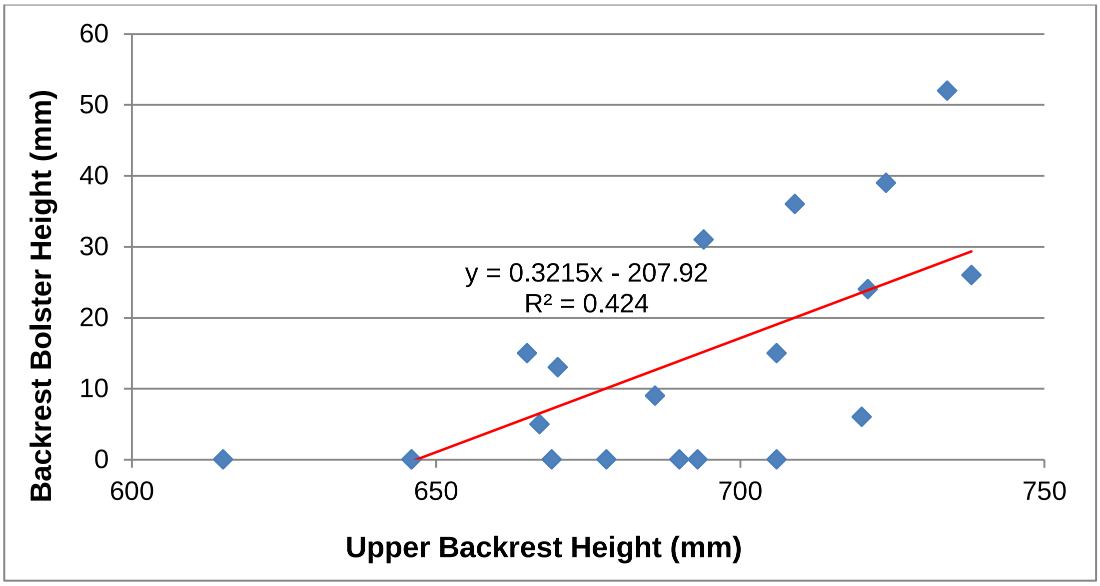

Figure 4.10. Upper backrest height (mm) vs. Backrest bolsters height (mm) – positive correlation plot ($p < 0.01$).

The plot (Figure 4.10) shows that the upper backrest position and the backrest bolster height dimensions have a strong positive correlation, with a higher backrest position resulting in a greater predicted distance of the bolsters away from the top of the backrest, in Z.

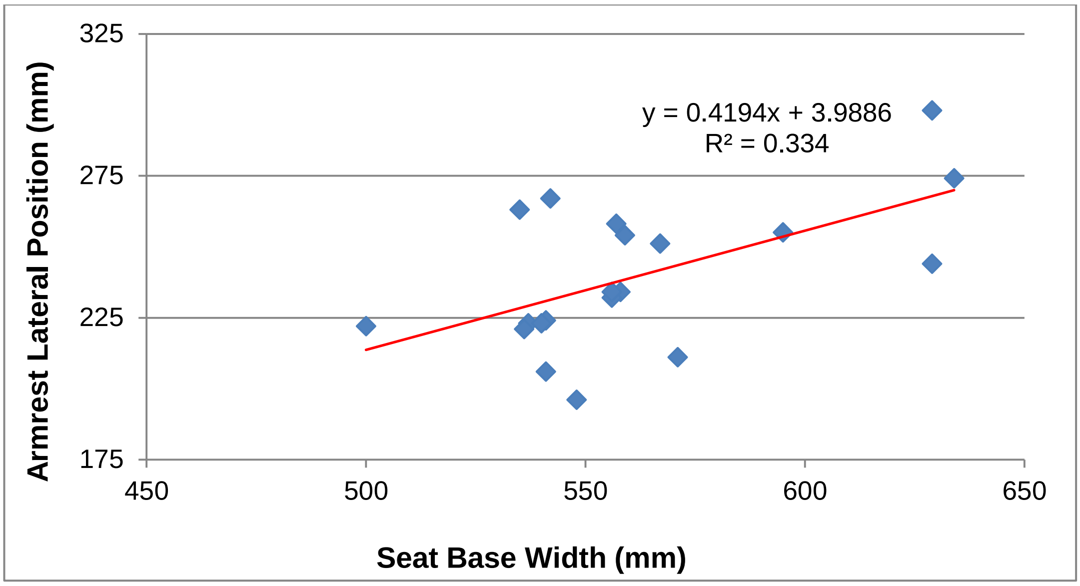

Figure 4.11. Seat base width (mm) vs. Armrest lateral position (mm) – positive correlation plot ($p < 0.01$).

The plot (Figure 4.11) shows that the seat base width and the armrest lateral position dimensions have a strong positive correlation, with a wider selected seat base resulting in a further outbound armrest position being selected.

4.4.4. Multiple regression analysis

Using the results from the anthropometric and seat sub-component correlation analysis (section 4.4.2. and 4.4.3.), those variables shown as being significant predictors, with a minimum threshold r value of > 0.3, were chosen for multiple regression analysis. The Pearson correlation coefficient values are presented in Table 4.12.

Table 4.12. Pearson correlation coefficients for multiple regression analysis.

Dependent variable	Independent variable 1	Independent variable 2	Pearson correlation coefficients
Seat base length	Popliteal length	Seat width	.331*
Seat base width	Sitting hip width	Seat base length	.281*
Backrest height	Sitting height	Backrest bolster height	.568**

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

4.4.4.1. Seat base length vs. Popliteal length and seat base width

Multiple regression analysis was conducted to ascertain the prediction of seat base length from popliteal length and seat base width. Preliminary analyses were performed to ensure no violation of the assumptions of multicollinearity, normality, linearity, homoscedasticity and independence of residuals. The results indicate that these variables predict seat base length, $F(2, 17)$ = 5.695, p = < 0.05, $R2$ = 0.331. Seat base width had the strongest unique contribution (beta value of 0.502) with a statistically significant unique contribution (0.020). Heel step had a smaller unique contribution (beta value of 0.269) and was not a statistically significant contributor (0.187).

4.4.4.2. Seat base width vs. Sitting hip width and seat base length

A multiple regression was run to ascertain the prediction of seat base width from the sitting hip width and seat base length. Preliminary analyses were performed to ensure no violation of the assumptions of multicollinearity, normality, linearity, homoscedasticity and independence of residuals. The results indicate that these variables predict seat base width, $F(2, 17) = 4.708$, $p = < 0.05$, $R2 = 0.281$. Seat base length had the strongest unique contribution (beta value of 0.505) with a statistically significant unique contribution (0.033). Sitting hip width had a smaller unique contribution (beta value of 0.165) and was not a statistically significant contributor (0.457).

4.4.4.3. Backrest height vs. Sitting height and backrest bolster height

A multiple regression was run to ascertain the prediction of the backrest height from the sitting height and backrest bolster height. Preliminary analyses were performed to ensure no violation of the assumptions of multicollinearity, normality, linearity, homoscedasticity and independence of residuals. The results indicate that these variables predict backrest height, $F(2, 17) = 13.504$, $p = < 0.001$, $R2 = 0.568$. Backrest bolster height had the strongest unique contribution (beta value of 0.493) with a statistically significant unique contribution (0.020). Sitting height had a smaller unique contribution (beta value of 0.463) which was also statistically significant (0.010).

4.4.5. Root-mean-square analysis

The fitting trial produced a range of positions and dimensions of the seat sub-components to achieve an optimal static posture in the elevated driving posture. These values were explored to determine the ‘best-fit’ dimension for each component. This was achieved by calculating the lower r.m.s. error value and thus the least difference between the observed values and the model. Figure 4.12 shows an example of the r.m.s. calculation for seat base length. The lowest point of the trend line indicates the lowest r.m.s. error, which for seat base length is approximately 23, read on the Y axis. At this point the seat base length dimension is 380mm, as read on the X axis which indicates that 380mm is the best-fit dimension for the driving sample tested in this study. This calculation was repeated for the remaining four key seat parameters as identified in the analysis (seat width; lumbar height; backrest width; backrest height).

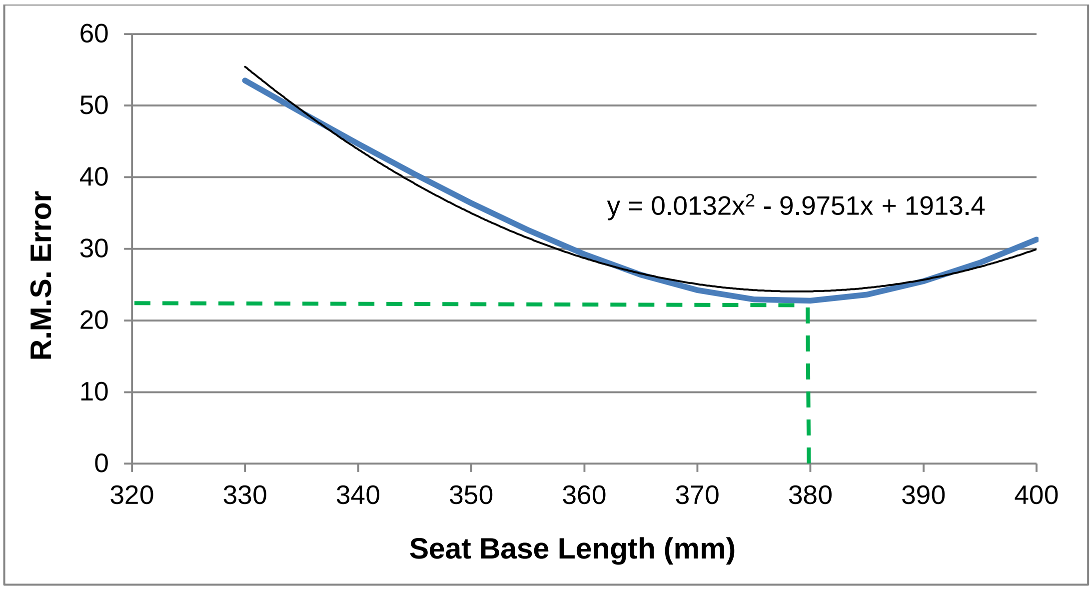

Figure 4.12. Seat base length dimension – r.m.s. calculation plot.

Table 4.13 details the results of the r.m.s. analysis, providing the best fit dimensions for the key seat design parameters and comparing them with the identical seat parameters from the reference seat, used in a conventional driving set-up.

Table 4.13. Root-mean-square analysis provided best-fit dimensions for seat sub-components.

Seat sub-component	Elevated posture best-fit dimension	Standard posture best-fit dimension
Seat base length (mm)	380	460
Seat base width (mm)	560	480
Lumbar height (mm)	180	n/a
Backrest width (mm)	480	510
Backrest height (mm)	690	650

.

The best-fit results (Table 4.13) show that participants preferred the seat base length to be shorter than that of the standard seat, with a difference of 80mm (380mm compared with 460mm) between the two postures. Participants also preferred the seat width to be wider than the standard seat, with a difference of 80mm (560mm compared with 480mm). For the backrest of the seat, participants preferred it to be narrower for the elevated seat compared with the standard seat, with a difference of 30mm (480mm compared with 510mm). Furthermore, participants preferred the height to be

40mm higher in the elevated seat compared with the standard (690mm compared with 650mm).

The nature of this posture means that both the heel step and the PH gap are adjusted in order to self-select an elevated position, relative to the pedals. These two adjustments relate to the fore-aft seat slide and vertical seat rake adjustments that are commonly found in standard vehicles. For this reason, these two dimensions were not included in the analysis for a ‘best-fit’ dimension, which focused specifically on the seat design parameters.

4.4.6. Participant verbatim

Following the completion of the fitting trial process, participants were asked to review their driving posture whilst remaining in their set-up (detailed verbatim can be found in Appendix A10).

4.4.6.1. Positive feedback

- The majority of participants summarised that their optimal elevated posture set-up was more comfortable than their conventional LCV driving posture.
- The majority of people were at first sceptical of a shorter seat base length, but having the rest of the seat adjustments around them made it was noted as being a first impression of a different sensation.
- Most people thought that armrests were a good option to have in this vehicle/posture, with the left-hand armrest being preferred.
- Two drivers, who often experienced upper back pain in LCV driving, stated that the more upright posture and more support for the back felt good.
- Two drivers asked if the elevated posture could be built in to their conventional vehicle for the drive home.
- Two drivers reported the feeling of driving higher up in a vehicle rather than being ‘slouched’ as a positive one.
- One larger percentile driver who often had to compromise comfort between the interaction with the seat (e.g. back, buttocks and thighs)

with the interaction with the pedals (e.g. ankle) said that this posture was more comfortable than any van they had ever driven.

4.4.6.2. Negative feedback

- Drivers with more experience (miles driven) queried whether or not the initial comfort in the elevated posture would remain after long-term driving.
- One driver with heavy goods vehicle (HGV) experience commented that the more upright back angle felt comfortable initially, but after long drives the need to sink in to the seat to adjust seat comfort wouldn't be possible.

4.5. Discussion

The fitting trial was conducted to identify key seat design parameters for the elevated driving posture and to understand the effect of seat design parameters on initial impressions of comfort. Additionally, a further objective was to understand the suitability of the chosen research methods in identifying key seat parameters for the elevated posture. This will be discussed in the context of the findings, followed by the limitations of the research and conclusions. It should be noted that there was limited literature for comparisons of seat parameter requirements for automotive seating, especially with consideration of the elevated posture which is absent from the literature. However, the results will be compared with the standard seat dimensions (Nissan NV200) for direct comparisons between postures.

The observed results of the fitting trial met the objectives for this case study (section 4.2), specifically identifying seat base length, seat base width, backrest width and backrest height as key seat design parameters for the elevated posture. Supported by participant verbatim, it was identified that in the elevated posture the seat base length becomes very important due to the change in biomechanics and the weight of the driver being shifted towards the front of the seat. With the change in driver biomechanics, more of the leg needs to be free in order to negotiate the pedals whilst the seat base still needs to provide the fundamental support for the driver, for the buttocks and thighs. The difference between the observed best-fit dimension and the standard posture seat dimension was 80mm, which is considerably shorter, highlighting how important this dimension is when designing a seat suited for this posture. Furthermore, Gyi (2013) identifies that a slouched seated posture can be exacerbated by the seat base length being too long for the driver, highlighting the importance of this dimension for a heathy posture. There was a statistically significant relationship between the seat base length and the seat base width, and participants preferred a width 80mm wider than that of the standard seat. This was more prominent with larger drivers, who found that standard driving seats very often offered little or no lateral support. This finding again fits in with the change in biomechanics for the elevated posture and the fact that drivers require more of their leg free to negotiate between the pedals. This is truer towards the front of the seat as opposed to the rear, which fits with the standard seat design (80mm wider at the front than the back of the seat pad).

Participants preferred the seat backrest to be set higher (40mm higher than the standard production seat). This matched the observations from the fitting trial, with participants sitting noticeably more upright and thus more aware of the support being offered for the upper back and shoulders. This finding is in concurrence with the literature which identifies that larger occupants normally have to compromise their comfort based on the limited adjustment of production driving packages and discomfort increases at a faster rate for taller drivers as a result (Porter and Gyi, 1998; Na et al., 2005). If the elevated posture gives the driver a straighter back then the shape of the spine would remain closer to that of a standing posture and could lead to health benefits and a reduction in musculoskeletal discomfort. Furthermore, with the knowledge that workers with manual handling jobs, as a group, are more susceptible to musculoskeletal discomfort (Sang et al., 2010), the implication is that LCV drivers will especially benefit from this change in posture in day to day work.

The trial itself was effective in obtaining optimum self-selected driving positions and their relevant seat sub-component positions for a range of drivers. The iterative process of adjustment allowed participants to explore the full range of adjustment available to them before setting them in place. The process of adjustment (Appendix A6) accounted for the interactions between sub-components and allowed further adjustment when necessary to provide an optimal comfortable set up. This further validates the methods employed by Porter and Gyi (1998) and Jones (1969), as being a good way of finding an optimum area of comfort for a given individual in a driving set up. This fitting trial actually goes a step further than the two aforementioned studies by having adjustments in multiple seat sub-components, as well as the conventional seat and steering set-up. These observations were validated by one participant who highlighted that as a larger driver they experienced many problems when driving current LCVs, including having to sit on the seat bolsters and lose any lateral support because the width of the seat was too narrow. This finding is in agreement with the literature on larger occupants (Porter and Gyi, 1998; Kolich, 2003). This has been explained by taller drivers having larger contact areas on the seat and therefore requiring more support considerations from the seat (Kyung and Nussbaum, 2008). The elevated driving posture allowed them to set up in a comfortable posture, whilst still achieving a reduced PH gap and thus a space saving benefit.

The ability to package a range of drivers in comfortable elevated seating positions supports this driving concept. Additionally, the results from the correlation analysis show that driver leg length is a strong predictor of where a driver will set their seat in the elevated posture (heel step and PH gap). However, research in to overall driver discomfort has demonstrated that a ‘show-room’ analysis is not sufficient as it excludes many other contributing factors e.g. vibration (Porter et al., 2003; Ebe and Griffin, 2000a,b; Mansfield, 2005).

4.5.1. Limitations

The main limitation regarding the elevated posture fitting trial was the sample size. Whilst there was a reasonable anthropometric percentile range and a large enough sample to conduct appropriate statistical testing, a larger sample would have allowed more representation of the LCV driving population and more confidence on the findings for the automotive industry.

There were a small number of limitations in the driving rig. The design of the rig was to allow as much adjustment as feasibly possible to encompass a range of comfortable driving postures. However, for the lumbar pad and the upper backrest, they were on the same vertical plane of adjustment meaning that there were limitations in terms of how these two positions could interact with each other. Additionally, participants were given free adjustment of the steering wheel position which is crucial in optimising a driving set up in a vehicle. Whilst the fitting trial was designed to have few constraints to get true optimised driving postures, it is important to consider that existent parameters in vehicle platforms are likely to impact upon final sub-component positions and priorities will need to be highlighted. There were physical limitations in the seat in that it was only feasibly possible to separate the seat in to 'obvious' sections, where the seat was contoured and could be cut whilst retaining its rigidity. Secondly, the seat was a Nissan NV200 production seat, which was designed for its purpose. The styling of the seat could have impacted upon the final positions of some sub-components e.g. the seat base length, being shorter could mean drivers would require a more rounded front edge which is not offered on the NV200 seat. In addition to this, the foam stiffness, compression at the front edge of the seat and the position of the anti-submarining bars/crash pan beneath the foam could all have had an influence on final positions. Finally, the measurement of the final seat sub-components was done manually using static equipment (stadiometer, tape measure and callipers) which has an element of human error. Whilst this method is often used in laboratory trials (Porter and Gyi, 1998), digital scanning methods are also widely used (Reed et al., 2000; Park et al., 2000; Andreoni et al., 2002) which bring an added element of accuracy for observing and measuring driving posture.

4.6. Conclusions

The objectives for this study were:

- Identify the key seat design parameters for the elevated driving posture.
- Understand the effect of seat design parameters on initial impressions of comfort in the elevated driving posture.
- Understand the suitability of the chosen research methods in identifying key seat parameters for the elevated posture.

The results from the seat design parameter trials met the objectives for this experimental study and it is possible to conclude the following:

1. The seat base needs to be shorter (380mm) in length compared with current benchmark LCV seat lengths (460mm).
2. The backrest height needs to be made longer (690mm) in height compared with current benchmark LCV seats (650mm).
3. The width of the seat base needs to be designed to offer lateral support for both smaller and larger percentile drivers; this could be done through angled seat bolsters splaying out from the back of the seat to the front.
4. Leg length was a significantly strong predictor of heel step and PH gap in the elevated driving posture. Additionally, it showed that sitting height was a significantly strong predictor of the upper backrest position.
5. The fitting trial method was effective in identifying optimised, self-selected elevated driving postures for the trial sample.

4.6.1. Summary

The fitting trial described and explored in this study shows that this was a good starting point for this research in to an elevated driving posture. The analysis indicated the seat parameters that need to be considered for the elevated posture and provide a good basis for the development of a seat for further research. The results indicated that all drivers were able to set themselves up in a comfortable position for the short-term and the method of the fitting trial was effective in allowing these positions to be self-selected. However, further research is needed to explore these parameters further under dynamic driving conditions, to gain a wider insight in to the impact of these dimensions on discomfort and support for the driver. In order to understand the seat design parameters further, a specification for a concept seat will be produced based on these findings in order to conduct dynamic testing (Chapter 5 and Chapter 6).

CHAPTER 5

LONG-TERM DISCOMFORT EVALUATION

5.1. Introduction

The previous chapter reported on a fitting trial study which identified key seat design parameters to consider for an elevated driving posture. The findings indicated that drivers required a higher backrest and a shorter seat length, compared to a conventional driving seat, in order to achieve their optimal set-up. These findings led to a specification for a seat design concept for the long-term discomfort evaluation of the elevated driving posture. This chapter details the study design and discusses the results of a comparison in reported discomfort over 50 minutes of driving between the elevated posture seat and a conventional posture seat.

Factors (static, dynamic and temporal) that affect the onset of seat discomfort were reviewed to identify considerations for comparing long-term driver comfort in an elevated driving posture with a conventional driving posture. Methodological approaches for research into long-term discomfort were also studied leading to a repeatable experimental design to meet the aims of the study. The plan for this study was to create a driving rig to house the elevated posture concept seat, which could be mounted on to a motion platform and allow for long-term dynamic comfort testing using a driving simulator. Results were compared with those obtained using a conventional LCV driving posture. The output of this study allowed for a direct comparison of reported discomfort between postures and provided understanding of the effect of a new seat design, with different seat parameters, on driver discomfort over an extended period of simulated driving. The findings from this study helped to validate the suitability of the seat designed through driver anthropometry and driver requirements in this posture, and highlighted areas of the seat which required a different consideration from the conventional posture.

5.2. Aims and objectives

Part of the focus of this thesis is to identify the seat parameters for a comfortable seat in an elevated posture, including consideration of both static and dynamic variables. A study was therefore designed with the following objectives:

- Understand the effects of a new seat design on long-term driver comfort, in comparison with a benchmark production seat.
- To identify the onset of musculoskeletal fatigue in comparison with a benchmark posture and the literature.
- Understand the suitability of the chosen research methods in assessing dynamic seat comfort with driving simulations in an elevated posture.

5.3. Research method

5.3.1. Sampling strategy

The sample size was defined by the following criteria: large enough to perform statistical testing and practical limitations (e.g. time constraints). Twenty participants were recruited using a stratified random sampling technique, with the following inclusion criteria:

- <u>18 to 65 years old</u>

  Rationale: younger (18 years) or older (> 65 years) individuals were considered vulnerable population groups by the university's Ethical Advisory Committee (LUEAC) at the time of the study.
- <u>Hold a full UK driving licence for a minimum of 2 years</u>

  Rationale: the minimum of 2-years driving experience ensures that drivers will be at least 19 years old. Additionally, it specifies duration of time in which drivers gain experience of comfort/discomfort in a driving posture.
- <u>Balanced sample (10 males and 10 females)</u>

  Rationale: a weakness highlighted from the literature is that the sample is often not balanced. As a new area of research, it is critical to understand the parameters for the elevated posture for both male and female drivers.

- Large anthropometric coverage
  Rationale: to fully understand the parameters for the elevated posture, for a diverse driving population, as large an anthropometric spread as feasibly possible should be tested, especially larger and smaller percentile drivers.

Ethical approval was granted by the Loughborough University Ethical Advisory Committee (LUEAC) from Loughborough University in March 2013.

5.3.2. Elevated posture concept seat

As an output from the seat design parameter study (Chapter 4), a specification for a concept seat design was created, detailing crucial seat dimensions for this posture. Additionally, a seat adjustment envelope was specified for a diverse anthropometric population. This specification was communicated to a UK based seat design group (Seat Design Company Ltd.) who specialise in concept seat development. The elevated posture seat was produced using a Nissan NV200 seat (LCV production seat) as a benchmark and was built with the structural strength required for dynamic testing, shown in Figure 5.1.

Figure 5.1. Elevated posture concept seat with extended backrest and shortened seat base.

5.3.3. Elevated posture rig

It was necessary to design and construct a driving rig to evaluate the elevated driving posture. The steering wheel set-up was adapted from the seat design parameter study described in Chapter 4. The identification of a refined steering wheel adjustment range was out of scope of the research and so the decision was made to retain a large scope of adjustment. This ensured that every participant could select a comfortable position of the wheel for their selected seat set up without adversely affecting discomfort. Additionally, the pedal set (accelerator and brake pedals) and their relative position to the seat were kept identical to the fitting trial and prior research. The initial and fully depressed positions of the pedals met the minimum requirements in terms of the lateral and vertical offset between each pedal for safe operation. The aim of the rig build was to provide a platform to harness the elevated posture seat securely, allowing relative adjustment within the driving set-up, as well as providing a platform which was secure and could withstand vibration.

5.3.3.1. Rig specification

In order to conduct a set of long-term discomfort trials a driving rig was built to the following specification:

- A platform capable of incorporating and supporting the elevated posture concept driver seat.
- The capacity for independent adjustment of two seat sub-components (adjustment range rationale is detailed in Table 5.1):
- Gas strut seat height adjustment (185mm of adjustment in Z from 547mm – 732mm).
- Electric fore-aft adjustment (150mm of adjustment in X from 626mm – 776mm).
- A large mechanical scope of adjustment for the steering wheel position, including height, fore-aft and angle.
- The capability of safe and easy seat adjustment by participants, with easy to reach electronic push buttons on the side of the seat.
- Fixings to allow firmly locking the steering wheel in place.

- Fixings must be easily accessible for the investigator, for a quick and responsive adjustment.
- The rig components must be fixed securely to a platform which can withstand vibrations at normal driving levels.
- The platform itself must be able to be fixed securely to the multi-axis vibration platform at Loughborough University.

Table 5.1. Seat adjustment ranges and the rationale.

Seat sub-component	Adjustment range	Rationale
Seat vertical adjust	185mm (547mm – 732mm)	A seat height of 400mm is currently observed in the LCV market and there is data available to support this driving posture. This study aimed at exploring seat heights upwards of this, where there was a gap in the knowledge.
Seat fore-aft adjustment	150mm (626mm – 776mm)	This study explored an elevated posture, where the seat height is increased and the PH gap is reduced. This adjustment range was defined by designing for the leg length dimensions for a JF05 and an AM99 driver.

The driving rig was mounted to a frame built with a combination steel and aluminium, to create a platform for the adjustable seat, steering wheel and pedal set to be fixed. The seat concept was made using a current Nissan NV200 seat, which was used for the construction of the seat design parameter study rig (Chapter 4, section 4.3.2.1) where the seat was adapted by cutting and re-forming several donor seats to provide a fully adjustable rig with many seat sub-components. Using the same reference seat for this study gave a reference for seat foam composition, fabric, metal underlying structure and foam contours. The rig allowed a comprehensive long-term discomfort comparison trial to take place.

5.3.4. Conventional posture rig

It was necessary to design and construct a second driving rig, which replicated a conventional driving posture and is currently used in the LCV market. This was designed to replicate the driving posture of the Nissan NV200 van, and included the following specification:

- The actual seat slide range as observed in the production vehicle (approximately 240mm).
- The back angle fixed at 15° for the purpose of a consistent seat set-up for the trials.
- Accelerator and brake pedal in the same starting positions as in the production vehicle.
- The same pedal forces and stroke values as in the production vehicle.
- The same steering wheel position and angle as in the production vehicle, with no built in adjustment.

The rig was constructed using carry over vehicle parts from the Nissan NV200 and constructed using MDF and metal fixings. The rig was designed with the structural strength to withstand vibration levels that would be used in the long-term discomfort trials (Figure 5.2).

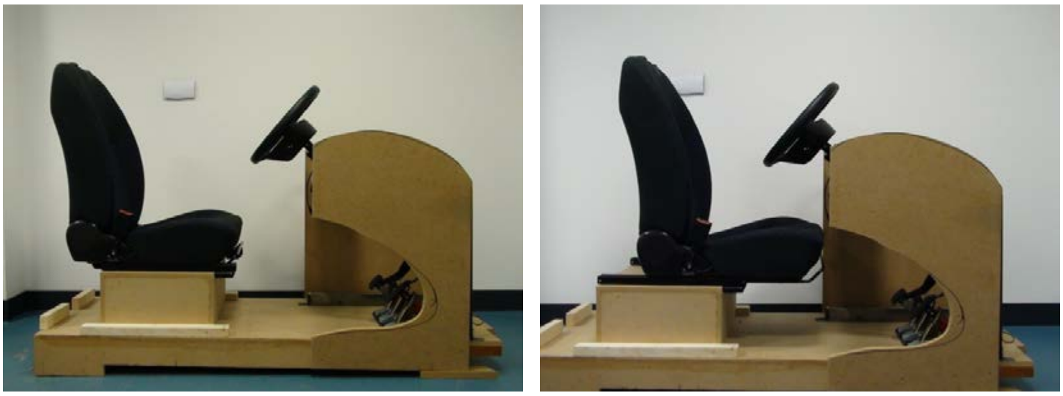

Figure 5.2. Nissan NV200 rig with the seat in its rearmost (left) and foremost (right) positions.

5.3.5. Laboratory set-up

For the long-term discomfort trials it was important to prepare the laboratory in the best way to immerse the driver in the task itself, to ensure that the trials were conducted safely and efficiently and to collect the most accurate data. The following section details the areas which were explored and identified through rigorous piloting, in order to achieve the best set-up for this study.

5.3.5.1. Multi-axis vibration simulator (MAViS)

MAViS is the platform on which both the elevated and Nissan NV200 driving rigs were mounted for the long-term discomfort evaluation. The platform is a Rexroth Hydraudyne B.V. Micro Motion 600-6DOF-200-MK5 multi-axis vibration simulator which allows six degrees of movement (X, Y, Z, roll, pitch and yaw) to replicate a vibration condition. The full list of procedures followed during operation of the vibration platform are detailed in Chapter 3.

The long-term discomfort evaluation trials used a pre-recorded pavé road surface input in to the MAViS system and a seat point vibration total value magnitude at the seat surface of 0.35 m/s^2 r.m.s. (r.s.s. of x- y- and z-axis motion) was used. This level of vibration was observed in normal road driving conditions during the piloting phase for these trials, where road vibration recordings were measured on the seat surface of an NV200 van, bringing participants closer to a ‘real driving experience’. The vibration was set to loop and run for 10-minutes in line with each driving scenario and was started once participants began to engage with the driving simulator. The level of vibration level was kept constant irrespective of driving scenario (e.g. motorway and town driving).

5.3.5.2. Vibration levels at the seat surface

The vibration on the seat surface and platform was measured before each trial using a Larson Davis HVM-100 with a tri-axial seat pad accelerometer (detailed in Chapter 3, section 3.5). The system settings were adjusted to compensate for the dynamics of the seat-person system so that seat surface vibration was set at the target level (0.35 m/s^2 r.m.s.). The seat pad was removed from the seat surface to ensure that it did not influence the seat comfort ratings during the driving trial.

5.3.5.3. XPI driving simulator

The driving software for the long-term discomfort evaluation offered dynamic driving simulations which incorporated both town, rural and motorway driving. This included all types of driving to test different driving environments and situations (Table 5.2). The motorway driving required less pedal and steering operation and so the driver was expected to have a more static posture whilst driving. The town scenarios were more dynamic, involving more frequent operation of the pedals and use of the steering wheel, resulting in a more dynamic posture whilst driving.

Table 5.2. XPI driving scenarios and their respective specifications.

Driving scenario type	Specification
Motorway driving	• 70 mph speed limit • Follow cars at self-selected safe distances • Change lanes for overtaking as per normal driving • Take junctions exits and roundabout exits as per verbal instructions • Pull over to the left to finish the scenario as per verbal instructions
Town/rural driving	• Range of 30 mph to National speed limit • Follow cars at self-selected safe distances • Turn at junctions as per verbal instructions • Take exits and roundabouts as per verbal instructions • Pull over to the left to finish the scenario as per verbal instructions • Perform an emergency stop if verbally and visually instructed to do so (one of the scenarios)

As part of optimising the laboratory for the trials, the simulator was upgraded to a three-screen system to provide a 180^0 field of view, which allowed for the inclusion of rear view and wing mirrors to add to the realism of the driving task (Figure 5.3). The speedometer was rendered on the central screen.

Figure 5.3. XPDS XPI driving simulator three-screen set-up.

The piloting and the development of the experimental design led to a number of routes being explored using the ‘town map’ available in the software, to achieve suitable routes that if driven perfectly (no collisions) would last approximately 10 minutes. From this work, three pre-planned routes were devised for the driver offering different directions, roads and decision making for scenario numbers two, three and four. The three routes were randomised for the set of trials using a balanced Latin-square design (Appendix A11). Each participant completed five driving scenarios, each lasting 10 minutes (50 minutes of driving in total). The participant always began and ended with the same motorway loop driving condition, to control for order effects and allow for repeated testing at the end of the trial (scenario numbers one and five).

5.3.5.4. Blackout environment

The laboratory in which the long-term discomfort evaluation took place had artificial lighting with little room surrounding the platform in which to manoeuvre. To help immerse drivers in the driving simulation, a blackout environment was designed and constructed, encircling the MAViS platform and the driving simulator. A metal frame was constructed around the testing area, with space at the rear of the rig from which to ingress/egress the platform. Following this, customised blackout material was fixed all around the frame, including a layer of fabric above the platform and driver, to create a monotonous surround leaving the screens as the point of focus (Figure 5.4).

Figure 5.4. Blackout environment in development (left) and completed, surrounding the test area (right).

Pilot work found that when engaging with the driving simulator, having this blackout environment improved immersion in the task. The objective of the trials was to collect long-term discomfort ratings from drivers i.e. over a 50 minute period, so being able to immerse drivers in the task itself was of paramount importance.

5.3.5.5. TV screen and camera system

The software was upgraded to enable a three-screen system, which was utilised with three identical Samsung 50" 1080p screens and set-up to provide as little refraction as possible when considering the differences in eye levels between participants and trials. The screens were chosen to have as little bezel around the edge as possible, to provide the illusion of one large windscreen as opposed to three separate screens. The stands and mounts of the screens were covered with the blackout fabric to leave just the screens themselves visible to the driver.

As a result of the blackout environment, there was no direct line of sight between the participant and the investigator controlling both the MAViS platform and the driving simulator. To mitigate for this, two Microsoft LifeCam

HD-3000 webcams were mounted on to the three-screen system, on the top of the outer screens respectively. The first webcam was set to record the entire long-term discomfort trial, providing observation data to explore any possible anomalies in the discomfort ratings (e.g. changing posture or a jolt in the vibration loop at a particular time in the trial). The second webcam was used as a health and safety check for the investigator to observe the participant during the trial. This was displayed on a split screen with the investigators pre-planned route soundboard (section 5.3.5.6) ensuring that the investigator had a maintained visual of the participant throughout the trial.

5.3.5.6. Audio system and control panel layout

In addition to the visual output from the driving simulator, the audio output was ‘Mackie thump’ powered loud speakers. The audio output had two layers, the first being the engine noise from the driving simulator, and the second being pre-formatted navigational instructions to the driver to guide them around the map, which was incorporated in to a soundboard for the investigator to manually engage (Appendix A12). The volume was set to a level which allowed the navigation instructions to be communicated clearly to participants as a layered sound track above the engine noise from the simulator. The soundboard for the audio output was located next to the control panel layout by the investigator, for ease of use if needed to communicate with participants. The control station was designed so that the investigator had easy access to all of the relevant equipment in order to efficiently and safely conduct the trials. The investigator workstation was designed to incorporate the following:

- MAViS system (motion control)
- XPI system (driving simulation; central screen)
- Pre-planned routes and direction soundboard
- Webcam view of driver

5.3.6. Study design and rationale

The literature indicates a link between driving and back pain (Porter and Gyi, 2002; Sang et al., 2010) and therefore there is a need to investigate the seated driver and their environment to minimise discomfort. The literature (Chapter 2, section 2.2) identified that there are various factors that affect subjective perceptions of automobile seat comfort (Thakurta et al., 1995; Ebe and Griffin, 2000a,b). Factors such as styling, foam stiffness and breathability of the seat will influence discomfort as well as vehicle factors such as knee room, pedal and steering positions and seat height (Kolich, 2008). It has been recognised in the field that both static and dynamic factors also affect seat discomfort, however it is also known that temporal factors affect the onset of discomfort (Mansfield et al., 2014). It has been concluded that although a seat may appear to be comfortable in a 'showroom' test, prolonged duration will result in discomfort irrespective of vibration being present. Additionally, when vibration is present discomfort will increase accordingly with an increased magnitude of vibration (Mansfield, 2005).

Laboratory based driving trials have been shown to be reliable in simulating the driving task to evaluate discomfort and allowing good control over the parameters. The literature shows that when observing overall car seat discomfort, trial durations have ranged from 60 seconds to 135 minutes (Kolich, 2003; Gyi and Porter, 1999). Gyi and porter (1999) found that significant changes in overall discomfort occurred at approximately 80-110 minutes of driving, however this was a static driving trial and the literature tells us that the presence of vibration accelerates the onset of discomfort (Mansfield, 2013). In support of this, Mansfield et al. (2015) found significant differences in discomfort between two different seat foams after only 40 minutes of driving in a dynamic laboratory trial, with trends identified in even less time.

This research is aimed at understanding the effects of the concept seat in an elevated posture on long-term driver discomfort, in comparison with a benchmark production seat in a conventional posture. This was achieved using a repeated measures design with a balanced order of testing. The data will also help to understand how the discomfort experienced in the elevated posture compares to that of previous studies and if the methods used were appropriate in obtaining these results. Furthermore, these long-term discomfort evaluations will provide more understanding on how drivers interact with the elevated posture in a driving task which is vital for further development work.

5.3.6.1. Recruitment

Two methods of recruitment were adopted: contact was made with the facilities management department on the University campus which led to an internal department circular for LCV drivers; secondly adverts were placed on the intranet staff noticeboard, detailing the nature of the study. The first contact with the 20 participants (10 male and 10 female) was via e-mail, telephone or in person, with a brief explanation of the research and the nature of the long-term discomfort evaluation. Following that, interested parties were sent participant information sheets (Appendix A13) and asked their height in order to monitor anthropometric spread. If the individual agreed to take part, a first session (of two) was scheduled and participants were instructed to wear flat shoes (e.g. trainers or a shoe with a heel of <4cm) to standardise footwear.

5.3.6.2. Anthropometric data collection

On arrival, participants were asked to re-read the information sheet, sign a consent from (Appendix A4) and fill in a health screen questionnaire (Appendix A5). Following this, anthropometric data was collected using a stadiometer, a sitting height table and an anthropometer. Anthropometric measurements were taken (Table 5.3) relevant to seat design and driving posture. The definition of each measurement was taken from a Nissan engineering manual (NEM) which outlines a set of guidelines for anthropometric data collection (Appendix A1). Japanese and American percentiles were calculated as they represent some of the smallest (JF) and largest (AF) populations in the world.

Table 5.3. Anthropometric data measurements selected for collection.

Dimension number	Anthropometric description
1.	Sitting height
2.	Shoulder width
3.	Sitting hip width
4.	Knee height
5.	Popliteal length
6.	Seat height
7.	Leg length
8.	Foot length
9.	Sitting elbow height
10.	Shoe size

5.3.6.3. Setting drivers' driving position and familiarising

Before each trial began, participants were taken through a short fitting trial in order to be able to set themselves up in each respective posture. For the conventional driving posture, the only possible adjustment was the seat slide, which offered approximately 240mm of adjustment in the fore-aft position. For the elevated posture, the three adjustments were described to participants (Table 5.4). For this posture participants were briefed about the concept of the elevated driving posture, sitting higher within the vehicle cabin and how this differs from a conventional driving posture. Participants were asked to firstly adjust the height of their seat, starting with their feet resting flat on the floor, to a height which felt comfortable. Subsequently, participants were asked to adjust their fore-aft position using the electronic controls. This adjustment typically compromised the comfort of participants' initial seat height choice, so they would then use both controls to optimise the seat position. Lastly, participants would guide the investigator in adjusting the steering wheel to a position which best suited their driving position.

Table 5.4. Method of setting drivers in their optimum elevated driving posture.

Adjustment	Type	Method
Seat height 	Manual	Participants were instructed to operate the lever to the right-hand side of the seat base, which operated a gas strut mechanism. This was a weight off release to increase the height of the seat and a weight on operation to lower the seat.
Seat fore-aft 	Electronic	Participants were instructed to operate the hand control buttons, located next to the participant to the right. Two buttons electronically adjusted the seat in X between its foremost and rearmost position.
Steering wheel position 	Manual	The steering wheel was adjusted in 3 ways; The investigator released the mechanism lock and was able to move the steering wheel fore-aft and up and down. Once locked in place, the investigator then released the wheel plate lock, which allowed the adjustment of the steering wheel angle itself.

Once participants were in their optimum driving posture, the investigator ran the driving simulator and briefed them on the tasks of the trial. Participants were then given 5 minutes of driving with no vibration input to familiarise themselves with the driving software and their driving set-up. After this familiarisation period, participants were given the choice to once more adjust their driving set-up before the trial began, after which no further adjustments were made.

5.3.6.4. Assessing and scoring discomfort

Discomfort was reported over a period of extended driving (50 minutes). After the 5-minute familiarisation period, participants were introduced to the body part discomfort map, modified from a map used by Gyi and Porter in 1999. Participants were asked to rate each body part before the trial began to give a starting level of comfort to refer back to. Participants were subsequently asked to complete a further five body part discomfort maps, one at the end of each individual driving scenario (every 10 minutes). A seven point scale was used (Figure 5.5) based on Gyi and Porter's body map using verbal anchors from ISO 2631-1. Verbal anchors (not uncomfortable to extremely uncomfortable) were designed for use in motion environments in laboratory settings, based on extensive piloting.

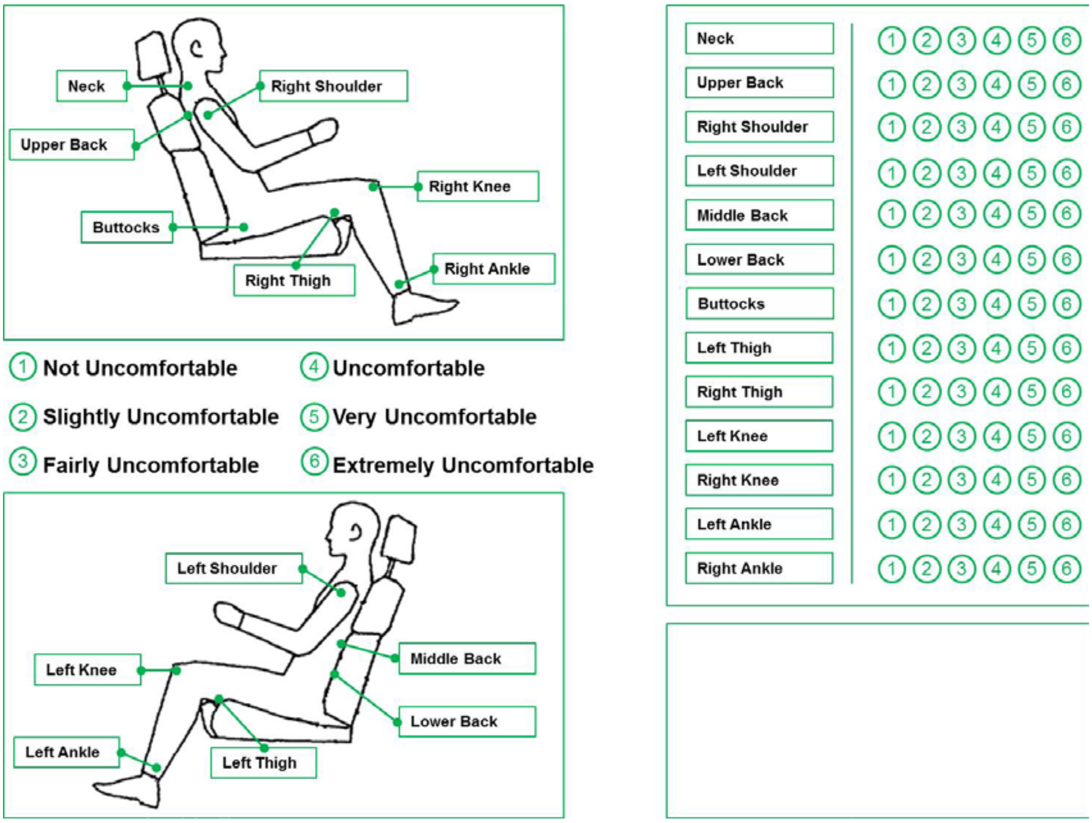

Figure 5.5. Modified body map (with ISO 2631-1, 1997); 1. Not Uncomfortable; 2. Slightly Uncomfortable; 3. Fairly Uncomfortable; 4. Uncomfortable; 5. Very Uncomfortable; 6. Extremely Uncomfortable

The category rating scale has the advantage of providing a verbal descriptor at any point, and piloting showed that participants could easily identify with a given discomfort score when asked. For this trial, participants were asked to remain seated whilst the investigator gave them a discomfort form to complete (Figure 5.5) so that the feedback was immediate and without a change in posture. The use of this scale helped to get an accurate and efficient set of data collection from the sample. The discomfort scores were recorded manually and then uploaded to spreadsheets for data analysis.

5.3.7. Data analysis

Statistical Package for the Social Sciences (SPSS) software for Windows (Release 21.0. SPSS©, Inc., 2014) was used for analyses. For a repeated measures design, data is collected from each participant at all levels of the independent variable in the study (Brace et al., 2006). A paired samples t-test was used to compare the discomfort scores of participants driving in the elevated posture with the discomfort scores of the same sample of participants in the conventional driving posture. A Wilcoxon signed-ranks test was also used for analysis of the data; however the results were not affected by using this non-parametric test equivalent. Microsoft Excel for Windows 7 (Microsoft© Office, 2013) was used to divide the data appropriately and import to SPSS. Differences observed in discomfort scores between postures of less than 0.2 were defined as ‘ties’ (deemed too low to signify a real difference on a 6-point scale).

The data analysis was conducted in a four-step approach:
Step 1. Paired samples t-test to compare overall discomfort between postures.
Step 2. Paired samples t-test to compare male and female (separately) overall discomfort between postures.
Step 3. Paired samples t-test to compare musculoskeletal fatigue effects within postures.
Step 4. Driver verbatim to identify themes.

5.3.7.1. Steps 1 and 2: Whole sample overall discomfort (by gender)

The method of testing overall discomfort (step 1) was to compare the mean discomfort rating at the 50-minute mark (end of trial recording) for all body parts individually, between both driving postures. This gave a comprehensive list of 13 areas which could be compared to identify which posture had most discomfort for all portions of the body after 50 minutes of driving (Table 5.5).

Table 5.5. Overall discomfort comparison method.

Dependent variable	Independent variable 1	Independent variable 2
Neck		
Left shoulder	**Compared with** →	
Right shoulder		
Upper back		
Middle back		
Lower back		
Buttocks	Discomfort scores in the elevated posture at 50 minutes	Discomfort scores in the conventional posture at 50 minutes
Left thigh		
Right thigh		
Left knee		
Right knee		
Left ankle		
Right ankle		

Step 2 analysis followed the same method as for step 1, with the data for male and female participants separated in to groups. With the smaller sample size, this gave only 10 participants in each gender group and was designed to investigate if gender had any influence on how high discomfort was rated and/or how the discomfort scale was used.

5.3.7.2. Step 3: Musculoskeletal fatigue effects

To examine driver fatigue effects i.e. discomfort over time, the paired samples t-test was used to compare the base line discomfort score (taken before the trial began at 0 minutes) with the discomfort score at the end of the trial (after 50 minutes of driving). This analysis was used to understand firstly if driving fatigue for both postures fell in line with the literature and secondly to compare the fatigue between the two postures. Additionally, individual time differences (every 10 minutes) were examined to understand the onset of discomfort across the 50-minute trial (Table 5.6). The 50-minute exposure only included the time spent driving and did not include the time taken to fill in the discomfort forms after each 10-minute period. This time was negligible and participants could fidget and adjust their posture in this time and was therefore not counted as time spent in the seat.

Table 5.6. Driver fatigue test methods for both driving postures.

Discomfort Score	Test 1	Test 2	Test 3	Test 4	Test 5
Neck	Between 0 minute score and 10 minute score	Between 0 minute score and 20 minute score	Between 0 minute score and 30 minute score	Between 0 minute score and 40 minute score	Between 0 minute score and 50 minute score
Left shoulder					
Right shoulder					
Upper back					
Middle back					
Lower back					
Buttocks					
Left thigh					
Right thigh					
Left knee					
Right knee					
Left ankle					
Right ankle					

5.3.7.3. Step 4: Driver verbatim

The final method was the collection of driver verbatim. This was recorded for the elevated posture with participants asked to give their feedback in comparison to their conventional driving posture in day to day driving, which helped to identify themes relating to comfort for the elevated posture. Driver views were very important for concept development and will guide future research.

5.4. Results

The anthropometric data and driver characteristics of the twenty participants recruited for the discomfort evaluation (10 male and 10 female) were collected (Appendix A14) and the percentile ranges were calculated (Table 5.7). Participants were 22-62 years of age (*M* = 33; *SD* = 13), with differing levels of driving experience, ranging from (estimated) 500 to 100,000+ miles (*M* = 12,500; *SD* = 15,200) driven in LCVs.

Table 5.7. Anthropometric data percentile range (n=20).

Dimension	Min (mm)	Max (mm)	Range (mm)	Percentile Range
Sitting height	821	961	140	JF23 – AM81
Shoulder width	370	562	192	JF08 – AM99
Sitting hip width	315	500	185	JF01 – AM99
Knee height	469	570	101	JF94 – AM60
Popliteal length	416	564	148	JF25 – AM99
Seat height	365	515	150	JF64 – AM99
Leg length	872	1127	255	JF22 – AM86

*JF = Japanese female; AM = American male (Nissan Engineering Manual percentile calculation)

The final elevated posture seat set-up for each participant was recorded at the end of the discomfort evaluation (Appendix A15). Table 5.8 shows that the heel step had a range of 547mm – 645mm and the PH gap had the biggest range of adjustment of 638mm – 746mm. These adjustment ranges are comparable with the fitting trial study reported in Chapter 4 (albeit smaller ranges due to the reduced adjustment capability of the seat) with the PH gap having a larger scope of adjustment across the sample than heel step.

Table 5.8. Final elevated seat positions for the long-term discomfort evaluation.

Seat sub-component	Minimum (mm)	Maximum (mm)	Range (mm)	Mean (mm)
Heel step (mm)	547	645	98	589
PH gap (mm)	638	746	108	677

5.4.1. Reporting discomfort

Discomfort was recorded before the trial began to obtain a baseline recording and subsequently every 10 minutes until the end of the trial, at 50 minutes, providing six data sets. Discomfort was analysed as overall discomfort, comparing the elevated and standard posture mean discomfort scores at 50-minutes of driving and as musculoskeletal fatigue effects comparing within posture between each 10-minute interval of reported discomfort. The overall discomfort allowed a direct comparison between postures to understand how the elevated posture seat design impacted upon discomfort in long-term driving with reference to a production seat, as a full sample and by gender. The musculoskeletal fatigue effects gave an understanding of how musculoskeletal fatigue progressed during a prolonged exposure to driving in both postures in comparison to the literature on onset driving discomfort.

Reported discomfort scores were explored to identify areas of the body which reached an uncomfortable rating for individual participants (rating of 4 or above) across the trial and to recognise the driver characteristics which may have contributed to this. Table 5.9 identifies that the buttocks were reported as being uncomfortable for the most number of people in the elevated posture (n=6). The table also shows that eight participants reported being uncomfortable for at least one area of the body during the trial, with participant 14 reporting being uncomfortable most frequently (n=5). Of the 15 reported uncomfortable ratings the majority (n=10) were reported by females. There were no direct similarities between anthropometry or seat set-up to suggest that these characteristics influenced the number of uncomfortable ratings. Whilst one participant reported uncomfortable ratings most frequently (p14), they also commented that they had driven for a long duration that morning driving to Loughborough where the trials took place and their average baseline rating reflected this (M = 2.5; SD = 0.5).

For the conventional posture, six participants reported being uncomfortable for at least one area of the body during the trial, with participant 1 reporting being uncomfortable most frequently (n=8). Of the 20 reported uncomfortable ratings, it was a fairly even split between males (n=9) and females (n=11) however eight of the nine reports for male drivers came from one participant. There were some similarities in anthropometry e.g. both of the males who reported uncomfortable ratings for the right thigh had a similar leg length; however there were a selection of other male drivers in the sample with similar leg lengths who did not report similar ratings. It should be noted that the participants who reported the most number of uncomfortable ratings also had higher baseline recordings than the rest of the sample; participant 1 (M = 1.9; SD = 0.5) who reported a shoulder injury before the trial began, and participant 2 (M = 2.5; SD = 0.5) which suggests that on the day of the trial their discomfort levels were already higher due to external factors. There are no obvious individual driver characteristics which seem to influence an uncomfortable rating, which suggest that any differences observed in the discomfort ratings over time are a result of the driving posture.

Table 5.9. Individual uncomfortable ratings (≥4) across the trial for both the elevated and conventional driving postures.

Posture	Area of body	No. of 'uncomfortable' ratings	Participants	Driver characteristics
Elevated	Upper back	2	P14, P16	• Both female drivers • Different anthropometry (JF36 and JF91 for sitting height) • P14 commented that most areas were more uncomfortable than normal following a long-drive that same morning • P15 did not allude to 'out of the ordinary' discomfort relating to the upper back
	Middle back	2	P4, P14	• Both female drivers • Different anthropometry (JF95 and JF36 for sitting height) • P4 had a higher heel step but identical PH gap to P14 • P14 had higher discomfort ratings due to a long drive that same morning
	Lower back	1	P14	• Female driver (JF36 for sitting height) • P14 had higher discomfort ratings due to a long drive that same morning
	Buttocks	6	P1, P14, P15, P16, P18, P20	• Mixture of males (n=2) and females (n=4) • Range of anthropometry from JF36 to AM35 in leg length • Majority of drivers (n=4) reported a numbing sensation which was no different to the discomfort they would experience in their own vehicle
	Left thigh	1	P17	• Male driver (AM35 for leg length) • Also had numbness of buttocks are reported similar feeling to their own vehicle
	Right thigh	2	P1, P17	• Both male drivers • Similar anthropometry (AM31 and AM35 for leg length) • Similar heel step but different PH gap positions • P17 also had uncomfortable rating in left thigh
	Right ankle	1	P14	• Female driver (JF36 for sitting height) • P14 had higher discomfort ratings due to a long drive that same morning

Posture	Area of body	No. of 'uncomfortable' ratings	Participants	Driver characteristics
Conventional	Neck	1	P1	• Male driver (AM59 for sitting height) • Comment that participant was suffering with a shoulder injury
	Left shoulder	2	P1, P16	• 1 male and 1 female driver • Similar anthropometry across the board • Both complained about a lack of support in the upper backrest for the shoulders • P1 comment that participant was suffering with a shoulder injury
	Right shoulder	1	P16	• Female driver (JF91 for sitting height) • Comment that participant was suffering with a shoulder injury • Also had uncomfortable rating for the left shoulder
	Upper back	2	P16, P20	• Both female drivers • Similar sitting height anthropometry (JF91 and JF97 for sitting height) • P16 had already commented on the lack of support for the upper back and shoulders
	Middle back	2	P1, P20	• 1 male and 1 female driver • Similar sitting height anthropometry (AM59 and JF97) • P1 would have preferred more recline in the fixed seat angle
	Lower back	4	P1, P9, P12. P20	• 2 male and 2 female drivers • Different anthropometry across the board
	Buttocks	3	P1, P14, P20	• 1 male and 2 female drivers • Different anthropometry across the board • Participants also reported being uncomfortable in the buttocks for the elevated posture
	Right thigh	1	P1	• Male driver (AM35 for leg length) • Reported uncomfortable for all of the right side of the lower limbs but not for the left
	Right knee	1	P1	• Male driver (AM35 for leg length) • Reported uncomfortable for all of the right side of the lower limbs but not for the left
	Right ankle	2	P1, P20	• 1 male and 1 female driver (AM35 and JM73 for leg length) • P1 reported uncomfortable for all of the right side of the lower limbs but not for the left

5.4.2. Overall discomfort after 50-minutes of driving

Mean discomfort scores after 50 minutes of driving showed the largest differences for the left shoulder, right shoulder, and lower back (Figure 5.6) where scores were higher for the conventional driving posture. For the majority of the body parts (n=10) there were ties. The highest mean discomfort score after 50 minutes of driving in the conventional posture was for the lower back (*M* = 2.3; *SD* = 1.3), and for the elevated posture the highest mean discomfort score was for the buttocks (*M* = 2.3; *SD* = 1.4). The plots label the verbal anchor 'uncomfortable' at a discomfort rating of 4, a level which was not reached in the mean discomfort scores for either posture. Significant differences in discomfort were observed between the elevated and conventional posture at the end of the trial (50 minutes) only for the right shoulder (*t* = -2.438, df = 19, p<0.05, two-tailed) and the lower back (*t* = -2.238, df = 19, p<0.05, two-tailed) with the NV200 posture having the higher discomfort ratings. There were no significant differences in mean discomfort ratings taken at 0 minutes, between the two postures. This suggests that baseline discomfort was similar for both postures and that the differences observed for right shoulder and lower back were real increases in discomfort.

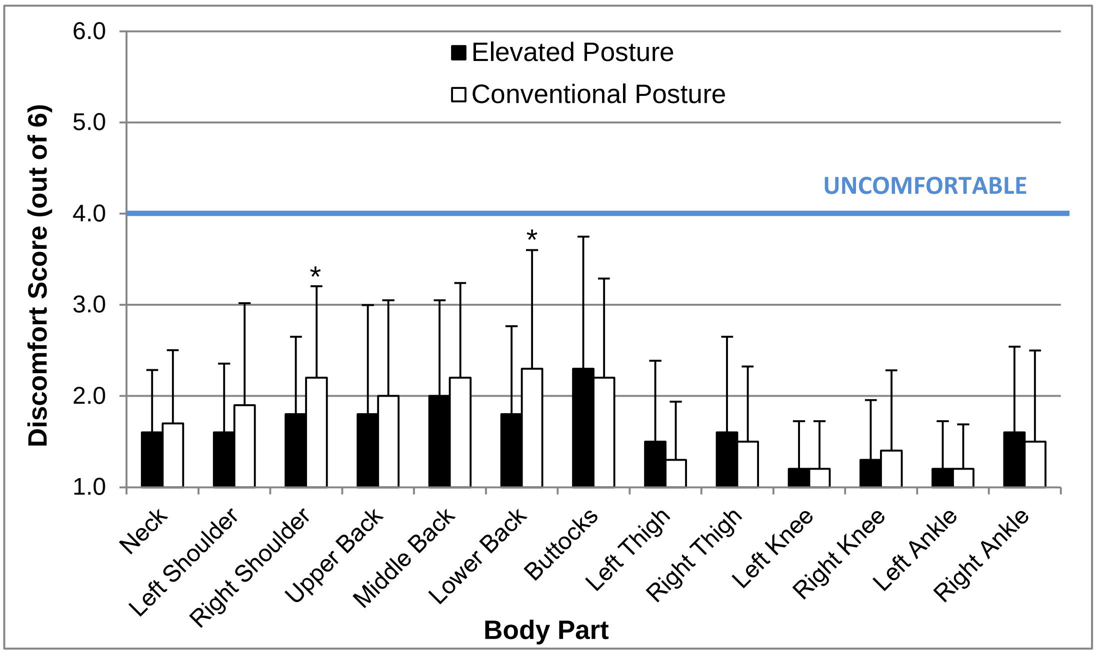

Figure 5.6. Whole sample mean discomfort scores at 50 minutes between the elevated posture and the conventional posture (*p<0.05, two tailed, n=20).

5.4.2.1. Male mean discomfort scores after 50-minutes

For male drivers (n=10) the results indicate that the largest differences between mean discomfort scores after 50 minutes of driving occurred for the neck, left shoulder, right shoulder, upper back, middle back, lower back where the conventional posture had higher mean scores, and for the left thigh and the right thigh having higher mean scores for the elevated posture (Figure 5.7). The buttocks, knees and ankles showed ties. The highest male mean discomfort scores after 50 minutes of driving in the conventional posture were for the middle back (M = 2.1; SD = 1.1), the lower back (M = 2.1; SD = 1.3) and buttocks (M = 2.1; SD = 1.1) and for the elevated posture the highest mean discomfort score was for buttocks (M = 2.2; SD = 1.2).

There were no significant differences in discomfort observed between the elevated posture and the NV200 (benchmark) posture at the end of the trial (50 minutes) for male drivers. There was no significant difference in mean discomfort ratings taken at 0 minutes, between the two postures for male drivers, which shows that the baseline discomfort recordings were consistent. It should be noted that due to the smaller sample size, the statistical tests used for male drivers did not have as much power as that used for the whole sample.

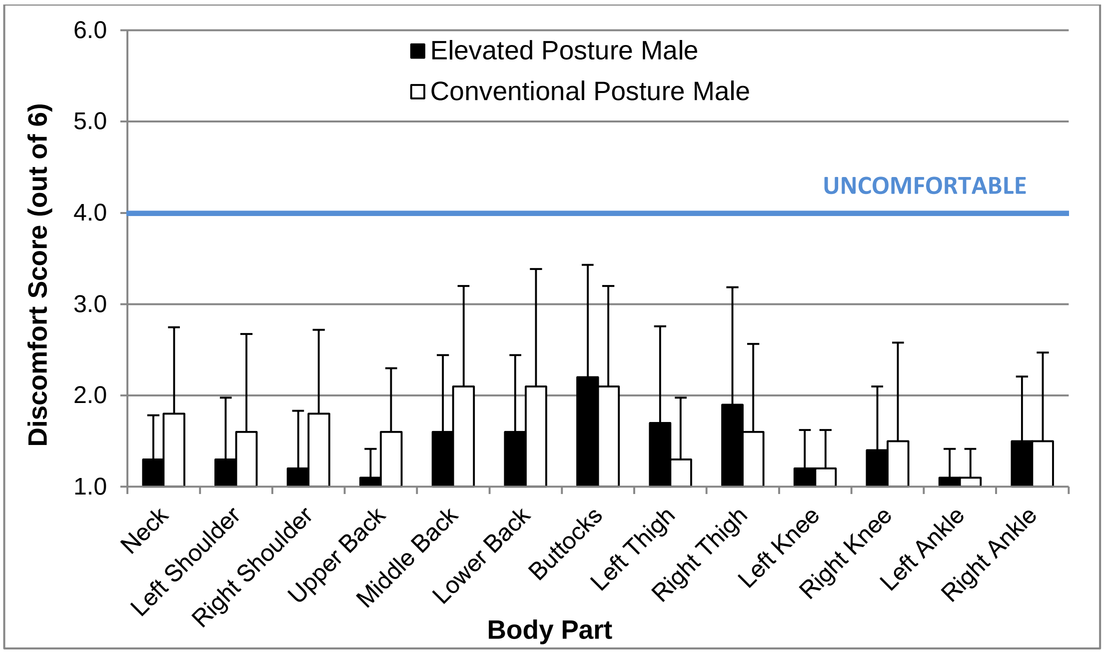

Figure 5.7. Male sample mean discomfort scores at 50 minutes between the elevated posture and the conventional posture (n=10).

5.4.2.2. Female mean discomfort scores after 50 minutes

For female drivers (n=10) the results indicate that the largest differences between mean discomfort scores after 50-minutes of driving occurred for the left shoulder, right shoulder and lower back where the conventional posture had higher mean scores than the elevated posture (Figure 5.8). All other body parts (n=10) showed ties. The highest mean discomfort score after 50 minutes of driving in the conventional posture was for the right shoulder (*M* = 2.6; *SD* = 1.0) and for the elevated posture the highest mean discomfort score was for the upper back (*M* = 2.5; *SD* = 1.4).

There were no significant differences in discomfort observed between the elevated posture and the NV200 (benchmark) posture at the end of the trial (50 minutes) for female drivers. There was no significant difference in mean discomfort ratings taken at 0 minutes between the two postures for female drivers, which shows that the baseline discomfort recordings were consistent. It should be noted that due to the smaller sample size, the statistical tests used for female drivers did not have as much power as that used for the whole sample.

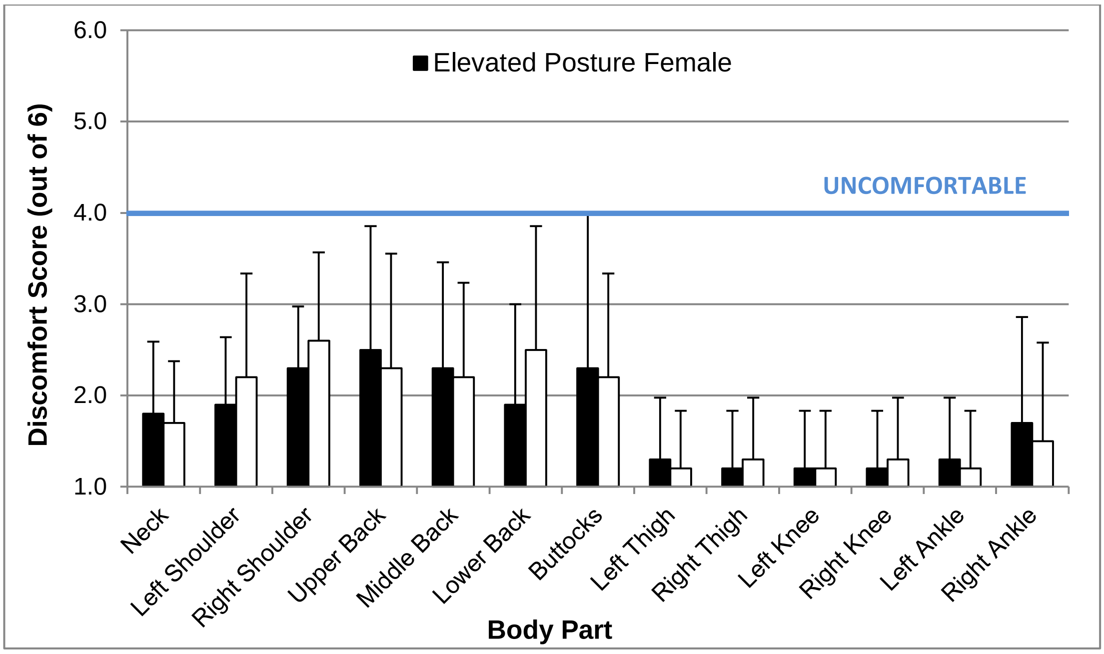

Figure 5.8. Female sample mean discomfort scores at 50 minutes between the elevated posture and the conventional posture, n=10).

5.4.3. Musculoskeletal fatigue effects

Musculoskeletal fatigue effects were compared between the baseline and the end of trial discomfort ratings within each posture. Furthermore, discomfort was analysed across the trial for each posture to identify the onset of discomfort in each posture for comparison.

5.4.3.1. Elevated posture musculoskeletal fatigue effects

For the elevated posture, the results indicate that the mean discomfort score increased for 9 of the 13 body parts (left shoulder, right shoulder, upper back, middle back, lower back, buttocks, left thigh, right thigh, right ankle) from the beginning to the end of the driving trial (Figure 5.9).

Descriptive statistics showed that discomfort reported between 0-minutes and 50-minutes of driving in the elevated posture, was significantly different for the left shoulder (t = -3.327, df = 19, p<0.01, two-tailed), right shoulder (t = -3.584, df = 19, p<0.01, two-tailed), upper back (t = -2.896, df = 19, p<0.01, two-tailed), middle back (t = -3.387, df = 19, p<0.01, two-tailed), lower back (t = -3.249, df = 19, p<0.01, two-tailed), buttocks (t = -3.133, df = 19, p<0.01, two-tailed) and right ankle (*t* = -2.932, df = 19, p<0.01, two-tailed) with the highest discomfort ratings observed at the 50-minute recording.

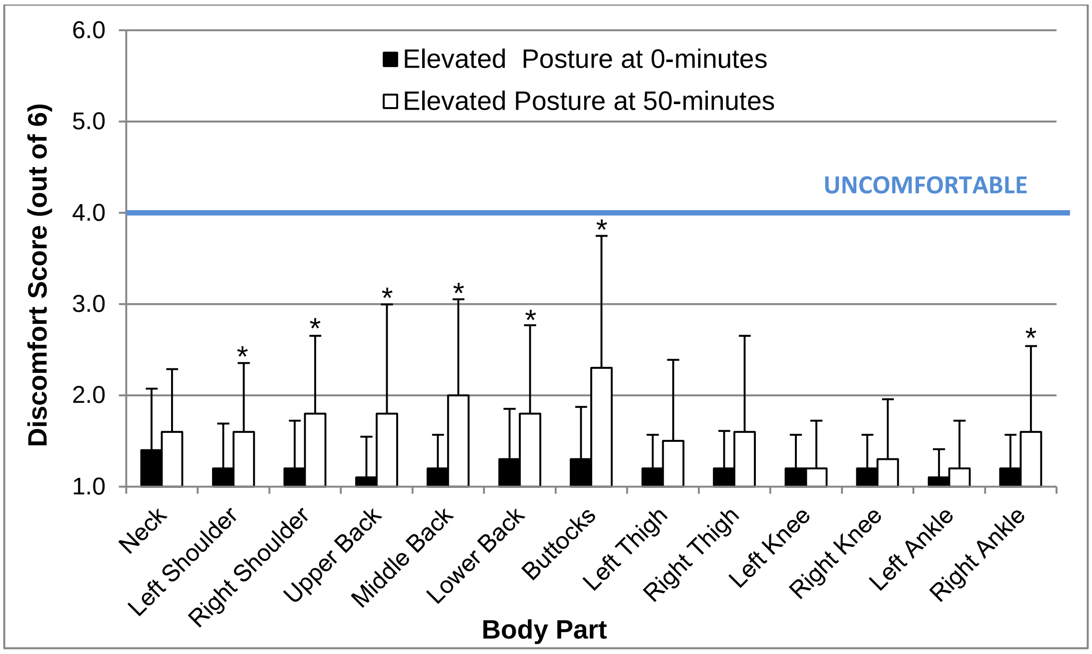

Figure 5.9. Body discomfort for the elevated posture between 0 and 50 minutes of driving (*p<0.01, two-tailed, n=20).

Table 5.10 details the seven reported areas of discomfort that were significantly higher at the end compared to the beginning of the trial, using p<0.05 as the measure of significance. The musculoskeletal fatigue within driving postures was explored further to identify the progression of discomfort across time. Table 5.10 shows that significant differences in discomfort occurred after as little as 20 minutes of driving (upper back and buttocks). All significant differences in discomfort for the elevated posture were observed after 40 minutes of driving (left shoulder, right shoulder, middle back, lower back and right ankle). These results show that the on-set of discomfort for drivers in the elevated posture occurred between 20-40 minutes of driving exposure and that there were no significant increases between 40 and 50 minutes of driving.

Table 5.10. Driving fatigue progression using p<0.05 as the measure of significance in the elevated driving posture.

Body portion	Time of significant differences in discomfort (mins)	Paired samples t-test 'p' value
Left shoulder	40-minutes	0.015
Right shoulder	30-minutes	0.028
Upper back	20-minutes	0.017
Middle back	40-minutes	0.007
Lower back	30-minutes	0.015
Buttocks	20-minutes	0.049
Right ankle	40-minutes	0.015

Figure 5.10 shows that the mean reported discomfort rating for the buttocks was the highest at the end of the trial (2.2) and along with the middle back, these area showed the most consistent progressive increase in rating between each 10-minute recording with no drops.

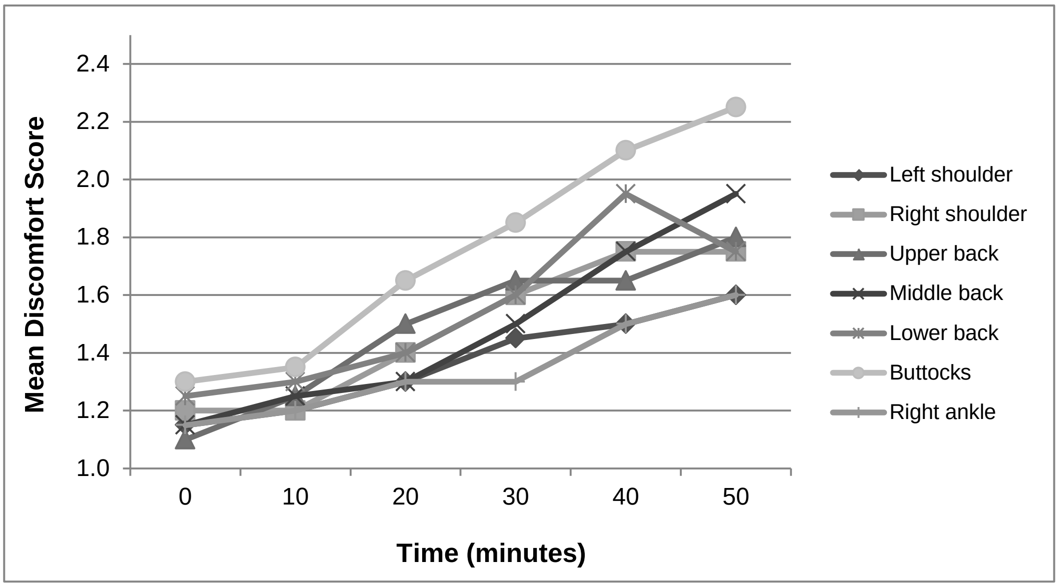

Figure 5.10. Development of discomfort in individual body parts across a 50 minute trial whilst driving in the elevated posture (n=20).

5.4.3.2. Conventional posture musculoskeletal fatigue effects

For the conventional posture, the results indicate that the mean discomfort score was higher for 8 of the 13 body parts (left shoulder, right shoulder, upper back, middle back, lower back, buttocks, right thigh, right ankle) from the beginning to the end of the trial (Figure 5.11).

Descriptive statistics showed that discomfort reported between 0-50 minutes of driving in the conventional posture, was significantly different for the left shoulder (t = -3.199, df = 19, p<0.01, two-tailed), right shoulder (t = -3.847, df = 19, p<0.01, two-tailed), upper back (t = -3.621, df = 19, p<0.01, two-tailed), middle back (t = -4.414, df = 19, p<0.001, two-tailed), lower back (t = -3.567, df = 19, p<0.01, two-tailed), buttocks (t = -5.146, df = 19, p<0.001, two-tailed) and right thigh (t = -2.666, df = 19, p<0.05, two-tailed) with the highest discomfort ratings at the 50-minute recording.

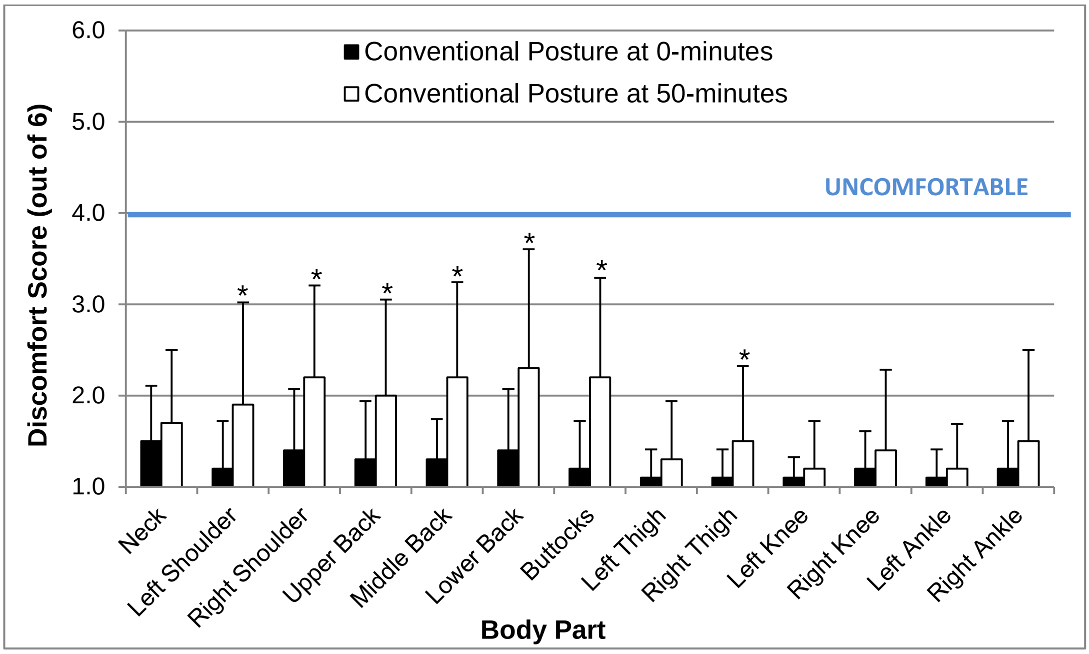

Figure 5.11. Body discomfort for the conventional posture between 0 and 50 minutes of driving (*p<0.01, two-tailed, n=20).

Table 5.11 details the seven reported areas of discomfort that were significantly higher at the end compared to the beginning of the trial, using p<0.05 as the measure of significance. The musculoskeletal fatigue within driving postures was explored further to identify the progression of discomfort across time. Table 5.11 shows that significant differences in discomfort occurred after as little as 10 minutes of driving (middle back). Results show that five of the seven areas reported showed significant differences after 30 minutes of driving, which matches the same trend in the elevated posture. These results show that the on-set of discomfort for drivers in the elevated posture occurred between 10-50 minutes of driving exposure. The minimum amount of time before the onset of discomfort in the conventional posture is therefore shorter than for the elevated posture. However, with the inclusion of the reported right thigh discomfort shows that it took 50 minutes before all seven areas showed signs on onset discomfort in the conventional posture, whereas it took only 40 minutes for the same result in the elevated posture.

Table 5.11. Driving fatigue progression using $p<0.05$ as the measure of significance in the conventional driving posture.

Body portion	Time of significant differences in discomfort (mins)	Paired samples t-test 'p' value
Left shoulder	20-minutes	0.049
Right shoulder	30-minutes	0.008
Upper back	30-minutes	0.009
Middle back	10-minutes	0.042
Lower back	20-minutes	0.031
Buttocks	40-minutes	0.001
Right thigh	50-minutes	0.015

Figure 5.12 shows that the mean reported discomfort rating for the lower back was the highest at the end of the trial (2.3) and along with the right shoulder and the middle back these areas showed the most consistent progressive increase in rating between each 10-minute recording with no drops and exceeding 2 on the rating scale.

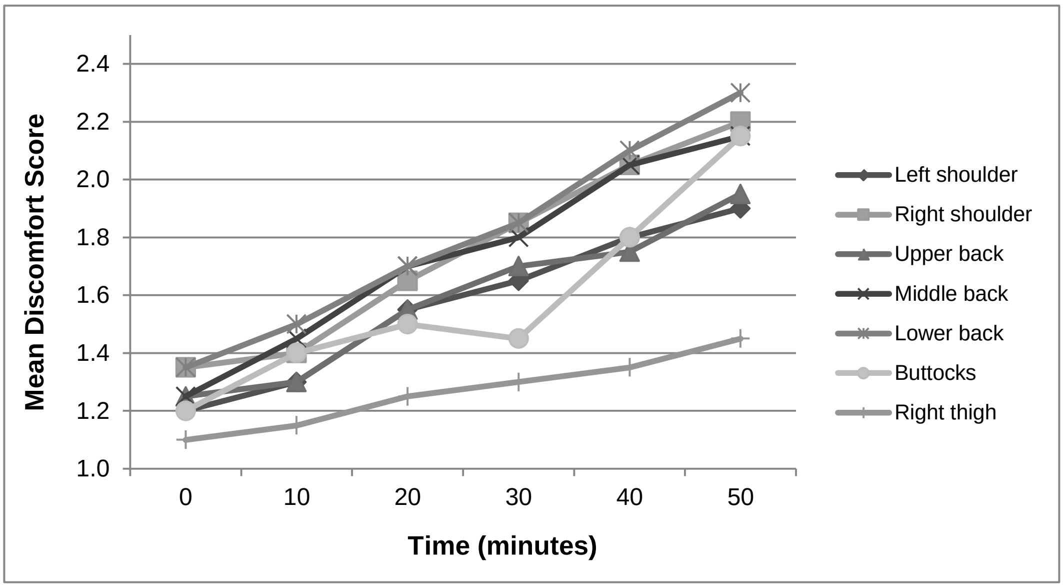

Figure 5.12. Development of discomfort in individual body part areas across the 50-minute trial whilst driving in the conventional driving posture (n=20).

5.4.4. Participant verbatim

Following the completion of the long-term discomfort evaluation and whilst in their chosen seat set-up, participants were asked for their views on the elevated driving posture. The main findings are summarised below (full details in Appendix A16).

5.4.4.1. Positive feedback

The verbatim was collated to identify positive feedback from the sample relating to reported discomfort in the elevated posture. The main findings are detailed below:

- The majority of participants surmised that the discomfort they felt throughout and at the end of the trial, was comparable to that they would experience in their normal driving posture (in own vehicles).
- The trend was that whilst participants felt a bit ‘fidgety’ towards the end of the trial, this was a common sensation when driving for an extended period of time in any vehicle, especially in comparable vehicles such as vans.

- Two drivers commented that the driving posture felt very intuitive, elaborating that it felt very natural to adopt and drive in and felt no different to their respective postures in similar vehicle types.

5.4.4.2. Negative feedback

The verbatim was analysed to identify negative feedback from the sample relating to reported discomfort in the elevated posture. The main findings are detailed below:

- Some drivers felt that the seat cushion itself could have been softer to avoid a numbing sensation in the buttocks and thighs.
- Some drivers made comments about how sitting more upright, whilst not uncomfortable, made them much more aware of the backrest and how they interacted with it whilst seated.
- Elaborating on the previous point, some drivers felt that they needed more support from the backrest specifically for the lower and middle back.
- One driver noted that the discomfort they experienced in the thighs was most likely a consequence of positioning themselves slightly too high before the trial began and would have been alleviated if they had adjusted their posture at the time.

5.5. Discussion

The aim of the long-term discomfort evaluation was to understand the effects of the elevated driving posture (and new seat design) in comparison with a conventional driving posture (and benchmark production seat). Factors affecting seat comfort are well documented (Thakurta et al., 1995; Ebe and Griffin, 2000a,b; Kolich, 2008), along with the methods of assessing discomfort in the laboratory trials (EMG, subjective discomfort ratings). There are no known studies that have investigated long-term discomfort in an elevated posture, such as the one described in this research. The findings will therefore be discussed in this context, linking to the literature for onset musculoskeletal fatigue in driving followed by the limitations of the research and conclusions.

The observed results of the long-term discomfort evaluation met the objectives for this study (section 5.2), identifying significant differences in discomfort between the two driving postures after 50 minutes of driving. The discomfort reported in the elevated posture was lower than in the conventional posture, which gives an insight in to how drivers interact with the higher seated position. This suggests that may be postural and comfort advantages from driving in this posture. It has previously been discussed that as the biomechanics of this posture forces drivers to adopt a more upright position, the shape of the spine naturally moves towards a natural ‘S’ shape which minimise pressure on the lower vertebrae during sitting. This would need exploration with longer exposures (more than 50 minutes) to further understand possible health benefits. Additionally, long-term studies with a larger sample size would be needed to test this hypothesis; this is out of the scope of this study.

The literature suggests that the presence of vibration accelerates the onset of seat discomfort (Mansfield, 2005) and musculoskeletal fatigue. Participants in both driving postures experienced musculoskeletal fatigue through the central core of the body over 50-minutes of driving (left and right shoulder, upper middle and lower back and buttocks). Griffin et al. (1982) investigated a seated driving posture with vibration and found that vibration at the seat level affects the buttocks and is transmitted in to the spine and the observed areas of fatigue seem to match this. With the exception of the buttocks (40-minutes) and right thigh (50-minutes), the onset of discomfort for the other five body parts (collectively) in the conventional posture was significant after only 30 minutes. The same body parts in the elevated posture had significant differences in discomfort after 40 minutes. Furthermore, in the conventional posture it took only 10 minutes before the ‘middle back’ had significantly more discomfort than at the beginning of the trial, whereas it took 40 minutes for the same body part in the elevated posture. This effect is in agreement with the findings of Mansfield et al. (2014) and Sammonds et al. (2014), which observed significant differences in seat discomfort after only 30 minutes and 40 minutes respectively. The findings from this study enforce the hypothesis that the elevated posture is at least similar to and may have potential advantages over a conventional driving posture in delaying the onset of discomfort.

Participants in the elevated posture had musculoskeletal fatigue in the right ankle (after 40 minutes) and the conventional posture in the right thigh (after 50 minutes). It was likely that musculoskeletal fatigue would be observed in the right leg, due to a repetitive movement operating the pedals, leading to an increase in ankle flexion and an increase in thigh interaction with the seat. There was no evidence of musculoskeletal fatigue in any portion of the left leg, which was likely due to the automatic transmission driving configuration. The right foot controlled both the accelerator and brake pedals in the automatic transmission configuration and there was no clutch, thus no left foot operation. This meant that the left leg was free to move for the entirety of the trial and could be adjusted and moved to alleviate any discomfort that occurred, which was not an option for the right leg. In a long-term driving trial (140 minutes), Sammonds et al. (2014) identified that that the rate of discomfort onset decreased >70-minutes of driving, concluding that discomfort does not increase linearly. Additionally, it was observed that drivers alter their behaviour to cope with increased levels of discomfort and the frequency of these ‘fidgets’ may increase as seat discomfort increases. This finding indicates that a driving posture, such as the elevated posture, with room for adjustments and fidgets to alleviate the onset of discomfort would be beneficial for the occupant. In further development of an elevated driving posture, the angle, force and stroke of the pedals needs further research to ensure that the ankle angle is not becoming too acute for pedal operation.

The experimental design was effective in providing participants with an immersive driving task. This was achieved as a result of the blackout environment constructed around the platform and the three-screen driving simulation system, offering more ‘realism’ to the task. The laboratory environment took many weeks to set-up with considerable piloting and iterative development to ensure that this was achieved. The long-term discomfort trial further validated the findings and seat specification outlined in

Chapter 4, as all twenty drivers were able to set themselves up in a comfortable elevated driving position. Whilst these results indicate that the elevated posture does not lead to higher levels of discomfort during driving, the static and dynamic properties of the seat need further exploration to understand how the higher seated position reacts to lateral motion. This is explored in Chapter 6.

5.5.1. Limitations

The main limitation in this study was the sample size. Whilst there was a good anthropometric spread and a large enough sample to conduct appropriate statistical testing, a larger sample would have allowed a bigger representation of the LCV driving population and more confidence of the findings for the automotive industry. A larger proportion of smaller percentile drivers would have been desirable as the smallest leg length was equivalent to Japanese Female 24th percentile (JF24). The nature of this posture has so far shown that in the current set-up smaller drivers will have most difficulty in achieving an optimum driving position. Time restrictions meant that it became difficult to find a balanced sample with LCV driving experience and as a result, two of the participants (16 and 17) who took part in the trial only had conventional vehicle driving experience. The elevated posture is most similar to a LCV driving posture which is generally seated higher in the vehicle. Without the experience of this driving posture, participants were unable to draw a comparison to their real driving. However, the inclusion of the benchmark production seat in the NV200 LCV posture in these trials allowed these drivers to compare between the two in a controlled way.

The adjustment features on the elevated driving seat were operated in two ways: a gas strut for vertical adjustment and electronic adjustment for the fore-aft seat position. Towards the latter stages of the trial period, the gas strut on the seat became stiffer, which hampered the ability of participants to make accurate incremental adjustments when setting their driving position. Additionally, the force required to lower the seat (with a weight-on lowering design) was a problem for some of the lighter participants. Both of these issues were mitigated by allowing more time and by giving participants additional help from the investigator during the set-up process.

The driving simulator was upgraded to a three-screen system for the trials (section 5.3.5.5) which offered participants a wider field of view. In the familiarisation period three participants (not included in the final sample of 20) suffered from ‘simulator sickness’. This was the sensation of the information on the screen moving past either side of their focus on the left and right outer screens as they performed the driving task. This was an expected sensation for approximately 10% of participants and the three drivers for which it occurred all wore glasses when driving. These trials were stopped immediately, with the expectation that this sensation was unlikely to alleviate. These trials were all stopped in the familiarising period of the trial and were excluded from the analysis (n=20). This was a limitation of these laboratory simulation trials, and the symptoms would not have occurred in road trials. However, the nature of the elevated posture in its early development rendered it impossible to incorporate it in to a vehicle for road trials.

5.6. Conclusions

The objectives for this study were:

- Understand the effects of a new seat design on long-term driver comfort, in comparison with a benchmark production seat.
- To identify the onset of musculoskeletal fatigue in comparison with a benchmark posture and the literature.
- Understand the suitability of the chosen research methods in assessing dynamic seat comfort with driving simulations in an elevated posture.

The results from the long-term discomfort evaluation met the objectives for this experimental study and it is possible to conclude the following:

1. Right shoulder and lower back discomfort was significantly higher in the conventional posture than in the elevated posture, after 50-minutes of driving.
2. There were no gender differences in overall discomfort reported after 50-minutes of driving.
3. The onset of musculoskeletal fatigue results fell in line with the literature and validated that 50 minutes was a long enough driving exposure to observe significant differences in discomfort.
4. The laboratory set-up and experimental design provided the basis for a repeatable driving trial to collect reliable reported discomfort.

5.6.1. Summary

The results from the long-term discomfort evaluation have shown that this study was a progressive research step in the exploration of the elevated driving posture, leading on from the conclusions of the seat design parameter study as described in Chapter 4. The experimental design was developed to immerse the driver in the task for as much realism as feasibly possible, whilst providing participants with an intuitive subjective rating scale to accurately collect their perceived discomfort. The analysis has shown that the elevated posture does not accelerate the onset of seat discomfort and the levels of discomfort are comparable to a conventional driving posture. From this stage, further research is needed further explore potential issues in dynamic driving conditions, such as the lateral stability from being seated higher up in the vehicle.

CHAPTER 6

LATERAL STABILITY EVALUATION

6.1. Introduction

The previous chapter reported on a long-term discomfort evaluation, comparing the newly developed elevated posture seat with a conventional production driving seat. The findings showed that the elevated posture seat performed well in comparison to the benchmark and that the conventional posture had significantly higher reported discomfort scores for the right shoulder and the lower back after 50 minutes of driving in a driving simulator, under WBV. These results indicate that drivers could achieve a comfortable elevated driving posture. This chapter details a lateral stability evaluation, comparing two iterations of the new elevated posture seat with the conventional driving seat. Seat 1 was the one used for the long-term discomfort evaluation trials and seat 2 has design features to improve lateral stability under lateral accelerations.

When driving, vehicle occupants are exposed to lateral acceleration in their seats. A higher centre of gravity means that body-roll experienced during these lateral accelerations will be greater for a seat mounted higher in the vehicle. The hypotheses therefore were that occupants in the elevated posture, subjected to the same lateral accelerations, would have a greater perception to motion and feel more unstable in comparison with the benchmark posture, mounted lower in the vehicle. As the second iteration of the elevated posture seat had design features to help with lateral stability, it was expected that this seat would perform better.

6.2. Aims and objectives

Part of the focus of this thesis is to identify the seat parameter considerations for a comfortable seat in an elevated posture, including assessment of the support (and lateral stability) offered to drivers seated higher in the vehicle. A study was therefore conducted to address the following objectives:

- Understand whether the increased height of the driver's hip point results in an increased sensitivity to and perception of vehicle motion.
- Develop and evaluate research methods in assessing lateral stability and perception of movement in automotive seating.

6.3. Research method

6.3.1. Sampling strategy

The sample size was defined by the following criteria: large enough to perform statistical testing, practical limitations (e.g. time constraints), and driving experience. Twenty participants were recruited using a stratified random sampling technique, with the following inclusion criteria:

- 18 to 65 years old
  Rationale: younger (<18 years) or older (>65 years) individuals were considered vulnerable population groups by the university's Ethical Advisory Committee (LUEAC) at the time of the study.
- Hold a full UK driving licence for a minimum of 2 years
  Rationale: the minimum of 2-years driving experience ensures that drivers will be at least 19 years old and have experience of lateral acceleration, stability and comfort while driving.
- Balanced sample (10 males and 10 females)
  Rationale: a weakness highlighted in the literature is that the sample is often not balanced in laboratory driving trials. As a new area of research, it is critical to understand the parameters for the elevated posture for both male and female drivers.
- Large anthropometric coverage
  Rationale: to fully understand the parameters for the elevated posture, for a diverse driving population, as large an anthropometric sample as feasibly possible should be tested, especially larger and smaller percentile drivers.

Ethical approval was granted by the Loughborough University Ethical Advisory Committee (LUEAC) from Loughborough University in March 2014.

6.3.2. Driving seats

In order to identify the lateral stability performance of the elevated posture seat, 3 separate seats were selected for testing (Table 6.1): two elevated posture seats and one NV200 production seat. The latter was used as a benchmark for the long-term discomfort evaluation, detailed in Chapter 5.

Table 6.1. Descriptions of the 3 seats tested in the lateral stability evaluation trials.

Seat	Description
Nissan NV200 production seat	Replicated a current light commercial vehicle (LCV) production seat, with actual seat fore-aft adjustment range and corresponding cabin parameters (pedal set up and steering wheel position).
Elevated posture seat number 1 (EPS1)	A seat designed for use in an 'elevated driving posture' based on the seat parameters identified in Chapter 4. This seat was also used for the long-term discomfort evaluation trials (Chapter 5).
Elevated posture seat number 2 (EPS2)	A seat with the same basic structure as EPS1, with modifications to the seat base to improve driver support and stability under lateral motion.

The same driving rig that was constructed for the long-term discomfort trials was utilised for these lateral stability trials as it had the capability to interchange two different seats on a mounted platform.

6.3.2.1. Seat modifications to the elevated posture seat 2 (EPS2)

The hypothesis is that drivers will be able to perceive lateral acceleration more strongly in the elevated driving posture, in comparison to a conventional driving posture (section 6.1). Therefore, following the long-term discomfort evaluation trials, EPS1 was fitted in to a donor vehicle (by Concept Group International Ltd) at the request of the automotive sponsor for this research. This vehicle was driven by the automotive sponsor in a series of test-track laps on an inner city circuit at a private proving ground to provide further understanding of the lateral stability issues that may occur with a higher seated driving position. This testing identified that specific seat design features were needed in order to improve the lateral stability of the elevated posture seat. These are detailed in Table 6.2 and modifications were made to EPS1 in order to create EPS2.

Table 6.2. Lateral stability considerations for the elevated posture seat and modifications made to EPS1 to create EPS2.

Consideration	Description	Modification
Stability from the seat base during tight cornering.	The feeling of sitting on top of the seat foam and not sinking in to the foam. This created a feeling of rolling around on top of the seat.	Changes were made to the metalwork at the front edge of the seat below the occupant's thigh, moving the front cross member lower and forwards. This change allowed the occupant to sink a little lower in to the foam to feel more supported during normal driving. Additionally, the support wire was made wider at the front corner to support the foam better.
Support from seat bolsters during tight cornering.	The seat bolsters not offering as much support as preferred when cornering in the elevated posture.	An advantage of the elevated posture is that the ingress and egress from the seat is greatly improved. With this in mind the profile of the seat bolsters were not raised. However, the change in structure detailed above meant that the current bolster profile would feel like they were providing more lateral support due to sinking a little more in to the seat foam.
Slipping off the seat surface during tight cornering.	The material of the seat itself not creating enough friction between seat and occupant.	The trim material was changed to 'alcantara' which is an artificial substitute for suede leather. This provided an increase in friction between the seat and the occupant.

The structural changes include a new position of the front cross member allowing the foam to sink a little lower in to the seat structure. This modification was made so that occupants could sink a little lower in the seat, to provide a more supportive feeling during normal driving. This was an important consideration for lateral stability.

6.3.3. Laboratory set-up

For the lateral stability evaluation trials the laboratory needed to be prepared to ensure that they were conducted safely and efficiently and to collect reliable and accurate data. The following section details the areas of focus for rigorous piloting in order to provide the optimum environment for this study.

6.3.3.1. Multi-axis vibration simulator (MAViS)

MAViS is the platform upon which the EPS1, EPS2 and Nissan NV200 driving rigs were to be mounted for the lateral stability evaluations. The platform is a Rexroth Hydraudyne B.V. Micro Motion 600-6DOF-200-MK5 multi-axis vibration simulator which allows six degrees of movement (X, Y, Z, roll, pitch and yaw) to replicate a vibration condition. The full details of the procedures followed whilst operating the vibration platform are detailed in Chapter 3, section 3.5.

The trials used a pre-recorded pavé road surface input in to the MAViS system, with a low level of vibration in z (0.1 m/s² r.m.s. W_k weighted) to give underlying motion for the participant. This level of vibration was used to provide the feeling of slow driving and to immerse the participant in the context of being in a moving vehicle. Once participants were ready to begin, the vibration was set to loop and run for the entire lateral motion sequence. The platform was rolled to 14.5° (in both left and right directions) from its neutral position, in 1.3 seconds creating a lateral acceleration of 0.25g. Piloting had identified that this replicated similar forces to when cornering in real driving.

6.3.3.2. Standardised clothing for participants

Participants were required to wear standardised clothing for each trial (three seats). As the trial was exposing participants to lateral motion, standardised clothing ensured that the friction between participant and seat was constant. The clothing provided was ‘Campri’ base layers, consisting of a long sleeved top and trouser legging in a range of sizes suitable for male and female participants. The garments of clothing were washed after each trial and participants would wear their selected size for all three trials, to standardise across seats as well as across participants.

6.3.3.3. Blackout environment for participants

The laboratory development, as described in Chapter 5, led to the construction of a blackout environment which surrounded the motion platform. However, for these trials part of this was taken down so that the investigator had a clear line of sight between the operating system and the motion platform. In order to ensure that visual cues did not dominate the perception of movement, participants were asked to wear a double blindfold once they were seated and before the trial began. This blocked out all light and ensured that participants' perception to movement was processed by the vestibular system, as would occur during cornering.

6.3.3.4. Light and heat environment for participants

In the testing space there was low level lighting and piloting identified that there was a need for more light surrounding the platform in order for the investigator to safely manage the operation of the platform and to provide sufficient light for the cameras. To address this, two halogen lights were placed to the front left and the front right of the platform in the testing area. This provision was sufficient for the investigator but did not compromise the blackout environment for the participant. The addition of the halogen lights generated heat in the testing area, which was alleviated with a fan placed in front of the platform blowing the hot air through the back of the laboratory and thus keeping participants at a comfortable temperature during the testing. Piloting identified that heat increased the perception of discomfort in participants. This was mitigated to ensure that the participants' reported stability discomfort was centred on the lateral motion sequence rather than environmental factors.

6.3.4. Study design and rationale

When driving, vehicle occupants are exposed to different types of whole-body vibration and low frequency accelerations occur while the vehicle accelerates decelerates or corners. Lateral accelerations are typically less than 0.5g, and differ based on the speed the vehicle is travelling and the curvature of the corner (Mansfield and Whiting-Lewis, 2004). The elevated posture raises the seating position in the vehicle which subsequently leads to a higher centre of gravity and thus occupants are likely to be more perceptive of lateral motion. This provided rationale to investigate the lateral stability of occupants in the elevated posture.

This study aimed at understanding the perception of lateral motion in two elevated posture seat concepts and in comparison with a production seat in a conventional posture. This was achieved using a repeated measures design with a balanced order of testing. Currently there is a gap in the literature for repeatable methods of assessing lateral stability in car seats from a seat occupant's point of view. As a result, this trial was designed to develop and evaluate research methods suitable for this field of study.

6.3.4.1. Recruitment

For recruitment, adverts were placed on the intranet staff noticeboard, detailing the nature of the study and the investigator also generated interest through word of mouth. Participants were required to be drivers however they were not required to be experienced. The first contact with the 20 participants (10 male and 10 female) was via e-mail, telephone or in person, with a brief explanation of the study and the nature of the lateral stability evaluation. Following that, interested parties were sent participant information sheets (Appendix A17) and asked their height in order to monitor anthropometric spread. If the individual agreed to take part, the first session (of three) was scheduled and participants were instructed to wear flat shoes (e.g. trainers or a shoe with a heel of <2cm) to standardise footwear. Participants were recalled for the remaining two trials at the nearest convenience which was usually on the same day the following week. Trials were a minimum of 1-week apart to compensate for learning effects.

6.3.4.2. *Anthropometric data collection*

On arrival, participants were asked to re-read the information sheet, sign a consent from (Appendix A4) and fill in a health screen questionnaire (Appendix A5). Following this, anthropometric data was collected using a sitting height table and an anthropometer. Anthropometric measurements were taken (Table 6.3) relevant to seat design and driving posture. The definition of each measurement was taken from a Nissan engineering manual (NEM) which outlines a set of guidelines for anthropometric data collection (Appendix A1). Japanese and American percentiles were calculated as they represent some of the smallest (JF) and largest (AM) populations in the world.

Table 6.3. Anthropometric data measurements selected for collection.

Dimension number	Anthropometric description
1.	Sitting height
2.	Shoulder width
3.	Sitting hip width
4.	Knee height
5.	Popliteal length
6.	Seat height
7.	Leg length
8.	Foot length
9.	Shoe size

6.3.4.3. *Setting drivers' driving position*

For each seat, participants were taken through a short fitting trial in order to set their driving position (Chapter 5, section 5.3.6.3). For the elevated posture seats drivers could adjust their seated position both vertically and in fore-aft, which moved on a 25° incline. The difference between EPS1 and EPS2 was that the EPS2 seat had an electronic vertical lifter, whereas the EPS1 seat had a gas strut manual lever system; however the adjustment range remained the same. Participants were advised to explore the travel of adjustment before fixing their final seat position. The trials were conducted in a randomised order, to control for learning effects in each respective posture, detailed in Table 6.4. As a result, the final seat position for which ever elevated posture seat was tested first was replicated for that participant's second trial. Additionally, participants had a freely adjustable steering wheel, with adjustment in Z, X and wheel angle.

For the NV200 posture, the only adjustment was fore-aft of the seat along the actual seat slide range of the production vehicle (240mm). The steering wheel position was fixed for this trial, as per the production vehicle.

Table 6.4. Randomised order of testing of the 3 seats.

Participant	1st Trial	2nd Trial	3rd Trial
1 - 7	NV200 seat	EPS1	EPS2
8 - 14	EPS1	EPS2	NV200 seat
15 - 20	EPS2	NV200 seat	EPS1

*NV200 – Nissan LCV production seat

*EPS1 – Elevated posture seat 1, developed for the long-term discomfort evaluation (Chapter 5)

*EPS2 – Elevated posture seat 2, modified for improvements of stability during lateral motion

6.3.4.4. Lateral motion sequence

For each driving seat trial, the platform was rolled both left and right an equal number of times in a randomised order. This predetermined order compensated for any learning effects, detailed in Table 6.5. Of the 5 repetitions, only the 3rd, 4th and 5th lateral motion scores (section 6.3.4.5) were used for data analysis. The purpose of discarding the first two scores was in anticipation of a higher score for the initial sequences and thus to compensate for learning effects. It also allowed participants to familiarise themselves with the level of motion they would be exposed to.

Table 6.5. Randomised order of lateral motion sequences to compensate for learning effects.

Participant	1st Sequence	2nd Sequence
Odd (1, 3, 5 etc.)	Left roll (5 repetitions)	Right roll (5 repetitions)
Even (2, 4, 6 etc.)	Right roll (5 repetitions)	Left roll (5 repetitions)

The aim of the lateral motion was to induce a perception of movement to provide understanding of the support participants were given in each of the three seats tested. The trial consisted of two sequences (left and right roll) replicating the lateral acceleration that is observed when cornering in real-world driving. The platform was held at 14.5° for 2 seconds before being negotiated back to its neutral position. At this point participants were asked to report their lateral stability score to evaluate their experience of the lateral acceleration (section 6.3.4.5).

6.3.4.5. Lateral stability scores

Piloting of the lateral stability scales led to the selection of a numerical scale that had extreme definitions for the lowest and highest values. This enabled participants to associate and understand two extreme states of mind, one being stable, comfortable and calm and the other feeling anxious, unstable and uncomfortable. This scale was viewed as being intuitive for participants and easy for them to remember. This was of significant importance as participants were blindfolded for the motion sequences and were asked for a quick response once the rig had returned to its neutral position. The lateral stability scores were recorded using a lateral stability scale, rating from 1-100. There were two descriptors which described the extreme ends of the scale respectively:

- 1 = “I feel stable, comfortable and calm in this seat”
- 100 = “I feel unstable, uncomfortable and anxious in this seat”

The scale as detailed in Figure 6.1 was shown to participants before the trial began. This scale was printed on A3 paper and presented in participants’ field of view before application of the blindfold; they were asked to look at this until they were familiar with the format. Additionally, there was support from a second investigator who had the sole responsibility of asking participants for their chosen score after each lateral sequence. This process ensured that participants could be reminded of the scale should they need to be and also that the platform could be controlled by the first investigator efficiently without indeterminate gaps between each sequence whilst the score was recorded.

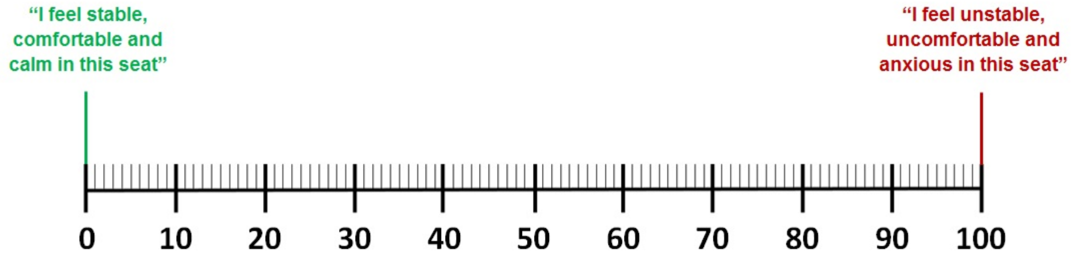

Figure 6.1. Lateral stability scale with verbal descriptors representing the extreme values of comfort during lateral motion exposure.

6.3.4.6. Familiarising participants with the lateral motion

Participants were asked to fasten their seat belt before the platform was turned on and instructed not to leave the seat and step off the platform until they were asked to do so by the investigator. Before the main trial began, participants were asked to put on their blindfold (in order to eliminate the dominance of the visual cues during perceptive motion) and informed that they would be exposed to a preliminary motion sequence, once to the left and once to the right, which replicated the motion that would be experienced in the trial.

In conjunction with the lateral motion, participants were asked to move the steering wheel in the opposite direction of the platform motion to provide a 'real driving' feeling of controlling the lateral acceleration. This meant that turning the wheel to the right was matched with a platform roll to the left and vice versa, matching the physical exertions in real cornering. Participants were briefed to hold the wheel with both hands in the centre and to negotiate a 'quarter turn' on the wheel, or by 45° as the platform rolled. This led to a hand placement at the top and bottom of the wheel, respectively as the platform reached 14.5° in roll (Figure 6.2). Participants were asked to then turn the wheel back to the starting position in the same movement as the platform was negotiated back to its neutral position. This motion of steering the wheel under lateral motion was intuitive for participants.

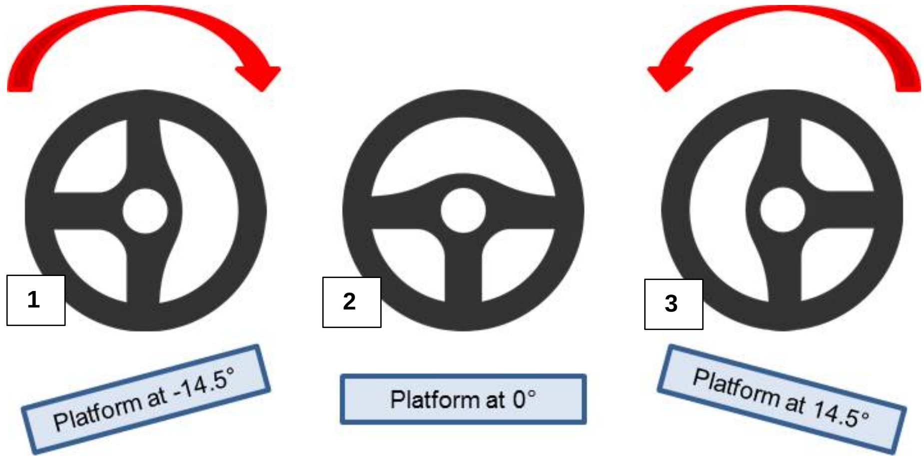

Figure 6.2. Steering wheel turning during lateral motion: 1. Wheel turned to the right during a left-hand roll; 2. Wheel and platform in neutral positions; 3. Wheel turned to the left during a right-hand roll.

The investigator verbally instructed the participant to turn the wheel after a countdown, giving the instruction to turn left or right, based on the roll direction of the sequence (and platform), and shown in Table 6.6.

Table 6.6. Verbal instructions from the investigator to blindfolded participants based on the lateral roll sequence.

Lateral sequence	Verbal instruction
Left roll	"After my countdown, I would like you to turn right. In 3, 2, 1, turn right"
Right roll	"After my countdown, I would like you to turn left. In 3, 2, 1, turn left"

6.3.5. Data analysis

Statistical Package for the Social Sciences (SPSS) software for Windows (Release 21.0. SPSS©, Inc., 2014) was used for analyses. For a repeated measures design, data is collected from each participant at all levels of the independent variable in the study (Brace et al., 2006). A Friedman test was used to compare the lateral stability scores (1-100) of each participant in the three driving seats. After identifying a seat effect based on lateral stability, a Wilcoxon signed-ranks test was then used to identify the differences between each seat. Microsoft Excel for Windows 7 (Microsoft© Office, 2013) was used to divide the data in to whole sample, by gender and by roll direction and imported to SPSS. Differences observed in lateral stability scores between seats of less than 1 were defined as 'ties' (deemed too low to signify a real difference on a 100-point scale).

The data analysis was conducted in a five-step approach:
Step 1. Friedman test to compare lateral stability scores between three seats.
Step 2. Wilcoxon signed-ranks test to identify individual differences between the seats.
Step 3. Wilcoxon signed-ranks test to compare male and female lateral stability scores between 3 seats, by gender.
Step 4. Wilcoxon signed-ranks test to compare mean lateral stability scores within seats, between left and right roll direction.
Step 5. Driver verbatim to identify themes.

6.3.5.1. Step 1: Comparing lateral stability scores

The method of testing the whole sample lateral stability scores (step 1) was to take the mean lateral stability score for each participant. The first and second scores (out of five) in each roll direction were not used in the analysis as they were designed to familiarise participants with the motion. The mean score was therefore calculated by combining three left roll scores and three right roll scores (six in total) and dividing the total by six. The mean score for each driving seat was analysed using a Friedman test to identify a seat effect.

6.3.5.2. Step 2: Identifying individual seat differences

The method of identifying individual seat differences (step 2) was to take the mean lateral stability score for each participant. The mean score was therefore calculated by combining three left roll scores and three right roll scores (six in total) and dividing the total by six. In order to identify individual seat differences a Wilcoxon test was used for paired comparisons (Table 6.7).

Table 6.7. Identifying individual differences using a Wilcoxon signed-ranks test.

Method	Independent variable 1	Independent variable 2
Combined mean of 3rd, 4th and 5th scores for left and right roll	NV200	EPS1
	NV200	EPS2
	EPS1	EPS2

Compared with

6.3.5.3. *Step 3: Identifying individual seat differences by gender*

The method for identifying individual seat differences by gender followed the same method as for Step 2, with the further step of separating the male and female data before calculating the mean lateral stability scores. There were six tests in total, detailed in Table 6.8. Analysing gender groups led to a smaller sample size (n=10) and was designed to investigate if gender had any influence on lateral stability scores and/or how the scale was used.

Table 6.8. Lateral stability score by gender comparison method.

Method	Independent variable 1	Independent variable 2
Combined mean of 3rd, 4th and 5th scores	Male NV200	Male EPS1
	Male NV200	Male EPS2
	Male EPS1	Male EPS2
	Female NV200	Female EPS1
	Female NV200	Female EPS2
	Female EPS1	Female EPS2

Compared with

6.3.5.4. *Step 4: Comparing lateral stability scores (by roll direction)*

The method for comparing stability scores by roll direction was to separate the data in to ‘left roll’ and ‘right roll’. The mean score was calculated by combining three scores and dividing by three for each roll direction. There were three tests in total, representing the mean stability scores for left-wards roll and for right-wards roll, in each of the three driving seats (Table 6.9.).

Table 6.9. Lateral stability score by roll direction comparison method.

Method	Independent variable 1		Independent variable 2
Combined mean of 3rd, 4th and 5th scores	Left roll NV200	Compared with	Right roll NV200
	Left roll EPS1	Compared with	Right roll EPS1
	Left roll EPS2	Compared with	Right roll EPS2

6.3.5.5. Step 5: Driver verbatim

The final method was to collect driver verbatim, which was recorded once the trial had been completed and the platform was settled. Participants were asked to give their feedback on how stable and secure they felt within the seat during the lateral motion sequences and for any specific areas of the seat that they would change to improve their comfort. For the NV200 driving seat, this was achieved through informal discussion with participants following their trial. For the EPS1 and EPS2 seats this was achieved with the addition of trigger questions about specific areas of the seat (seat bolsters and backrest bolsters).

6.4. Results

The anthropometric data and driver characteristics of the twenty participants recruited for the lateral stability evaluation trials (10 male and 10 female) were collected (Appendix A18) and the percentile ranges were calculated (Table 6.10).The anthropometric range shows that there was a good spread for shoulder width (JF10–AM94) and for sitting hip width (JF17-AM98), dimensions which are similarly deemed important to lateral stability and how drivers interact with the seat bolsters. Participants were 21-55 years of age (*M* = 34; *SD* = 10) and whilst it was not stated in the inclusion criteria, every participant had a full UK driving licence.

Table 6.10. Anthropometric data percentile range (n=20).

Dimension	Min (mm)	Max (mm)	Range (mm)	Percentile Range
Sitting height	799	976	177	JF07 – AM89
Shoulder width	372	505	133	JF10 – AM94
Sitting hip width	344	489	145	JF17 – AM98
Knee height	448	578	130	JF59 – AM69
Popliteal length	367	514	147	JF01 – AM75
Seat height	385	493	108	JF85 – AM99
Leg length	849	1207	358	JF10 – AM99

*JF = Japanese female; AM = American male (Nissan Engineering manual percentile calculation)

The final elevated posture seat set-up for each participant was recorded at the end of the discomfort evaluation (Appendix A19). Table 6.11 shows that the HS (dimension in Z between the heel-point and the hip-point) had a range of 547mm – 679mm and the PH gap (distance in X between the leading edge of the B pedal and the hip point) had a range of 634mm–750mm. The minimum dimension for both the HS and the PH gap is similar to the positions observed in seat design parameter fitting trials (Chapter 4) and the long-term discomfort evaluation (Chapter 5). This highlights that the range of adjustment incorporated in to the elevated posture seats is adequate to encompass a large anthropometric driving population, as validated by two independent samples of drivers (n=60).

Table 6.11. Final elevated seat positions for the lateral stability evaluation.

Seat sub-component	Minimum (mm)	Maximum (mm)	Range (mm)	Mean (mm)
Heel step (mm)	547	679	132	586
PH gap (mm)	634	750	116	677

6.4.1. Step 1: Comparison of lateral stability scores

Lateral stability scores were explored to understand how participants reported their perceptions of lateral motion and to identify participant characteristics or trends. Table 6.12 details the lateral stability score breakdown and identifies that the lateral stability scale was used broadly, in that participants rated their perception of motion very differently, shown by the seats having score ranges of 80 (NV200), 85 (EPS1) and 90 (EPS2) respectively.

Table 6.12. Reported lateral stability score summary on the 100-point scale.

Seat	Min. score	Median	Max. score	Range	Score >80
NV200	**15**	**40**	**95**	**80**	
NV200 male	15	35	95	80	1 (P13)
NV200 female	15	40	90	75	1 (P6)
EPS1	**10**	**45**	**95**	**85**	
EPS1 male	10	40	95	85	1 (P13)
EPS1 female	15	50	90	75	1 (P6)
EPS2	**5**	**35**	**95**	**90**	
EPS2 male	5	30	95	90	1 (P13)
EPS2 female	15	40	80	65	

The stability scores were reported after each lateral sequence and were subsequently analysed using a Friedman test to understand if there was a seat type effect on the perception of lateral stability. The results indicated that there was a statistically significant difference in reported lateral stability scores depending on which seat participants were sat in ($x^2(2) = 7.600$, p < 0.01, Friedman). These results provided a platform to run post-hoc tests to understand the individual differences between the 3 seats, using a Wilcoxon signed-ranks test (section 6.4.2).

6.4.2. Step 2: Individual differences between seats

The average of six recorded scores (section 6.3.5.2.) were compared to identify individual differences between seats. Median lateral stability scores indicate that the largest differences were between the EPS1 seat and the EPS2 seat where scores for lateral stability were higher for the EPS1 seat (15 out of 20). The highest median lateral stability score following the lateral motion was for the EPS1 seat (*Mdn* = 45; *Q1* = 30; *Q3* = 60), followed by the NV200 seat (*Mdn* = 40; *Q1* = 25; *Q3* = 46) and the EPS2 seat ending with the lowest median stability score (*Mdn* = 35; *Q1* = 25; *Q3* = 60). The highest possible score of 100 was not reached for any of the three seats.

Significant differences in lateral stability were observed between the NV200 seat and the EPS1 seat ($z = -2.577$, p<0.05, Wilcoxon) and between the EPS1 seat and the EPS2 seat ($z = -2.013$, p<0.05, Wilcoxon) with the EPS1 seat having the higher lateral stability scores in both cases (Figure 6.3). There were no significant differences between the lateral stability scores of the NV200 and the EPS2 seats respectively. This suggests that the modifications made to EPS2 (described in section 6.3.2.1.) to address lateral stability, were successful.

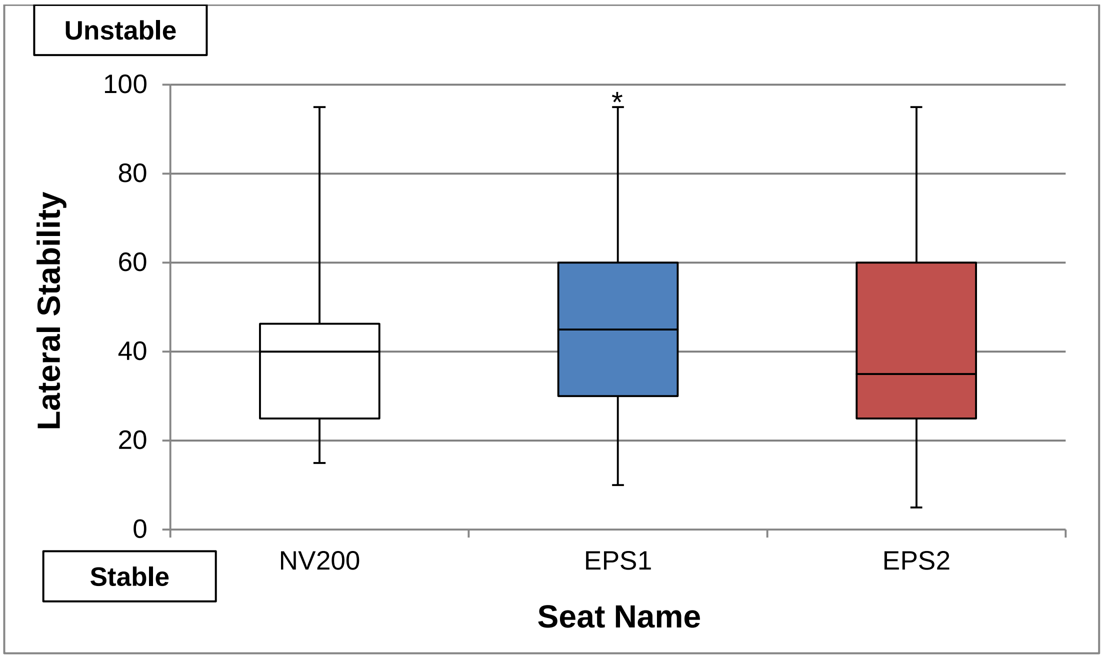

Figure 6.3. Full sample descriptive lateral stability scores between the two elevated posture seats (EPS1 and EPS2) and the NV200 seat (*p<0.05, Wilcoxon, n=20).

6.4.3. Step 3: Individual seat differences by gender

When the data is broken down to look at gender differences, the female participants had lower scores than the male participants (Table 6.12) and subsequently a lower range, specifically for the EPS2 (65 compared to 90 for male participants). However, closer analysis shows that in the sample (n=20) only two participants (one male and one female) report scores of over 80, which had a large effect on the observed ranges. Driver anthropometry for these two drivers is very different, with the male participant having a leg length of AM98 percentile and the female having a leg length of JF24 percentile. Additionally, the lowest scores reported for these individuals were 60 and 70 respectively, which suggests that these scores may be due to broad interpretation of the scale and how subjective it is, rather than gender or anthropometry having a large influence on perception of lateral motion.

6.4.3.1. *Individual differences between seats for males*

The average of six recorded scores (section 6.3.5.3.) were compared to identify individual differences between seats for male drivers. The results indicate that the largest differences were between the EPS1 seat and the EPS2 seat, where scores for lateral stability were higher for the EPS1 seat (8 out of 10). The highest male median score was for the EPS1 seat (*Mdn* = 40; *Q1* = 30; *Q3* = 63) followed by the NV200 seat (*Mdn* = 35; *Q1* = 25; *Q3* = 45) and the EPS2 seat (*Mdn* = 30; *Q1* = 20; *Q3* = 56) (Figure 6.4).

There were no significant differences in lateral stability scores between the three seats (NV200, EPS1 and EPS2) for male drivers. It should be noted that due to the smaller sample size, the statistical tests used for male drivers did not have as much power as that used for the full sample.

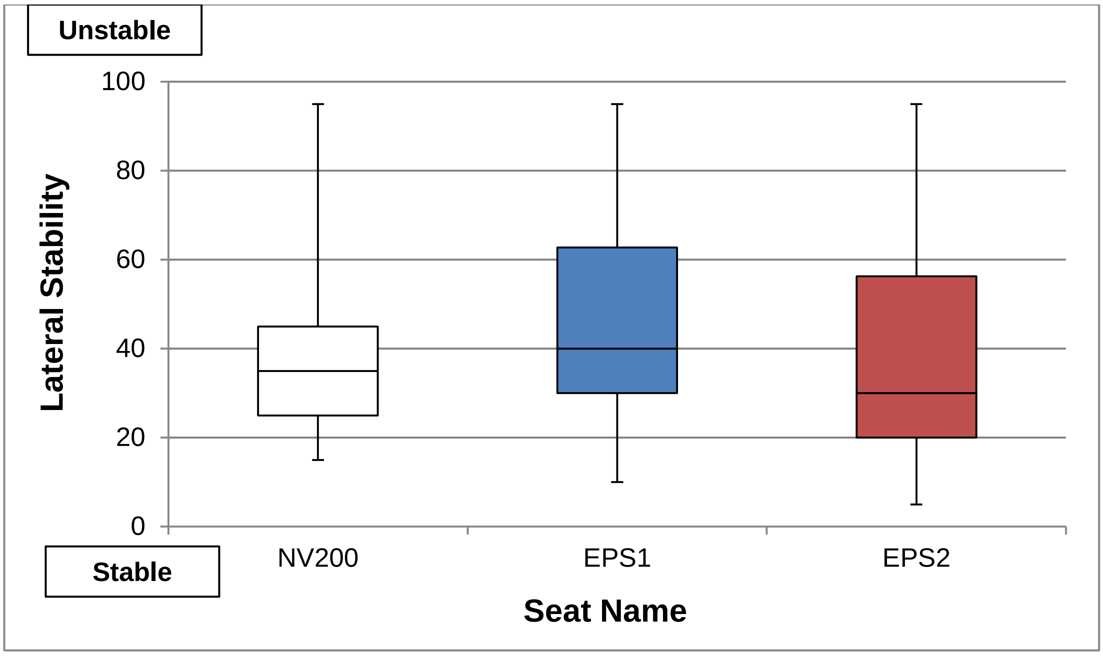

Figure 6.4. Male descriptive lateral stability scores between the two elevated posture seats (EPS1 and EPS2) and the NV200 seat (n=10).

6.4.3.2. *Individual differences between seats for females*

The average of six recorded scores (section 6.3.5.3.) were compared to identify individual differences between seats for female drivers. The results indicate that the largest differences were between the NV200 seat and the EPS1 seat, where scores for lateral stability were higher for the EPS1 seat (8 out of 10). The highest female median score was for the EPS1 seat (*Mdn* = 50; *Q1* = 39; *Q3* = 60) followed by the ESP2 seat (*Mdn* = 40; *Q1* = 30; *Q3* = 65) and the NV200 seat ending with the lowest median stability score (*Mdn* = 40; *Q1* = 33; *Q3* = 50)

For female participants, significant differences in lateral stability were observed between the NV200 seat and the EPS1 seat ($z = -1.989$, $p<0.05$, Wilcoxon) with the EPS1 seat having the higher lateral stability scores (Figure 6.5). These results suggest that female participants felt more unstable in the EPS1 seat than male participants in comparison to the other two. This may indicate that the higher mounted seat position in the vehicle has a greater effect on smaller drivers during lateral motion. It should be noted that due to a limited sample size (n=10), the statistical tests used for female drivers did not have as much power as that used for the whole sample.

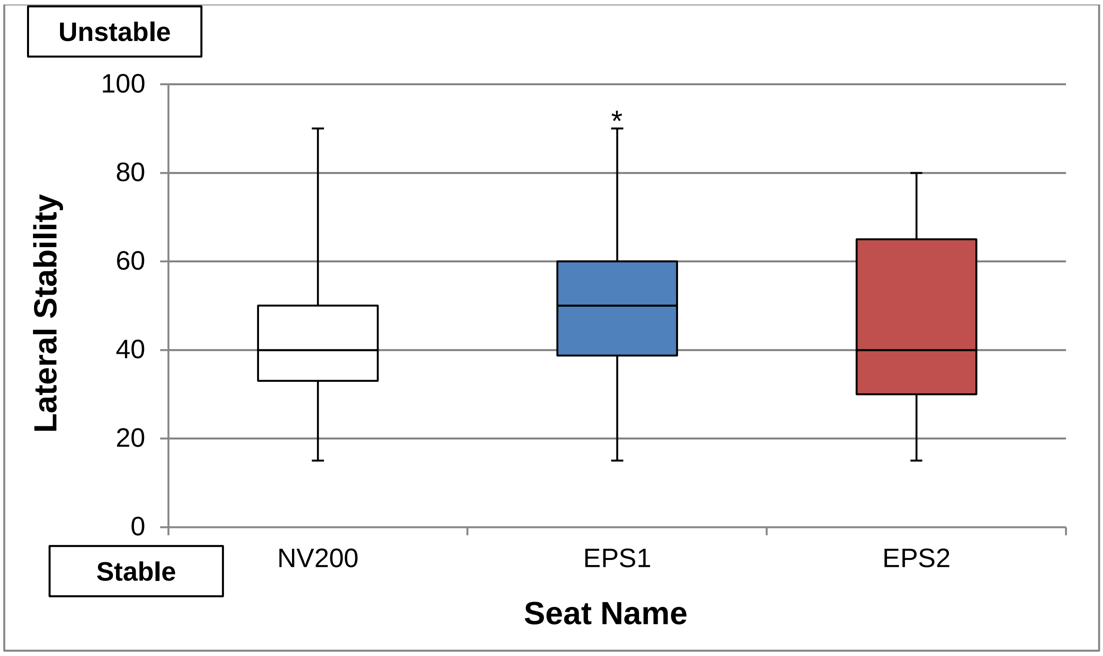

Figure 6.5. Female descriptive lateral stability scores between the two elevated posture seats (EPS1 and EPS2) and the NV200 seat (*p<0.05, Wilcoxon, n=10).

6.4.4. Step 4: Comparison of lateral stability scores by roll direction

The average of three recorded scores (section 6.3.5.4.) were compared to identify differences between roll direction. Results indicated that left and right roll ratings were identical for the NV200 (Left roll: *Mdn* = 40; *Q1* = 30; *Q3* = 46. Right roll: *Mdn* = 40; *Q1* = 25; *Q3* = 46, Figure 6.6). Results indicated that left roll had marginally higher stability ratings than right roll for the EPS1 seat (Left roll: *Mdn* = 48; *Q1* = 35; *Q3* = 60. Right roll: *Mdn* = 42; *Q1* = 30; *Q3* = 60, Figure 6.7) and the same trend was observed for the EPS2 seat (Left roll: *Mdn* = 40; *Q1* = 29; *Q3* = 60. Right roll: *Mdn* = 35; *Q1* = 20; *Q3* = 60. Figure 6.8). However, there were no significant differences between the roll directions for any of the three seats. These findings indicate that the lateral motion itself, rather than the direction of the sequence, effects stability when seated in a driving posture.

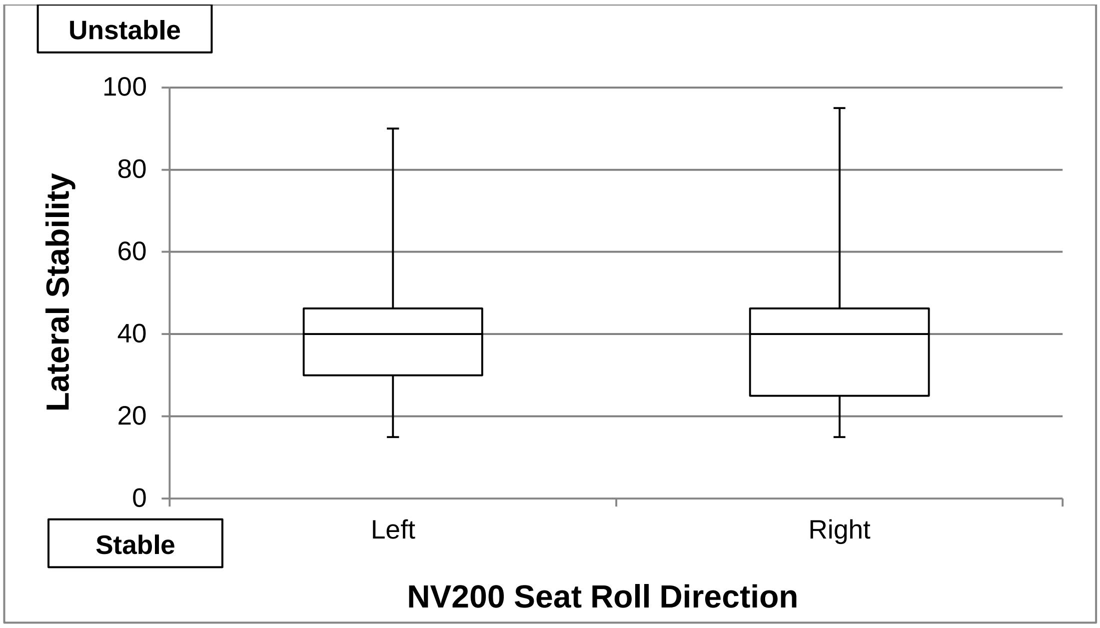

Figure 6.6. NV200 lateral stability scores between left and right roll direction (n=20).

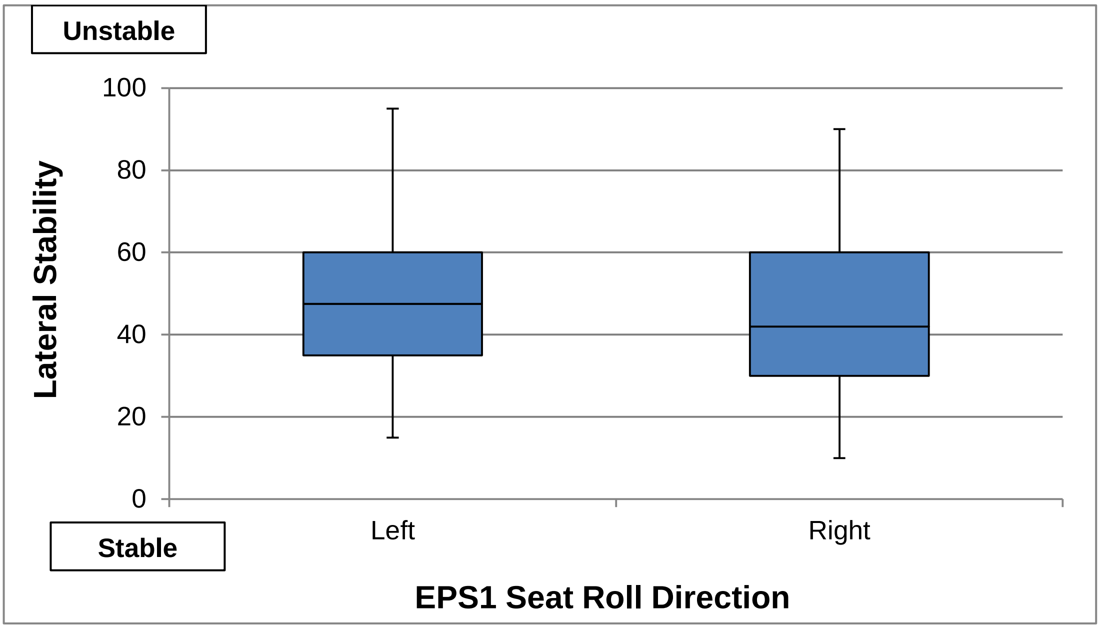

Figure 6.7. EPS1 lateral stability scores between left and right roll direction (n=20).

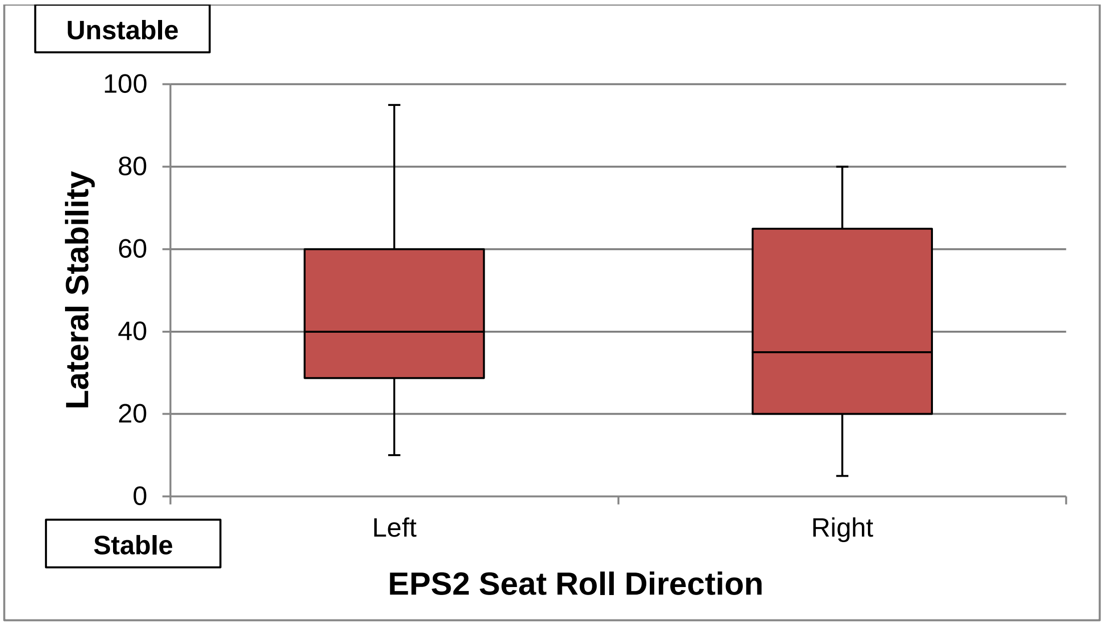

Figure 6.8. EPS2 lateral stability scores between left and right roll direction (n=20).

6.4.4.1. First roll sequence direction effects

An interesting observation from the lateral stability trials was that participants consistently reported higher scores (feeling more unstable in the seat during lateral motion) for the second sequence of rolls, irrespective of the first roll direction. There were no significant differences in the scores reported, but verbatim further backed this observation whereby participants generally felt that during the second sequence of lateral motion (left or right) the platform was being rolled to a further degree, when in actual fact this was designed to be 14.5° for all rolls. This was an interesting sensation which could be a result of participants learning and accommodating for the initial roll, leading to roll in the opposite direction to feel much greater. This sensation is likely to be a result of the absence of visual cues in this experiment and suggests that this method is an accurate measure of assessing people's perception to lateral motion.

6.4.5. Participant verbatim

Following the completion of the lateral stability evaluation and whilst in their chosen seat set-up (for the two elevated posture seats), participants were asked for their views on the lateral motion and how secure they felt within the seat, with several trigger questions. These trigger questions were not asked of the NV200 conventional posture seat, with it being a current production seat, however feedback was documented as and when provided by participants. The main findings are summarised below with full details in Appendix A20.

6.4.5.1. NV200 feedback

The feedback on the NV200 posture was collected in an informal way, noted down from discussions with participants after the trial had been completed. There were no trigger questions asked as with the EPS1 and EPS2 seats. The main findings were:

- The majority of participants felt very stable and secure in the NV200 seat during lateral accelerations.
- For those who had previously tested an elevated posture seat, the lateral motion was reported as seeming tamer in the NV200 seat. This is likely due to familiarity with a conventional driving posture, as well as the centre of gravity being much lower in this set-up.

- Participants generally felt that they did not move in the seat very much during the lateral motion and so did not consider the seat and backrest bolsters as much as they did in the elevated posture seats.

6.4.5.2. EPS1 positive feedback

The verbatim was analysed to identify positive feedback from the sample relating to reported stability in the EPS1 seat. The main findings were:

- The majority of participants felt comfortable in their seat during lateral motion sequences.
- Some participants felt that sitting more upright in this seat provided them with a good, comfortable posture.

6.4.5.3. EPS1 negative feedback

The verbatim was analysed to identify negative feedback from the sample relating to reported stability in the EPS1 seat. The main findings were:

- Some participants felt that there could have been more rigid support offered by the bolsters on the seat and the backrest, during lateral motion.
- Whilst participants wanted more support on the backrest, the positioning of the bolsters any closer to the occupant would have limited arm movement and placement during driving.
- One participant felt like they were flying off during the lateral motion and didn't feel they were provided with enough support from either the seat bolsters or the backrest bolsters. This participant provided identical feedback for the sensation during the EPS2 stability trial, suggesting that they did not feel comfortable with the motion in an unfamiliar seated position.

6.4.5.4. EPS2 positive feedback

The verbatim was analysed to identify positive feedback from the sample relating to reported stability in the EPS2 seat. The main findings were:

- Participants felt that the seat being harder and more rigid (in comparison to the EPS1 seat) increased their stability in the seat during lateral motion.
- The majority of participants felt very secure in the seat during the lateral motion sequences, especially with the seat base.
- Four participants, who had already tested the EPS1 seat, specifically noted that they felt a lot more secure in the EPS2 seat by comparison.
- Two participants said that the material helped them feel adhered to the seat and comfortably secured during the lateral motion.

6.4.5.5. EPS2 negative feedback

The verbatim was analysed to identify negative feedback from the sample relating to reported stability in the EPS2 seat. The main findings were:

- Five participants felt that the hardness of the backrest meant that the upper back and shoulders were not as well supported as they could be with softer foam, which could encase them more.
- One participant noted that they were experiencing discomfort underneath the thighs, which they did not experience in the EPS1 seat. This is likely due to the tighter material making the seat pad feel harder and thus less give in the foam under pressure.
- One participant felt like they were flying off during the lateral motion and didn't feel they were provided enough support from neither the seat bolsters nor the backrest bolsters. This participant provided identical feedback for the sensation during the EPS1 stability trial, suggesting that they did not feel comfortable with the motion in an unfamiliar seated position.

6.4.6. Using the 100-point lateral stability scale

The scale that was designed for this trial was a 100-point scale with verbal descriptors representing the two extreme states, as detailed in section 6.3. An interesting observation from the trial is how participants interacted with the scale during a lateral motion sequence. As previously discussed, the first two reported scores were discarded for analysis, leaving three scores for left roll and three for right roll (six in total). Table 6.13 details the differences between the first and the last of those three scores, identifying how many people increased, decreased or kept the same score over time. The table shows that in the biggest individual proportion of cases (50 out of 120) the scores were identical between the first and the last, suggesting that participants became accustomed to the lateral exposure and were able to score their stability consistently. On the contrary, there were a similar number of increases (n=36) and decreases (n=34) in scores between the first and last, suggesting that the scale was fit for design. Some participants reported that they did not like the lateral acceleration and their reported stability scores increased from exposure to exposure as a result.

Table 6.13. The breakdown of how the reported stability scores differed between the first and last sequence of lateral motion.

Seat	Frequency of score **increases**	Frequency of score **decreases**	Frequency of **identical scores**
NV200	8	15	17
EPS1	11	11	18
EPS2	17	8	15
Total	**36**	**34**	**50**

6.5. Discussion

The aim of the lateral stability evaluation trials was to understand if a higher mounted seat position leads to an increased sensitivity to and perception of lateral motion, comparing two elevated posture seats (one with modifications to address lateral stability considerations) with a conventional posture production seat (Nissan NV200). There is no widely-adopted method for assessing lateral accelerations in car seats from a seat occupants' point of view and therefore there are no known studies that have investigated the increased sensitivity to motion when seated higher in a vehicle. The findings will therefore be discussed in this context, comparing the findings for seats in an elevated posture with a current production seat (used as an industry benchmark) and outlining the limitations of the research, followed by the conclusions.

The observed results of the lateral stability evaluation met the objectives for this study (section 6.2), identifying that the reported stability scores were higher (representing a feeling of being more unstable and more uncomfortable during lateral accelerations) for the two elevated posture seats, compared with the conventional posture production seat. This being said, significant differences were observed between the NV200 and EPS1 seats and between the EPS1 and EPS2 seats only, with the EPS1 seat scoring worse in both cases. First and foremost, this suggests that an elevated seat height does in fact increase sensitivity to and perception on vehicle motion. The EPS1 seat was developed and constructed with static seat design parameters as the main focus for occupant comfort, based on the findings from the seat parameters study, detailed in Chapter 4. With the design of the seat driven by anthropometry, it was expected and seems logical that the seat was significantly poorer for occupant stability compared to the conventional NV200 seat. However, the EPS2 seat had design modifications to specifically address these concerns, without changing any of the seat design parameters themselves from the EPS1 seat. As a result, the seat performed similarly to the NV200 seat, with a mean difference of <1 on the 100-point stability scale. This suggests that whilst drivers in an elevated posture are susceptible to an increased sensitivity to motion, seat modifications can be made to successfully address this and make it perform as well as a production seat.

The literature identifies a collection of individual factors that affect vehicle seat comfort, with seat stiffness, geometry, contours and breathability to name just a few (Kolich, 2008). One of the key differences between the EPS1 and EPS2 seat was the material and how this changed participant's perception of showroom comfort for the seat. Participants reported that the material on the EPS2 seat made both the seat cushion and the backrest appear harder and more rigid, which actually went a long way to making them feel more secure in the seat during lateral motion. The foam compositions remained the same and so the fabric itself changed the feel of the seat and made the bolsters feel more pronounced and supportive for the occupant during motion. These findings align with the literature, which identified that occupants prefer a supportive and stiff feeling from the seat (Cunningham et al., 1994; Tan et al., 1996). Whilst this feeling of stiffness was reported as making drivers feel more secure in the EPS2 seat, it was also reported that this might not be comfortable after driving for a longer amount of time. The literature has highlighted that the showroom feeling does not represent seat comfort over a prolonged exposure to driving under vibration (Griffin et al., 1982; Ebe and Griffin., 2001; Mansfield et al., 2007). Consequently, whilst drivers prefer the more rigid seat feel for stability and comfort during lateral motion, this may not be appropriate for long term driving in the elevated posture. Additionally, it was reported that participants felt the firm backrest pushed them forward a little more in the EPS2 seat and received less support from the backrest, which in turn moves this further away from the key seat parameter recommendations made in Chapter 4. It is therefore recommended that in order to achieve a greater seat comfort in the elevated posture, this compromise between seat rigidness for stability and seat comfort from anthropometry driven design parameters over long-term driving needs to be explored.

The trials showed that participants were able to engage with the lateral stability scale and that the adapted laboratory environment for these trials was suitable. It is recommended therefore that this method should be followed and developed to assess reported occupant stability during simulated lateral motion in laboratory trials. The consistent use of the subjective scale within participants showed that it was intuitive and easy to understand, even with the absence of visual cues. The literature identifies that drivers adjust their speed during cornering, to reduce the maximum vehicle lateral accelerations (Reymond et al., 2001; Mansfield and Whiting-Lewis, 2004). Additionally, studies in recent years have identified that drivers anticipate and adapt their driving posture through cornering by moving with the direction of roll, to reduce the lateral accelerations. Koike et al. (2013) observed that drivers and passengers responded differently to vehicle motion (e.g. cornering), as drivers control their posture actively when performing the driving task. The design of this study was to be experimental and to explore a new method to collect data on drivers' perception to motion and resulting feeling of stability in the seat. The investigator gave participants a verbal cue as to when and in which direction the platform would roll and so, to some extent, participants could anticipate the lateral motion. However, the inclusion of blindfolds was effective in removing participants' visual cues which meant they could not process the movement ahead of time. This was taken from verbatim both during and after the trial (for all three seats), as many participants felt that the platform was being rolled to a greater degree as the trial progressed.

These findings, along with the literature, indicate that it is important to understand the behavioural response of drivers in relation to the sensitivity to lateral accelerations, in real world driving. However it should be noted that this method provides a good starting point for assessing participant's perception of lateral motion in a vehicle seat but also it could be further developed to accurately represent in-car motion in a wider field of conditions.

6.5.1. Limitations

Whilst there was a good anthropometric spread for most of the body dimensions and a large enough sample to conduct appropriate statistical testing, a larger sample would have allowed a bigger representation of the population and more confidence of the findings for the automotive industry. The sample represented a good spread of drivers in terms of leg length and thus a wide range of self-selected driving positions; however it would have been better for this study if there was a greater range of both sitting hip widths and shoulder widths. This trial was designed to look at occupants reported stability during lateral motion and this includes how much support the seat parameters, specifically bolsters, provide the occupant. In terms of sitting hip width, there was only one larger participant (AM75) and the smallest percentile participant was JF17, which does not represent many people at the extreme ends of the population. For shoulder width, the largest percentile participant was AM45 which again did not represent the largest extreme of the population. Time constraints and availability of participants to complete three trials were the limitations in obtaining a good spread for these dimensions. For future research, a larger sample of drivers with focussed anthropometric recruitment would be beneficial in understanding how the broadest and narrowest drivers report stability in a higher-mounted seat position under lateral motion.

The EPS1 seat had a gas strut manual lever for the vertical adjustment of the seat, and this seat was used in the long-term discomfort evaluation trials detailed in Chapter 5. In the latter stages of those trials, the gas strut on the seat became stiffer, which hampered the ability of participants to make accurate incremental adjustments when setting their driving position. Conversely, the EPS2 seat had an electronic vertical lift installed, which provided a greater degree of accuracy for the participants (n=6) that set their optimum elevated posture using this seat. This meant that the two elevated posture seats had different methods of height adjust with contrasting ease and accuracy. To mitigate this difference, the gas struts were recalibrated prior to the trials so that they adjusted smoothly and with more accuracy than before. Additionally, more time and help was given to participants from the investigator during the set-up process.

The lateral accelerations in this trial were designed to replicate a force similar to that observed in real world cornering (0.25g). This was achieved by rolling the platform to 14.5° in 1.3 seconds, which did not replicate an accurate sensation of cornering in real driving. When cornering, the typical movement of an occupant in their seated posture is a lateral ‘pulse’ (movement in Y on one plane) followed by a roll. The excursions of the motion platform meant that whilst a lateral pulse and a lateral roll could be achieved separately, this combined motion sequence could not be replicated together for these stability trials. These trials were aimed at understanding the sensitivity to and perception of motion and the experimental design for these trials was a new untested approach. This limitation should be considered when developing this method as a suitable approach for replicating real vehicle motion during cornering.

6.6. Conclusions

The objectives for this study were:

- Understand whether the increased height of the driver's hip point results in an increased sensitivity to and perception of vehicle motion.
- Lateral stability seat comparison (three seats); NV200 conventional seat, EPS2, EPS2.
- Understand the suitability of the chosen research methods in assessing lateral stability and perception to movement in an automotive setting.

From the lateral stability evaluation, it is possible to conclude the following:

1. The results observed in the lateral stability evaluation met the objectives for this case study.
2. An increased height of the driver's hip point leads to an increased sensitivity and perception of vehicle motion. This was shown with both elevated posture seats scoring higher than the conventional posture seat (EPS1 seat had significantly higher reported stability scores than NV200, $p<0.05$).
3. The modifications made to the EPS2 seat successfully addressed lateral stability considerations, as the seat scored well compared with the NV200 seat.
4. The lateral stability scale was intuitive to follow and engage with and should be taken from this study to be used in future research (could be easily developed to apply to a broader scope of lateral stability testing).

6.6.1. Summary

The results from the lateral stability evaluation have shown that this study was a progressive research step in the exploration and understanding of the elevated driving posture, leading on from the conclusions of the seat design parameter study (Chapter 4) and the long-term discomfort study (Chapter 5). A higher mounted seat position in a vehicle does lead to an increased sensitivity to lateral motion. However, focussed seat modifications can be made to an elevated posture seat to make it perform as well under lateral motion as a production seat in a conventional driving posture. The method, lab set-up and lateral stability scale were all developed through rigorous piloting, tailored to collect reliable reported stability scores under simulated cornering conditions. It was shown that this method is suitable to this field of experimental testing and should be considered for application in a wider scope of laboratory lateral stability testing.

CHAPTER 7

OVERALL SUMMARY AND CONTRIBUTION TO KNOWLEDGE

The overall aim of the thesis was to identify the ergonomics considerations and determine the requirements of drivers, in an elevated driving posture for LCVs. The results will help determine the feasibility for different vehicle types (e.g. LCVs and cars). The exploration of comfortable driving postures is well documented (Porter and Gyi, 1998; Kolich, 2008); however previous studies have reported their findings in the context of conventional driving postures and none have considered the application to an elevated posture. Furthermore, the effect of WBV and lateral accelerations on occupant discomfort over time has not been investigated in elevated seating postures. The approach taken within this thesis was to assess these factors (in comparison with a conventional driving posture) by conducting a series of laboratory studies and the results from these studies have been discussed in the relevant chapters. This chapter collates and summarises the findings in the overall context of the research and outlines the application of the elevated posture to future work.

7.1. Elevated posture seating positions

In each of the laboratory studies, participants were subjected to a fitting trial process which provided them with individual, self-selected seating positions in terms of heel step (HS) and pedal-hip (PH) gap (Figure 7.1). These results can therefore be compared across the chapters to evaluate the seat adjustment envelope for the elevated posture.

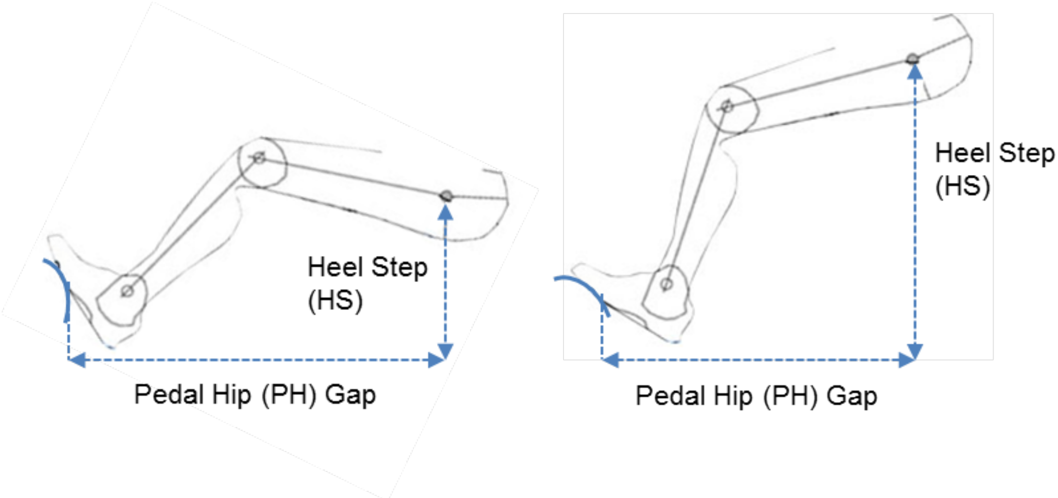

Figure 7.1. Heel Step (HS) vs. Pedal-hip (PH) Gap in conventional (left) and elevated (right) posture.

The final selected seat positions were collated and mapped to understand the adjustment required to package an anthropometrically diverse range of participants (Figure 7.2). The selected hip points show that in terms of PH gap, or fore-aft adjust as is typically designed into automotive seating, the range required to package the sample of participants in this research is <200mm. Lifters are often designed into automotive seats for small ranges of vertical adjustment, however for the elevated posture seat an adjustment range of 130mm is required.

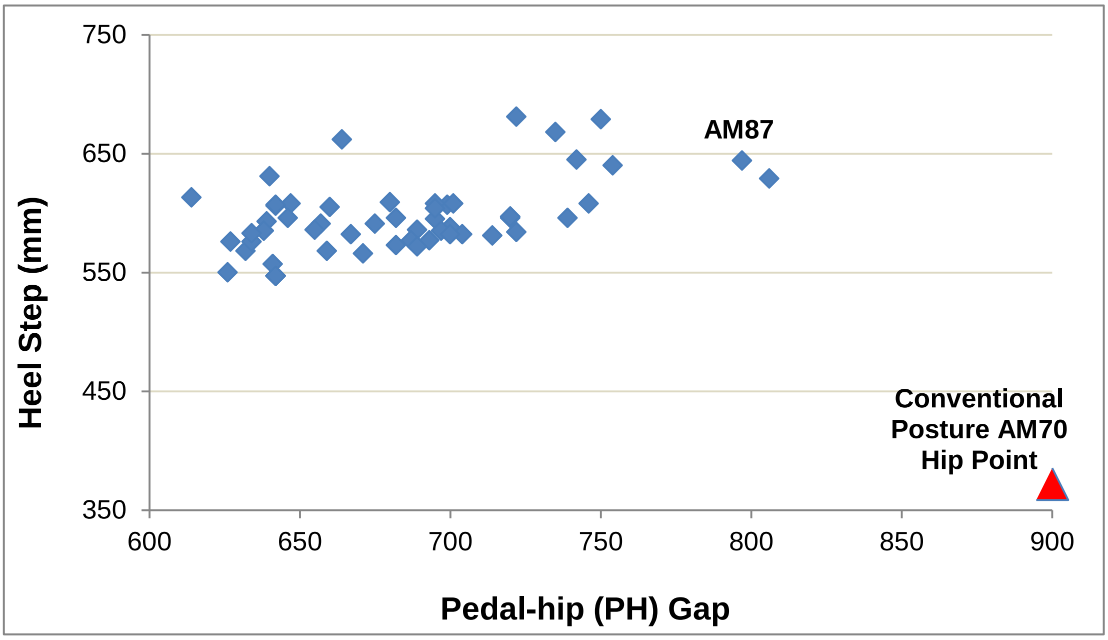

Figure 7.2. Elevated posture hip points across three laboratory studies in comparison with the conventional posture benchmark (n=60).

By comparison, the benchmark conventional posture production seat typically has 240mm of fore-aft adjustment. It can therefore be highlighted that as the driving posture changes from conventional to elevated, the fore-aft adjustment required to package occupants is notably less (50mm). However, there is the additional requirement of vertical lift needed for this posture. In order to understand what this means for vehicle packaging, the industry conventions need to be explored (section 7.1.1).

7.1.1. Anthropometric inclusion for vehicle packaging

A number of discussions can be drawn from the elevated seating position findings, the first of which is the anthropometric coverage and how this is applied in the automotive industry. It should first be acknowledged that the specified adjustment ranges (Figure 7.2) are inclusive of drivers with a leg length percentile of between Japanese female 7th percentile (AM07) to American male 99th percentile (AM99). The leg length percentile is often referenced in this thesis, as the results for the first laboratory study identified a strong positive correlation between the leg length dimension and the final selected elevated seat position. With respect to this dimension, the observed range of comfortable driving positions is inclusive and this is something of note. The literature has identified that typically in automotive design, those at the extreme ends of anthropometric dimensions often have to compromise their comfort based on the target population of a given vehicle design, specified by the automotive company (Porter and Gyi, 1998; Na et al., 2005). This is shown in application, as the conventional production seat package that was utilised for two of the laboratory trials reported in this thesis (Chapter 4 and Chapter 5) has a rear-most seat position which is designed to be inclusive of an AM70 percentile driver (Figure 7.2). This is an example of how anthropometric inclusion in vehicle packaging is determined by a number of combining factors and driving forces, where it is often a compromise between market requirements, practicality and profitability. This will also vary from company to company based on the importance that is placed on different parts of the vehicle during the design process. A key point is that the current seat slide length (facilitating the fore-aft adjustment of a vehicle seat) has typically evolved to approximately 240mm and so the question for automotive companies is ‘which proportion of the population do we want to cover with this length?’ Furthermore, the seat slide rails have pre-existing production facilities that are set up to mass produce a standard product and thus a change in the rail design/length would lead to an unfeasible increase in costs. Additionally, standard crash tests have a requirement for a particular seat position in a road vehicle which cannot be achieved with the elevated driving posture explored in this thesis. Subsequently, new safety testing will be needed for this new seating position.

These findings can be related back to the context and reasoning behind the development of the elevated posture explored in this thesis. The hypothesis was that by making the driving posture within a vehicle more upright, the space required to package a driver into the vehicle cabin can be much less. This has been corroborated by the findings in this research, which have identified that an AM99 percentile driver can select a comfortable elevated driving posture in a shorter vehicle cabin space (dimension in X) than the space required to package an AM70 percentile driver in the benchmark comparison. Furthermore, these selected seat positions have been validated in three separate laboratory studies, investigating static comfort and seat dimensions, long-term discomfort and lateral stability. These findings can be linked back to the literature, which highlights that to understand overall seat comfort, static, dynamic and temporal factors must be considered (Ebe and Griffin, 2000a,b; Mansfield et al., 2007).

7.1.2. Application to driving standards and conventions

The impact of this research is that the assumptions and knowledge that is applied when packaging a driver into a vehicle must be rethought and rewritten, when considering an elevated driving posture. One aspect of this is the current standards that are adopted, as highlighted in the literature review (Chapter 2, section 2.1.4). The literature identified a number of current driving conventions and standards (e.g. Tilley and Dreyfuss, 2002), which have been developed to provide guidance when packaging drivers into a 'normal' or 'conventional' driving posture. In the context of this research, a normal posture has been defined as having a knee point higher than the hip point when seated. The elevated posture explored in this research is defined as the knee point level with or lower than the hip point of the driver. The identification of these comfortable seated positions is new knowledge for vehicle packaging. Consequently, the current standards and conventions in place are not relevant in their application to this posture and new standards need to be developed specifically for these seated postures.

It can be summarised that space saving benefits have been observed for the elevated posture, which means that the weight reduction and/or increased loading space for LCVs can potentially be realised. As a result of this, the standards that are currently used in automotive ergonomics need to be rethought for the application of this posture and developed alongside further research.

7.2. Seat design for the elevated posture concept

Typically in automotive ergonomics different driver percentiles are targeted for specific vehicle designs, and thus a proportion of drivers are excluded.

This being said, the results from the laboratory trials reported in this thesis include the identification of a comfortable range of seat positions to encompass an anthropometrically diverse sample. This is a consequence of designing an unlimited amount of adjustment into the rig used in the first laboratory trial, exploring seat design parameters. The adjustment ranges for HS and PH gap were then used in the development of a robust concept seat that was used for testing in both the long-term discomfort evaluation (Chapter 5) and the lateral stability evaluation (Chapter 6). Despite the concept seat being over engineered to facilitate these adjustments, it remains vital that the elevated posture requires both vertical and fore-aft adjustment to encompass this sample.

7.2.1. Elevated posture seat design parameters

The first objective of this research was 'to identify key parameters (seat sub-component dimensions) for a seat design in the elevated driving posture'. These have already been discussed in Chapter 4; however it is important to understand the relationship between these key seat parameters and the development of the concept seat. There were notable differences in the best-fit dimensions of key seat sub-components between the elevated posture and a conventional posture production seat (Table 7.1). Most notably, preferences for the seat base length were considerably shorter (380mm compared to 460mm), the backrest height longer (690mm compared with 650mm), the seat width wider (560mm compared with 480mm) and the backrest width marginally narrower (480mm compared with 510mm). The preferred dimensions of the seat sub-components were determined by participant comfort and anthropometry and applied to the specification of the concept seat.

Table 7.1. Selected key seat design parameters for the elevated posture seat.

Seat sub-component	Elevated posture best-fit dimension	Conventional posture best-fit dimension
Seat base length (mm)	380	460
Seat base width (mm)	560	480
Backrest width (mm)	480	510
Backrest height (mm)	690	650

The concept seat was developed using the benchmark seat as carry over parts i.e. production seat parts from an existing seat and so the test track trials with the first iteration of the concept seat were part of the piloting for the stability evaluations reported in this thesis. The first iteration of the elevated posture concept seat (EPS1) was used for the long-term discomfort evaluation (Chapter 5) and compared with the benchmark conventional posture seat. The elevated posture performed as well for occupant seat comfort if not marginally better than the conventional posture seat. Indeed the conventional posture had significantly higher overall discomfort for two of the thirteen body areas reported (right shoulder and lower back, $p<0.05$, two-tailed). What can be taken from this is that the seat parameters that were identified in Chapter 4 as being important for static seat comfort in the elevated posture were validated by the results detailed in Chapter 5.

During the development of the elevated posture seat (Chapter 6, section 6.3.2.1.) the automotive manufacturer sponsor of this research conducted a series of test-track laps on an inner city circuit at a private proving ground. This provided early evaluative feedback on the lateral stability performance of the seat in a dynamic environment. Most notably, it was found that during tight cornering drivers felt that they weren't encompassed enough by the seat base cushion. The results of this piloting led to a modification of the concept seat (EPS1) and the creation of a second elevated posture seat (EPS2). Changes were made to the metalwork at the front edge of the seat below the occupant's thigh, moving the front cross member lower and forwards. This change allowed the occupant to sink lower into the foam to feel more supported during normal driving. Additionally, the support wire was made wider at the front corner to support the foam better.

The first and second iteration of the elevated posture seat (EPS1 and EPS2) were used for the lateral stability evaluation (Chapter 6) in comparison with the benchmark conventional posture seat. As expected, results showed that occupants sat in a higher seated position were more susceptible to lateral accelerations and thus felt more unstable in the seat. This was highlighted by a significant difference in lateral stability between the conventional seat and

EPS1 ($p<0.05$, Wilcoxon). However, the modifications that were made to create the second seat (EPS2) were effective in improving stability and this seat also performed significantly better than EPS1 ($p<0.05$, Wilcoxon). The conventional seat and the EPS2 seat performed equally which is a notable point in this discussion. The modifications that were made to the seat were concerned with the metal structure beneath the pan and the seat fabric; however the seat profiling was unchanged. Therefore, the same seat design parameters that were identified in Chapter 4 for static seat comfort and validated for long-term dynamic comfort in Chapter 5, were also validated as performing well for lateral stability.

In summary, the elevated posture seat design was developed and shaped by the series of experimental studies reported in this thesis. This process with ergonomics considerations at the heart of it was effective and the elevated posture seat was shown to perform equally well for static comfort, long-term dynamic comfort and lateral stability in comparison with a current production vehicle seat.

7.2.2. Seat design and weight reduction considerations

The context of this research is that the space saving, resulting from the elevated posture, could potentially have a knock on effect and reduce the CO_2 emissions of a vehicle over its lifecycle. This is achieved by reducing the overall length of the vehicle and maintaining the loading space or by reducing the overall length and thus the overall mass of the vehicle. The importance of this context is that the weight of a vehicle, along with many other parameters, has a direct impact upon the CO_2 emissions of a vehicle. It has been established that the concept elevated posture seat was over engineered to encompass a large anthropometric adjustment range. Inevitably, this scale of adjustment requires a robust mechanism built into the seat which in turn results in an increase in the overall weight of the seat. Whilst the seat was developed and designed for the purpose of this research, seat weight reduction should be a consideration for further exploration of the elevated posture seat. The literature review (Chapter 2, section 2.2.6) identified that a trend in automotive seating removing weight from the seat which in turn equals better fuel economy. Subsequently, a more slim-line seat will result in more space in the vehicle.

Applying this knowledge to the research reported in this thesis, two notable points can be drawn to take forward: Firstly, the space saving benefits from the elevated posture would need to offset any potential weight and/or cost increase as a result of a new seat mechanism. Secondly, the elevated posture would be an ideal posture to benefit from the trends in automotive seat weight reduction as it is designed with space saving benefits in mind.

7.2.3. Seat design safety considerations

As with any automotive seat, safety is of paramount importance. There are notable differences between the elevated posture and the conventional posture and subsequently, these highlight safety considerations for the elevated posture seat design. The literature (Chapter 2, section 2.2.5) identified the importance of the crash pan/anti-submarining system, beneath the seat foam, in preventing occupants from slipping forward and underneath the seat belt during a front-end crash. It was hypothesised that the positioning of this system (when using carry over parts in the seat development) could adversely impact upon occupants' comfort in the elevated posture as the weight distribution is shifted towards the front of the seat pad. This is further validated by the definition of the posture with the knee point being level with or below the hip point of the occupant (Figure 7.3).

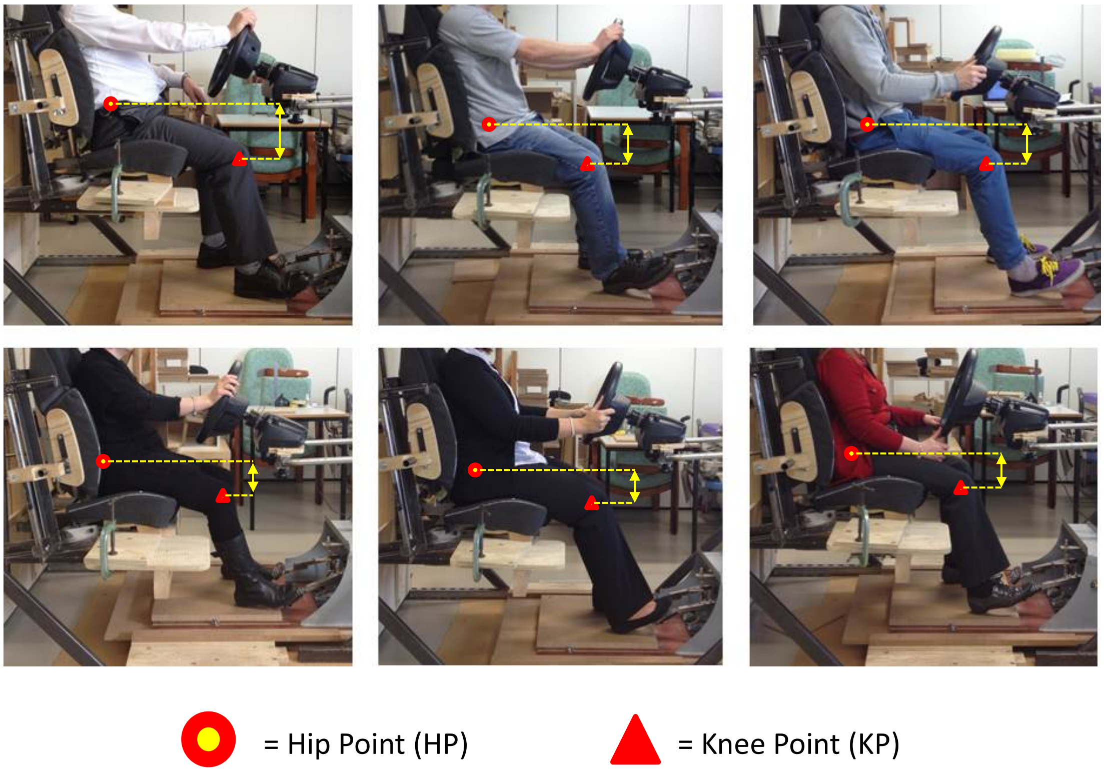

Figure 7.3. Participants (3 male and 3 female) in optimised seat set-ups – illustration of the 'knee-point below hip-point' elevated posture definition.

As already discussed, the best-fit dimension for the seat base length was calculated to be 380mm, which is 60mm shorter than the benchmark conventional seat. Inherently, this means that a shorter proportion of the leg is directly in contact and thus supported by the seat. Additionally, this means that the front edge of the seat interacts with the thigh of the occupant closer to the buttocks, in comparison with the conventional seat. The relevance of this finding for crash safety is that there is less distance for the occupant to travel forwards in the seat before slipping off the front edge. This is more of a concern for safety as the intention of a safe seat design is to contain the occupant in the seat during a crash scenario.

Furthermore, it was acknowledged that an elevated posture may make occupants' more susceptible to lateral motion, making them feel more unstable during normal driving. As reported (Chapter 6), modifications to the EPS1 seat were made to create an EPS2 seat which had a positive impact on the stability of occupants during lateral accelerations. The modifications may also benefit the crash safety performance of the seat as occupants sink lower in the seat and the anti-submarining system at the front of the seat is more robust. Crash simulation testing would be part of the vehicle design process moving forward to understand how the elevated posture performs in various crash scenarios.

7.2.4. Summary of the elevated posture seat design

The results from the laboratory trials reported in this thesis have shaped the development of the elevated posture seat. The anthropometric considerations have been validated by the long-term discomfort and lateral stability evaluations (Chapters 4-6). It should be highlighted that the concept seat was over engineered for this research to meet the adjustment requirements for the posture, which in turn led to more weight in the seat. For future research it should be acknowledged, therefore, that seat weight reduction is paramount to the impact of this posture in vehicle ergonomics. Additionally, the crash pan and anti-submarining system were based on carry over parts in the seat development and may need to be redesigned based on crash simulation investigation. Consequently, the positioning and design of the metal structure beneath the seat cushion could impact upon seat comfort.

7.3. Contribution to driving ergonomics knowledge

In this thesis, different methods were successfully used to understand the driving ergonomics of an elevated seat position in LCVs. This section discusses the contribution to the knowledge, structured by the objectives of this thesis.

7.3.1. Identifying automotive seat design parameters

The first and second objectives of this thesis were as follows:

Objective 1: to identify key parameters (seat sub-component dimensions) for a seat design in the elevated driving posture.

Objective 2: to understand the effects of the seat design parameters on initial impressions of comfort in the elevated driving posture.

Fitting trials were selected as the method to help meet these objectives. Fitting trials have been used in many laboratory studies assessing seating comfort/discomfort, for example Porter and Gyi (1998) and Kyung et al. (2008). The advantage of fitting trials is that they can be used to identify a range of 'comfortable body angles' but also to identify a range of comfortable seat sub-component dimensions. In this thesis, this method was used to identify key seat design parameters for the elevated posture (Chapter 4), with the philosophy that the adjustment of one seat sub-components will directly influence the comfort and optimum position of another. A robust driving rig was built with multiple adjustments of the seat sub-components deemed important to selecting a comfortable driving position (e.g. seat base length, backrest height). The ability to move many parameters iteratively in one trial allowed participants to fine tune adjustments until they had selected their optimum seat set-up.

The findings from this study led to the specification of a concept elevated posture seat which was used for the long-term discomfort and lateral stability evaluations (Chapters 5 and 6). As reported, the results show that this seat was found to be as comfortable as a conventional posture production seat. This highlights that the approach was extremely effective in identifying a series of comfortable seat set-ups for an anthropometrically diverse range of participants. Previous studies have used fitting trials in the exploration of conventional driving postures but it is important knowledge that the same techniques can be applied to new/novel driving postures in the early stages of design.

7.3.2. Long-term discomfort in an automotive seat

The fourth and fifth objectives of this thesis were as follows:

Objective 4: to understand the effects of a new seat design on long-term driver comfort, in comparison with a benchmark production seat.

Objective 5: to identify the onset of musculoskeletal fatigue in comparison with a benchmark posture and the literature.

Long-term discomfort evaluations using a driving simulator, a motion platform and discomfort ratings were selected as suitable methods for these objectives. The contribution to knowledge from these evaluations is that the onset of seat discomfort in the presence of vibration can occur after as little as 10 minutes. The literature highlighted that vibration accelerates the onset of seat discomfort and musculoskeletal fatigue (Mansfield et al., 2015) which is known as dynamic fatigue factors (Figure 7.4).

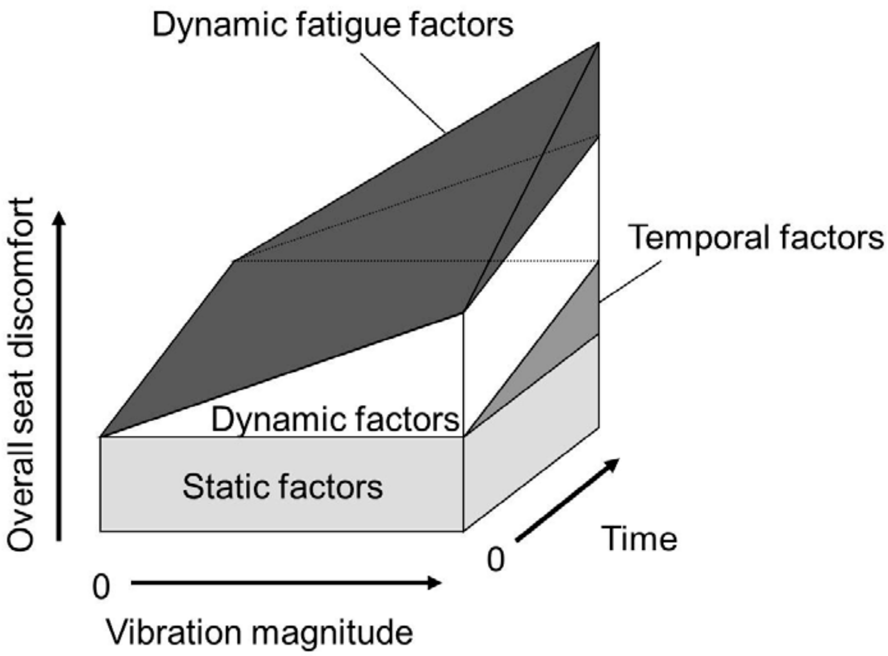

Figure 7.4. Modified Ebe and Griffin (2000a) model of overall car seat discomfort including static, dynamic, temporal and dynamic fatigue factors (Mansfield et al., 2015).

Previous studies (Mansfield et al., 2014; Mansfield et al., 2015) have observed significant differences in discomfort after as little as 30 minutes and 40 minutes respectively. The results from the current research have shown that for the conventional driving posture, significant differences in discomfort were observed after only 10 minutes for the middle back. This finding is a significant contribution in understanding how vibration in a vehicle seat can affect discomfort over time and corroborates the model of overall seat discomfort (Figure 7.4). The elevated posture seat developed had an upright backrest and did not allow for any recline. Some studies have shown that a reclined backrest can improve the comfort in the seat (e.g. Paddan et al., 2012) and further research is needed to determine the optimal backrest angle for the elevated driving position. Furthermore, the vertical dynamics of the seat were not modified with a view to improving the vibration response. Paddan and Griffin (1998) showed that careful matching of the dynamics of the seat with the vibration environment can have significant benefits in terms of predicted comfort.

7.3.3. Lateral stability in an automotive seat

The sixth objective of this thesis was as follows:

Objective 6: to understand whether the increased height of the driver's hip point results in an increased sensitivity to and perception of vehicle motion.

Lateral stability evaluations using a motion platform and a rating scale were selected as the methods to meet this objective. The scale that was used for the lateral stability evaluation study was the result of several iterations during piloting and was developed specifically as part of this research. The scale was developed on the principles of a continuous scale, which has the advantage of providing participants with a recognisable format and has often been applied to the assessment of comfort/discomfort (Richards et al., 1980; Karthikeyan and Sztandera, 2010). Furthermore, the scale was developed to evoke a quick decision from participants on their perceived stability following lateral accelerations. The scale had two verbal descriptors which described the extreme ends of the scale (Figure 7.5):

- 1 = 'I feel stable, comfortable and calm in this seat'
- 100 = 'I feel unstable, uncomfortable and anxious in this seat'

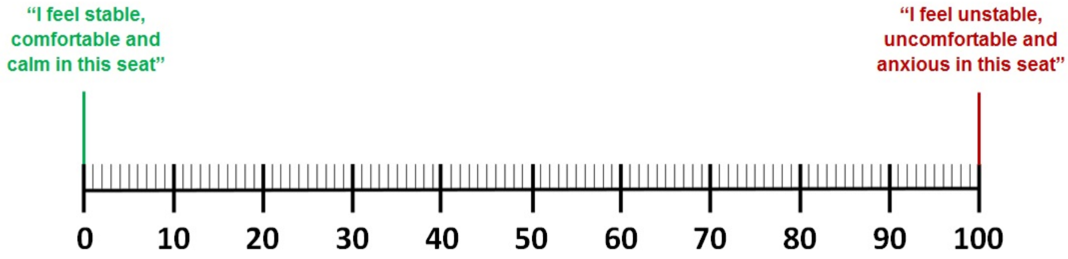

Figure 7.5. 100-point lateral stability scale developed for use in the lateral stability evaluation study.

Participants engaged with this scale in the study and the simplicity of the scale was of paramount importance, as participants were blindfolded for the duration of the lateral acceleration. There is little in the literature on methods of assessing perceived lateral stability during low-frequency accelerations. Consequently, the scale that was developed for this study is new knowledge and provides a platform from which to develop this method further when investigating lateral stability in a seated posture.

7.3.4. Contribution to knowledge summary

The results from the studies reported in this thesis have contributed to knowledge surrounding an elevated driving posture and the assessment of vehicle seat design, seat comfort and lateral stability. Building on this, it has been highlighted that fitting trials are an effective method of identifying seat design considerations early in the design process which is of importance for the new/novel posture explored in this thesis. It has been acknowledged that although rating scales are commonly used in the assessment of seat comfort/discomfort, no literature was found outlining scales to report lateral stability. The lateral stability scale that was developed and reported in this thesis is new knowledge and provides a potential method for the investigation of lateral stability in an automotive seat.

7.4. Future work and application to other sectors

The research reported in this thesis provides new fundamental knowledge considering an elevated driving position. However, it is recognised that there are many ergonomics aspects of interior vehicle design that need consideration for future work with this posture. The ‘eye ellipse’ is often referenced in automotive vehicle packaging, relating to a space in the vehicle that encompasses comfortable eye heights for a given range of drivers. Naturally, the elevated posture raises the occupant’s eye level and subsequently direct and indirect visibility requirements need to be explored (i.e. size and positioning of mirrors). It is important to identify all comfort considerations for this posture; the placement of instruments and controls inside the vehicle (e.g. speedometer) is integral for reach and visual comfort. It is important that these types of controls, deemed essential in performing a driving task, are situated in a comfortable line of sight and within comfortable reach limits for an anthropometrically diverse range of drivers. Additionally, a higher seat position means that vehicle headroom needs to be considered. Gyi (2013) highlighted that insufficient headroom can exacerbate a slouched posture, which in turn could counteract any musculoskeletal benefits from sitting more upright. Future research should investigate the headroom requirement with consideration of the vertical adjustment range identified for the elevated posture.

Whilst the elevated posture has been explored and discussed as an application for the automotive industry, it is important to acknowledge that the concept of this seating posture is one that could be applied beyond this into other transport sectors. The context of the elevated posture explored in this thesis is that by packaging an occupant with an increased HS (floor to hip point dimension) the PH gap (leading edge of pedal to hip point dimension) can be reduced, thus creating space saving benefits. This reasoning could be applied to any vehicle occupant package. When the first laboratory study was conducted, it was observed during the fitting trials that each seat sub-component had a direct influence on another e.g. the length of the seat base would influence the selected PH gap. The relationship between heel step, PH gap and seat base length was one of note during this study. When selecting preferred seat positions, it became clear that participants needed to find a balance between a comfortable ankle angle (e.g. not too acute when operating the pedals) and avoiding too much pressure on the underside of the thigh in contact with the front edge of the seat. This phenomenon arose because of the interaction with the pedals, something which is frequent and of paramount importance to comfort over long-term driving. However, this observation leads to a potential opportunity in the application of the elevated posture. Without pedals and other driving interactions in the vehicle cabin (e.g. steering wheel, primary and secondary controls), there are less defining parameters that need to be considered for comfort and ease of use. This directly leads to the application of seating in passenger transport, such as trains and aircraft.

7.4.1. Rail transport

Rail transport is a commonly used mode of transport and in the UK alone, the number of passenger journeys has doubled since rail privatisation, from 735 million in 1994/95 to nearly 1.5 billion in 2012/13 (DfT, 2013). The National Travel Survey (NTS, 2013) suggests that on an average week day, up to 50% of rail trips are taken by work commuters and commuting into cities is likely to account for the most of these journeys. For shorter journeys, typically less than one hour, it has been acknowledged that over one third of rail passengers are required to stand whilst travelling, due to the increase in passenger numbers and the limited available seating (DfT, 2013). If more seats could fit into the same carriage space then the number of standing passengers could be reduced. It should be noted that many commuters travel from across the country to their destination, which means that long-term sitting comfort is of paramount importance. In addition, long duration rail passengers will typically use their laptop to work on their commute and a seated position is an essential requirement for this task. This information provides the context to speculate that rail transport is a sector that could benefit from space saving design technologies, such as the elevated posture.

Travel by rail comes with the advantage that occupants do not need to interact with controls (e.g. pedals, steering wheel, primary controls) and also they do not have to perform a driving task whilst seated. Additionally, there are no legal requirements for passengers to wear a seat belt or safety restraint during rail travel, whether it is long distance over ground journeys or inner city underground journeys. In application for future research, this means that there are fewer parameters influencing occupant comfort in rail transport, than those that currently exist in automotive transport. On the other hand, rail transport seating is typically fixed in one position with no scope for adjustment. With this in mind, future research should investigate the feasibility of a fixed elevated posture seat in rail transport in encompassing an anthropometrically diverse range of people.

The most notable potential benefit of applying the elevated posture concept and seat to passenger vehicles such as trains is that space saving benefits could be multiplied. For example, only a small space saving per seat on a train carriage could lead to the possibility of adding one or more rows of seats, which could then be multiplied based on the length of the train/number of carriages. In the current global economy, people are encouraged to use public transport and rail travel wherever possible as an alternative to road transport in an aim to reduce CO_2 emissions per capita. The elevated posture seat could provide more seats and thus incentivise passengers to use rail transport as an alternative. Furthermore, the potential reduction in CO_2 as a result of packaging occupants into a smaller space would be realised on a much greater scale in a passenger vehicle of this size.

7.4.2. Air transport

Like rail travel, air travel is an ever-growing market, estimated to be 5.3% per annum. In 2012 it was forecasted that airlines would be carrying upwards of 3.6 billion passengers in 2016, which is an increase of 800 million passengers carried by airlines in 2011 (IATA, 2013). This is ratified by the Air Travel Action Group who indicated that 3.1 billion passengers were carried by the world's airlines in 2013. Furthermore, the average occupancy of aircraft is around 80% greater than other forms of transport (ATAG, 2015). This information provides the context as to why air transport is a sector that could benefit from space saving design technologies, such as the elevated posture seat.

In recent years there has been a lot of media coverage surrounding the possibility of ‘standing seats’ in aircrafts which in theory would be offered to the consumer at a lower rate than standard economy seating. This idea has been associated with budget airlines such as Ryanair and most recently China’s Spring Airlines as a step further in offering passengers the lowest rates for air travel. Several seat designs have arisen as a result of the standing seating premise, most notably by an Italian seat design company called ‘AvioInteriors’ who released a thinner, perching seat design called the ‘SkyRider’ (Figure 7.6). This saddle inspired seat was designed with short-haul air travel in mind (between 1–3 hour journey time) however it has been acknowledged that any new seat design such as this would need to meet all of the Federal Aviation Administration (FAA) requirements.

Figure 7.6. AvioInteriors concept aircraft seat design ‘SkyRider’ (image taken from Wired Online article, 2015).

In addition to new seat design, there is also movement in the aviation sector looking into seating design arrangements and how occupants can be packaged differently in aircraft to maximise the space. An example of this is the hexagon seating design created by ‘Zodiac Seats’ which incorporates a seating plan which would mean passengers facing each other, something which passengers currently adopt in both bus and rail travel (Figure 7.7). The premise of this design is that the seating arrangement can optimise the number of passengers on any given flight.

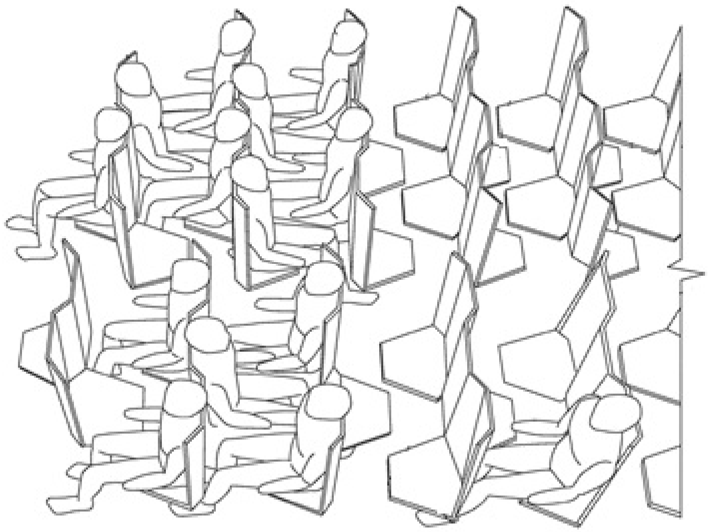

Figure 7.7. ‘Zodiac Seats’ hexagon seating arrangement for aircraft (image taken from Mail Online article, 2015).

These types of seats and seating arrangements are designed with the same purpose, to maximise the space inside an aircraft to package more passengers. However it should be acknowledged that comfort is an important issue with air travel and is directly linked to whether or not a passenger will book with the same airline in the future (Vink et al., 2012). Furthermore, Vink et al. (2012) found that along with crew attention and pre-flight experience, the physical characteristics (e.g. seat comfort and legroom) are key contributors to the passengers ‘comfort experience’. As with road vehicle design, seat comfort should no longer be considered a luxury, but a requirement (Kolich and Taboun, 2004) and this philosophy should be followed for occupant packaging in all vehicle types, as much as feasibly possible.

The opportunity and impact that the elevated posture seat could have on air travel is potentially enormous. The trends in the aviation sector show that novel seating designs and novel seating arrangements are being produced with the aim to maximise the number of passengers per flight. Similar to the future research considerations for rail travel, the benefits on a large passenger vehicle such as an aircraft could potentially be multiplied by realising just minimal amounts of space saving per seat. As with rail travel, there is typically little or no adjustment in air transport seating and so future research should investigate the feasibility of a fixed elevated posture seat.

7.4.3. Summarising the application of the elevated posture

The findings of this research have provided new knowledge by way of a seat design that is comfortable and can realise space saving benefits. There is now the opportunity to utilise this knowledge by exploring this elevated posture in other transport sectors, to understand the full impact it can have on CO_2 reduction. The application of the elevated posture seat has been considered in relation to two of the largest transport sectors, rail and air. This posture could have a profound impact on both of these sectors and beyond (e.g. maritime) in terms of space saving and the reduction in CO_2 emissions over the life cycle of the vehicle. It has been established that the space saving benefits can be multiplied on vehicle types that typically carry a large number of passengers in one journey and on a regular basis. It should also be noted that as a ‘passenger seat’, as opposed to a ‘driver’s seat’, there are fewer interactions with the environment around them (e.g. pedals, steering wheel, controls) that could adversely impact upon occupants’ seat comfort. However, it has also been acknowledged that typically, unlike road vehicle seating, rail and air seating is fixed. Future work for these sectors should focus on the feasibility of a fixed elevated posture seat in encompassing a diverse anthropometric population in comparison to current seating and how this impacts on any potential space saving benefits.

7.5. Summary

The results of this research have identified a range of comfortable elevated posture driving positions that achieve a space saving benefit in terms of a reduction in the PH gap dimension. Furthermore, these positions have been identified for an anthropometrically diverse population (JF07-AM99). The engineering process applied to this research has developed the concept from a driving rig with multiple seat adjustments to a well-received comfortable elevated posture seat. It has been acknowledged that the space saving benefits observed for this posture in a road vehicle, could be multiplied if applied to a larger mode of passenger transport such as rail and air travel. The potential positive environmental impact of this posture could be huge, across many transport sectors and this research has provided a comprehensive state of knowledge from which to build upon.

7.5.1. Critical reflection on the research

The body of work presented in this thesis has met the objectives that were outlined at the beginning of the research; however there are strengths and weaknesses which need to be acknowledged. The biggest weakness of this research is the sample size itself, in that only 60 participants in total were recruited throughout this research (20 participants for each of the three case studies). Whilst the sample represented a good anthropometric spread, it is too small a sample to generalise the findings for a diverse population. In anthropometry terms, the variation that exists from person to person makes it very hard to predict the ergonomics considerations for one driver based on another with similar body dimensions e.g. leg length is made up of the upper limb (popliteal length) and the lower limb (seat height); therefore two drivers with the same leg length are likely to have different seat comfort considerations based on the variable make-up of their leg length. This could be addressed if there was more time available and a bigger pool of people from which to recruit, allowing a field study of a much greater sample and results that could be generalised to the population with more confidence.

A notable strength of this research is that an inclusion criterion for recruitment was a large anthropometric spread of participants, with focus on having participants at the extreme ends of the anthropometric population (e.g. low and high percentile for leg length). This meant that the seat adjustment requirements for a diverse population, as outlined in this thesis, represent a population which is beyond what is normally considered and applied in practice and still observes space saving benefits. Although the space saving benefit of packaging drivers closer to the pedals could potentially lead to a reduction in CO_2 through vehicle weight reduction, a weakness of the research is that the concept seat developed for this posture was significantly heavier than the conventional posture seat. This was a result of over engineering the seat and the inclusion of a mechanism that could cope with adjustment required to encompass an anthropometrically diverse population. In application, it cannot be generalised that the overall weight of the vehicle would be reduced as a result from packaging drivers closer to the pedals. The weight of the elevated posture seat needs to be fully explored and developed to understand how much weight it would add to the vehicle, if any, to gain a fuller understanding of the potential environmental benefits of the posture detailed in this research. With further consideration about the adjustment built in to the seat, when discussing other applications for this posture, a weakness of this research is that it specifically focussed on a driver's seat with built in adjustment. It has been acknowledged that this seated posture could realise similar space saving benefits in application to other sectors (rail and air transport), however these sectors typically have fixed seats with no scope for adjustment. Therefore, the static and dynamic comfort considerations of the elevated posture seat are not directly applicable to, thus cannot be generalised for, a 'passenger seat'. In order to be applied to these types of vehicles, a comfortable fixed elevated posture seat for a diverse population needs to be explored as a separate piece of research.

It has been acknowledged that the experimental methods that were used in this body of work helped to develop a seat from a very early stage, with consideration of static comfort parameters, to a concept seat for this posture. One of the greatest strengths of this body of work is the positive impact that this approach can have in identifying the requirements of a user population and utilising these in the development of a seat fit for purpose. This approach is one that can be adopted for the development of new/untested driving posture seats and as a framework this is a valuable output from this research.

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APPENDIX A1

- **Anthropometric measurement definitions.**

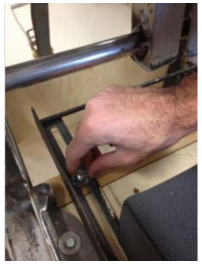
Anthropometric Dimension	Definition and Measurement
Stature	Distance from the floor to the top of the head. The participant stands upright, barefoot against the vertical surface with feet together and looking directly ahead. The measurement is taken when the horizontal bar touches the top of the head.
Sitting Height	Distance from the top of the seat surface to the top of the head. The participant sits on the seat with back against the vertical surface, with the backs of their knees against the seat surface and knees at a 90˚ angle. The participant looks directly ahead and the measurement is taken when the horizontal bar touches the head.
Shoulder Width	The distance between the widest points on each shoulder. The participant sits on a flat surface with a straight back. The calipers are used to measure from the widest points on each shoulder.
Sitting Hip Width	The distance between the widest points on the hip/outer thigh. The participant sits on a flat surface with a straight back and legs at a 90˚ angle. The calipers are used to measure from the widest points on each hip.
Knee Height	Distance from the bottom of the sole of the foot to the top of the patella. The participant sits on the flat surface with feet on the root rest and knees at a 90˚ angle. The measurement is taken from the footrest to top of knee.

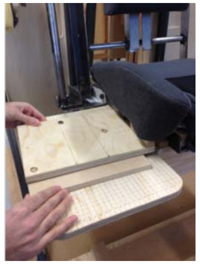
Anthropometric Dimension	Definition and Measurement
Popliteal Length	The distance from the back of the buttocks (where they meet the backrest) and the back side of the knee (or front of the seat surface edge). The participant sits on the seat with back against the vertical surface, with the backs of the knees against the front edge of the seat and with knees at a 90˚ angle. Measurement is taken from the vertical surface to the seat surface edge.
Leg Length	The distance between the back of the buttocks (where they meet the backrest) and the flat sole of the foot. The participant sits on the flat seat surface with their back against a vertical surface and their leg outstretched (supported if possible by an extended seat surface or measured on the floor). The measurement is taken from the back surface to the sole of the foot.
Seat Height	The distance between the sole of the foot and the underside of the buttocks or flat seat surface. Participants sit bare foot with feet on the floor, a straight back and knees at a 90° angle. The measurement is taken from the floor to the seat surface.
Foot Length	The distance between the back of the heel to the tip of the big toe. The participant stands upright in bare feet. The calipers are used to measure from the back of the heel to the tip of the big toe.
Back to Fingertip length	The distance between he back and the longest fingertip. The participant stands with their back against the wall and stretches their arm out horizontally with the back of the shoulder in contact with the wall. The measurement is taken from the wall to the furthest forward fingertip.

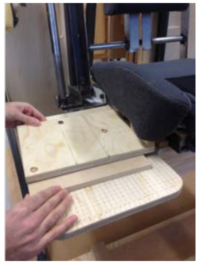
APPENDIX A2

- **Seat sub-component adjustment methods.**

Seat sub-component adjustment	Method of adjustment	Adjustment range
Heel step  	The seat height was adjusted using a ratchet strap, which allowed free flowing movement to provide accuracy when setting the position. A scale of reference lines 10mm apart on the back of the rig were used to ensure that the seat was locked in a level position. The seat height was locked in place securely with two large wing nuts, either side of the strap	400mm (from 400-800mm in Z)
Pedal-hip (PH) gap  	The PH gap adjustment was made using a lockable free sliding board with guide rails, on which the pedals were mounted. The pedal position was locked securely using two wing nuts either side of the board.	350mm (from 450-800mm in X)

Seat sub-component adjustment	Method of adjustment	Adjustment range
Seat base length  	The seat base was mounted on to a free sliding rail. It was expected that a shorter seat length would be needed for the elevated posture and the adjustment range reflected this. The seat was locked in position using two wing nuts on the rails either side of the pad.	160mm (from 300-460mm in X) *reference NV200 seat base length was 460mm*)
Lumbar pad adjustment  	The lumbar pad was attached to a vertical rail behind the seat, which also provided adjustment for the upper backrest. The lumbar pad was set by locking the wing nut in place behind the pad.	250mm (from flush with seat base to 250mm in Z)
Upper backrest adjustment  	The upper backrest was fixed to a vertical rail located at the back of the seat. The total possible adjustment from the bottom of the lumbar support in its lowest position to the top of the upper backrest was 670mm.The upper backrest was locked and unlocked using a wing nut at the back of the rig.	220mm (from flush with lumbar/seat base, to top of backrest in Z)

Seat sub-component adjustment	Method of adjustment	Adjustment range
Lumbar prominence adjustment  	The lumbar pad was adjusted on a horizontal plane. It was attached to a pole, which runs through to the back of the seat where it is locked in place. Unlocking a large screw allowed free movement of the lumbar support pad on this horizontal plane making it less or more prominent in to the lumbar region of the occupant. The minimum position was level with the backrest plane (zero prominence).	100mm (from level with upper backrest pad to 100mm forward in X)
Seat bolster adjustment  	The seat base had separate bolsters at the side, which could be moved independently towards the seat pad on a free moving board. The adjustment range was from 0mm (where the bolsters meet the side of the seat base flush, as per the NV200 seat) to 100mm, on each side, offering a total additional 200mm of adjustment to the overall seat width; The seat bolsters were locked in to position with a G-Clamp. The seat bolsters were mounted on a free moving board either side of the seat base. To adjust the height of the bolsters, 10mm incremented wooden boards were added underneath until the optimum height was achieved. The bolster board was locked in to position with a G-Clamp.	100mm each side (from 0mm, where the bolsters met with the NV200 seat to 100mm in Y)

Seat sub-component adjustment	Method of adjustment	Adjustment range
Seat bolster angle adjustment  	The angle of the seat bolsters was adjusted between 0º (matching up flush with the side of the seat base) and 45º. The bolster board was locked in to position with a G-Clamp.	45º (from 0º matching seat base contours to 45º)
Backrest bolster adjustment  	The backrest bolsters were attached behind the seat on a vertical pole wing mechanism, moving towards the upper backrest, in a free flowing movement. The bolsters offered 3 adjustments; Height, width and fore-aft each from the starting position (where the bolsters match up with the seat backrest). The backrest bolsters were locked and unlocked using wing nuts on the wing mechanism.	100mm (from where the bolsters matched the NV200 backrest contour to 100mm in X, Y and Z)
Armrest adjustment  	The armrests were adjusted in the Y and Z dimensions, to test the optimum height and lateral position. The armrests were introduced to the rig once all other seat sub-components had been adjusted, and offered unlimited adjustment for both dimensions using a free sliding board and the addition on 10mm wooden shims.	Unlimited in Z

APPENDIX A3

- **Seat design parameter study information sheet.**

Loughborough University

Main Investigator: Jordan Smith

What is the purpose of the study?

The purpose of this study is to explore the comfort and design of a new seat for a higher driving posture in Light Commercial Vehicles (LCV's).

This research will be run by Jordan Smith, Research Assistant, working as part of the Loughborough Design School (LDS) for Loughborough University. The research will be assisted and overseen by Dr. Neil Mansfield and Dr. Diane Gyi, also from the LDS at Loughborough University.

Are there any exclusion criteria?

You must be between the ages of 18 and 65 and held a full driving license for at least two years. You should have experience in driving LCV's including Vans, Minibuses etc.

Once I take part, can I change my mind?

Yes. After you have read this information and asked any questions you may have we will ask you to complete an Informed Consent Form, however if at any time, before, during or after the trials you wish to withdraw from the study please just contact the investigator. 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?

There will be one session, which will be a fitting trial. You will be expected to attend this trial, which will be held at Loughborough University in Loughborough Design School (LDS).

How long will it take?

Fitting Trial: Session 1 60 minutes

Is there anything I need to do before the sessions?

Read through this information sheet, fill out the medical questionnaire and sign the consent form provided.

What type of clothing should I wear?

For the fitting trial, you are advised to wear comfortable clothing and flat shoes e.g. sports shoes.

What will I be asked to do?

Fitting Trial: 1 session

The aim of the fitting trial is to explore the optimum comfort for a seat in a higher driving posture. You will be asked to sit in a driving rig and with the investigator controlling the adjustments, set the seat and all sub-seat components to a position which most comfortable to you, as the driver.

An optimum driving position will be found by adjusting;

- Seat Height.
- Distance to Pedals.
- Seat Base Length.
- Lumbar Position Height.
- Upper Backrest Position.
- Lumbar Prominence.
- Seat Base Width.
- Seat Base Side Bolster Height.
- Seat Base Side Bolster Angle.
- Backrest Side Support Position.
- Armrest Position.

What personal information will be required from me?

You will need to complete a Health Screen Questionnaire, to ensure that there are no significant health problems.

Some of your body dimensions will be measured relevant to selecting a driving posture.

Will my taking part in this study be kept confidential?

The storage of data will comply with the Data Protection Act 1998. Any video and audio recording will be kept in a secure place and will not be released for use by third parties. All video and audio recordings will be destroyed within six years of the completion of the study.

What will happen to the results of the study?

The results of the study will be owned by Loughborough University and archived. A technical paper will detail the results of the study.

What do I get for participating?

Each participant will receive a financial reward for participation:

Fitting Trial (one session) **- £10**

I have some more questions who should I contact?

If you have any further questions prior to, during or after the study trials, then please contact the main investigator (contact given at the top of this document). If there is a problem contacting the main investigator then please contact the academic supervisor for the study.

What if I am not happy with how the research was conducted?
Loughborough University 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 A4

- **Participant informed consent form.**

Loughborough University

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 Ethical Advisory 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 A5

- **Participant health screen questionnaire.**

Name or Number ....

It is important that volunteers participating in research studies are currently in good health and have had no significant medical problems in the past. This is to ensure (i) their own continuing well-being and (ii) to avoid the possibility of individual health issues confounding study outcomes.

Please complete this brief questionnaire to confirm fitness to participate:

1. **At present,** do you have any health problem for which you are:

(a)	on medication, prescribed or otherwise	Yes	☐	No	☐
(b)	attending your general practitioner	Yes	☐	No	☐
(c)	on a hospital waiting list	Yes	☐	No	☐

2. **In the past two years,** have you had any illness which require you to:

(a)	consult your GP...	Yes	☐	No	☐
(b)	attend a hospital outpatient department	Yes	☐	No	☐
(c)	be admitted to hospital	Yes	☐	No	☐

3. **Have you ever** had any of the following:

(a)	Convulsions/epilepsy	Yes	☐	No	☐
(b)	Asthma or respiratory disease	Yes	☐	No	☐
(c)	Diabetes	Yes	☐	No	☐
(d)	A blood disorder	Yes	☐	No	☐
(e)	Head injury	Yes	☐	No	☐
(f)	Digestive problems or disease of gastro-intestinal tract	Yes	☐	No	☐
(g)	Disease of genito-urinary system..............................	Yes	☐	No	☐
(h)	Heart problems or disease of cardiovascular system	Yes	☐	No	☐
(i)	Problems with bones or joints	Yes	☐	No	☐
(j)	Disturbance of balance/coordination	Yes	☐	No	☐
(k)	Numbness in hands or feet	Yes	☐	No	☐
(l)	Disturbance of vision or retinal detachment	Yes	☐	No	☐
(m)	Ear / hearing problems	Yes	☐	No	☐
(n)	Thyroid problems	Yes	☐	No	☐
(o)	Kidney or liver problems	Yes	☐	No	☐
(p)	Back pain	Yes	☐	No	☐

4. **Do you** use any prosthetic device (not including dentures, external hearing aids, spectacles and contact lenses)

Yes ☐ No ☐

If YES to any question, please describe briefly if you wish (e.g. to confirm problem was/is short-lived, insignificant or well controlled.)

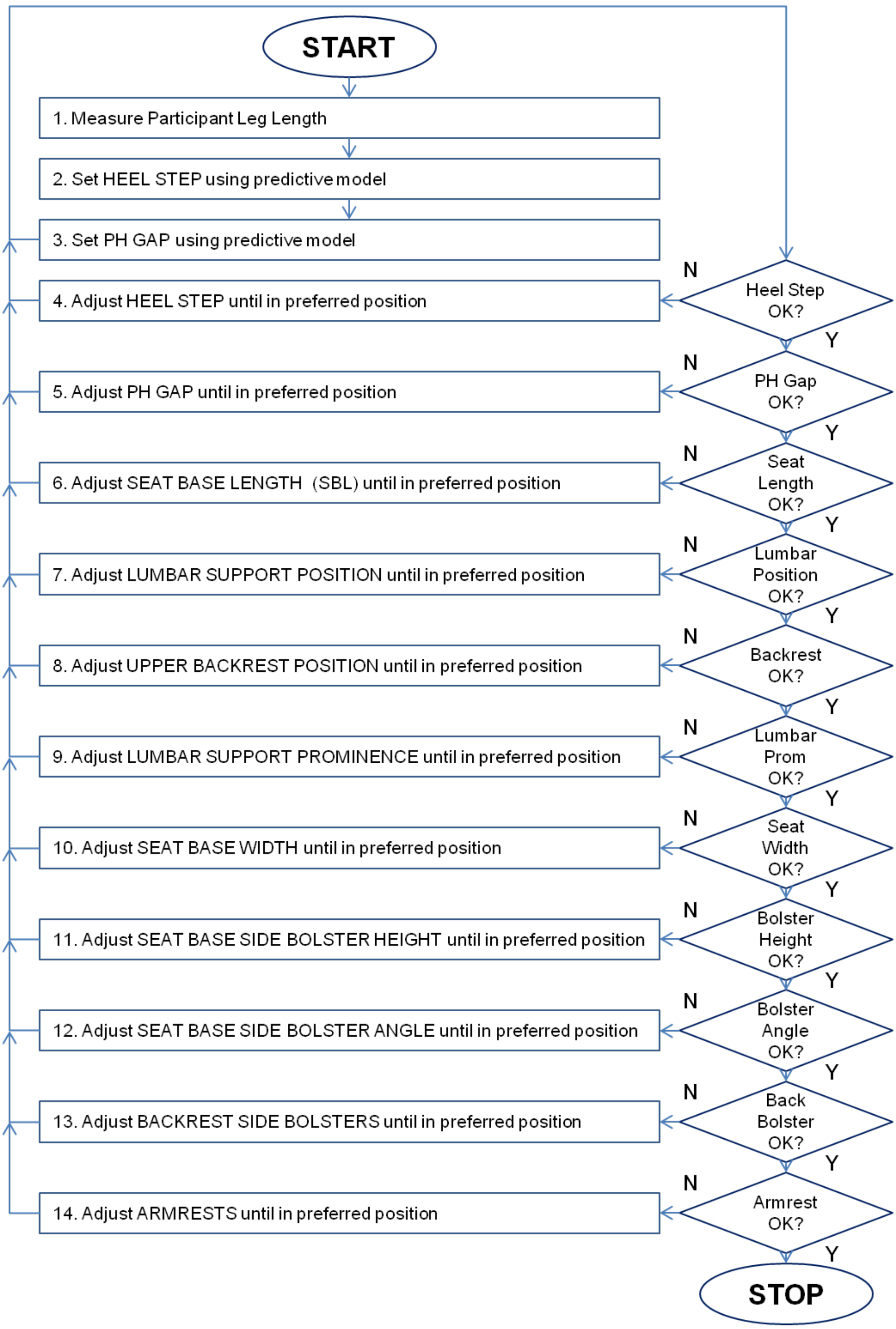
....

Additional questions for female participants

(a) Could you be pregnant? .... Yes ☐ No ☐

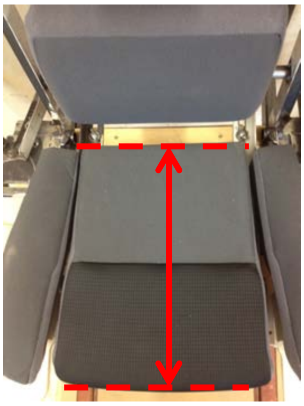
APPENDIX A6

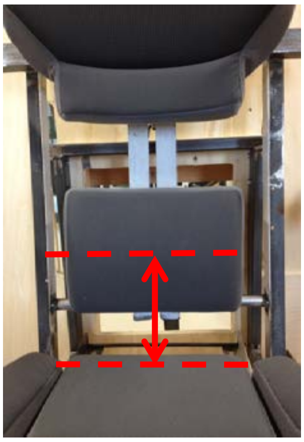
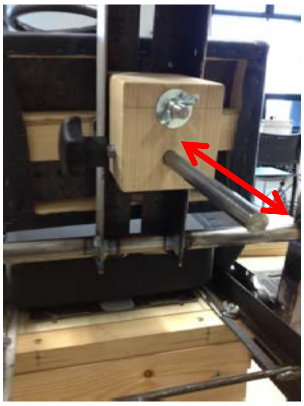
- **Fitting trial iterative method of adjustment flowchart.**

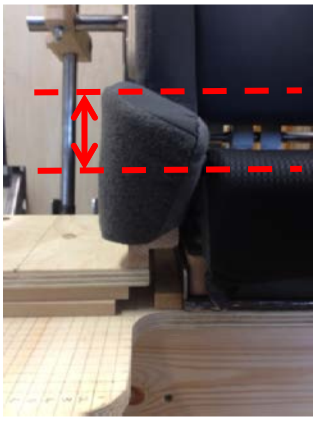


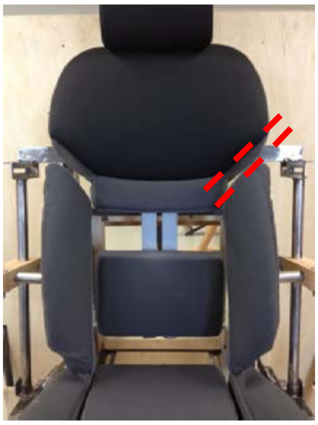
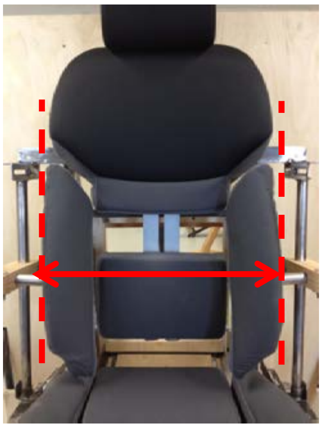
APPENDIX A7

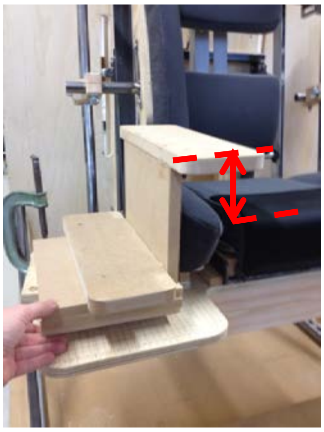
- **Seat sub-component measurement definition.**

Seat Measurement	Definition
Heel Step (HS) 	The Heel Step is defined as the height of the hip point from the cabin floor, in Z.
Pedal-hip (PH) Gap 	The PH Gap is defined as the distance between the hip point and the pedal set (leading edge of B pedal) in X.
Seat Base Length 	The seat base length is defined from the point at which the lower backrest meets the seat base, to the leading front edge of the seat base cushion.

Seat Measurement	Definition
Lumbar Support Position 	The backrest for the fitting trial will be split in to the lower and upper backrest. The lower backrest position will be used to define the lumbar position and it will be identified as the distance from the seat base surface, in height, to the central point of the lumbar support.
Upper Backrest Position 	The upper backrest position will be identified as the height of the top of the backrest relative to the seat base surface.
Lumbar Prominence 	The lumbar prominence is defined as how much support is given, in the pre-identified preferred lumbar position (section 2.1.3). This will be defined as the additional prominence from the starting level position, in line with the top of the backrest.

Seat Measurement	Definition
Seat Base Width 	The seat base width is defined as the width of the whole seat base, at its widest point, including the additional width of seat base bolsters.
Seat Bolster Height 	The seat side bolsters were separated from the seat pad in the construction of the rig and designed so that they could be brought back to that original position, independently. This position determined the starting height of the seat side bolsters. The seat base side bolster position is defined as the distance between the highest point of the side bolster and the highest point of the seat pad surface.
Seat Bolster Angle 	The seat base side bolster angle is defined as the position of the bolsters themselves relative to the seat base side surface.

Seat Measurement	Definition
Backrest Bolster Height 	The height from the highest most point on the bolster to where it meets flush with the contours of the backrest cushion.
Backrest Width 	The width of the entire backrest, including bolsters, from the widest most points of the backrest.
Backrest Fore-aft 	The fore-aft distance between the forward leading edge of the bolster and the backrest surface.

Seat Measurement	Definition
Armrest Lateral Position 	The lateral position from the inside edge of the armrest surface to the centre of the seat pad surface.
Armrest Height 	The height from the armrest top surface to the seat pad surface.

APPENDIX A8

- **Seat design parameter study: Participant anthropometric data and driver background information.**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Range
Gender	M	M	M	M	F	F	F	F	M	F	M	M	F	F	F	F	F	M	M	M	
Age (yrs)	55	41	53	51	65	30	42	24	26	55	26	24	28	34	33	33	44	44	28	46	41
Experience (miles)	100k	100k	90k	20k	50k	20k	0.5k	10k	1k	6k	1k	10k	0.5k	0.5k	8k	50k	1k	15k	6k	30k	99,500
Sitting Height (mm)	931	928	908	1004	881	858	861	928	955	895	961	936	900	952	819	927	821	947	987	903	185
Shoulder Width (mm)	460	477	488	487	389	393	387	387	452	402	466	482	382	387	386	406	387	416	472	440	106
Sitting Hip Width (mm)	389	379	410	420	380	431	428	400	372	419	439	347	329	399	372	422	376	362	396	393	110
Knee Height (mm)	560	503	496	608	473	526	458	500	570	524	517	549	479	525	439	538	477	514	545	497	169
Popliteal Length (mm)	508	409	456	409	421	482	451	451	481	483	487	472	385	452	436	446	416	415	468	403	123
Seat Height (mm)	444	382	369	384	385	414	358	400	459	413	412	470	383	408	350	401	371	391	431	399	120
Leg Length (mm)	1060	869	923	1131	883	952	893	928	1017	988	908	1049	855	948	843	967	880	942	1021	906	288
Foot Length (mm)	255	250	242	296	222	236	232	228	285	237	254	258	235	264	228	266	229	245	283	250	74
Sitting Elbow Height (mm)	209	257	206	228	212	189	163	262	257	196	233	195	278	252	186	222	172	227	249	243	115
Shoe Size	10	9	8	14	5	6	4.5	5	11	6	10	10	6	7	4	7	4	8	11	9	10

APPENDIX A9

- **Seat design parameter study: Final seat sub-component positions for the elevated posture.**

Dimension	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Range
Heel Step (mm)	662	613	586	644	568	608	576	609	640	607	608	681	593	595	550	596	576	588	629	577	131
PH Gap (mm)	664	614	689	797	632	647	634	680	754	699	695	722	639	695	626	720	627	700	806	693	192
Seat Base Length (mm)	409	332	357	381	357	380	376	403	408	392	384	347	341	381	364	405	392	367	384	409	77
Lumbar Position (mm)	216	120	179	197	215	187	195	196	60	214	177	157	168	176	177	197	136	163	192	217	157
Upper Backrest Position (mm)	678	646	724	738	665	690	669	709	694	721	667	734	670	686	646	706	615	706	720	693	123
Lumbar Prominence (mm)	15	0	6	10	0	26	0	6	0	11	18	27	19	23	0	4	0	14	0	0	27
Seat Base Width (mm)	634	558	556	629	535	541	537	542	595	557	567	536	498	559	556	629	548	541	540	571	136
Seat Base Bolster Height (mm)	55	45	45	45	55	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	10
Seat Base Bolster Angle (degree)	5	7	11	0	6	0	0	9	19	4	9	3	0	6	7	10	4	8	2	0	19
Upper Backrest Width (mm)	485	539	467	525	510	464	442	512	478	446	519	477	502	474	447	468	488	468	470	472	97
Backrest Bolster Height (mm)	0	0	39	26	15	0	0	36	31	24	5	52	13	9	0	0	0	15	6	0	52
Backrest Bolster Fore-aft (mm)	113	123	71	59	74	47	121	142	79	69	66	61	48	68	77	66	64	45	58	82	97
Armrest Lateral Position (mm)	274	234	232	298	263	206	223	267	255	258	251	221	222	254	234	244	196	224	223	211	102
Armrest Height (mm)	240	240	200	230	210	220	230	240	220	210	240	230	230	260	260	250	190	230	220	250	70

APPENDIX A10

- **Seat design parameter study: Selected detailed participant verbatim.**

Participant	Verbatim
1	I was driving HGV for 2 years full time, 6 days a week and 10-12 hour shifts. I experience discomfort towards my upper back after long period of driving and like to sink back in to the seat. I like to feel that the bolsters on the seat fully support me, along with the backrest and armrests - this way; I can be in a position of control, without any strenuous work of my arms or legs.
2	I have been driving small transit vans since I passed my driving test, driving with Royal Mail doing 30,000 miles a year, now driving 50 miles a week around campus. A lot of my time is spent in the van. I don't get much discomfort after driving for long periods of time. I like the shorter seat base, I thought it wouldn't offer me enough support under the thighs but it does!
3	I am used to driving in transit vans and I know that I usually have quite a slumped posture which is not good after time. I like having the seat side bolsters wider than usual, so my legs feel freer to operate the pedals and move around during driving to stretch.
4	I am used to compromising comfort in one area for another because of my size. I am used to sitting on the seat side bolsters and after time the foam loses its rigidity and the framework underneath become very uncomfortable. I like the option of widening these to I can shift my posture slightly to avoid numb buttocks and thighs. I would prefer the pedals to be higher, because my feet are size 14 I am using the middle rather than the ball of my foot to operate the peals. Saying that, this set up is more comfortable for me than any other van I have driven.
5	I used to drive a van in and out of the town centre when I used to transfer stock. I have hired many vans in the past for moving. I usually have a problem with my upper back as the head restraint doesn't fit my back well and becomes uncomfortable. I get discomfort in my right shoulder and the armrest on the door is too far away for me to reach and lean on it comfortably - so I push cushions down the side of my seat so I can rest my right arm on them. Would prefer the steering wheel to be a little closer as I like a compact posture when I drive.
6	I have been driving transit vans since I passed my driving test. I also have an HGV licence and drive an old lorry with not a very modern driving seat and no mod-cons such as armrests, so I am not used to needing them. I usually like to keep at least some of my arms free, rather than being boxed in, as it means I don't get too relaxed in driving, but instead remain alert to the road. I really like this posture I wish you could put it in to my car for the drive home!
7	I have mainly used vans as a hire vehicle when I used to move house and drive across the country to pick things up, but have done a couple of fairly long duration journeys in one go. This feels comfortable for me; I am used to not having my heel flat on the floor. It is good to get the flexibility in the steering so my eye line doesn't become compromised. One comment would be the length of the armrest would need to be shorter so it does not interfere with steering.

Participant	Verbatim
8	I really like this posture and could happily drive in it, in daily life. I am used to driving people carriers and that is the smallest vehicle I have driven consistently. This seat is supporting without being restricting, I like the fact that this lumbar support is optional as I am not used to having adjustment in that area, or even enough support to make me feel comfortable over a long period of time.
9	I am used to driving a variety of vans and don't usually have many problems in getting comfortable - however I have never driven them for a very long distance or time. My legs are quite long so at first the seat base length felt a little odd, but I don't need as much length as I thought I would in order to get comfortable as I want my leg to be free towards the knee.
15	I have real trouble buying any car because I am so short. I find that I need to bring my seat as close as possible to the pedals and then once I do this the steering wheel is too close. I often don't get the right support for my back and it is a constant struggle to find a car/vehicle that has the adjustment to fit my size. I really like this posture, could you please take this and put it in my car? It feels more comfortable to me being in a vehicle high up than slouching down. The visibility over the steering wheel is also a concern for normal driving posture.
16	I usually drive with the steering wheel quite far away and so armrests aren't really used. But, I do like the option. The backrest is really comfortable. I like that I get the support I need from these seat bolsters, without constricting me too much. A problem I encounter in the Berlingo.
17	I do usually drive with my heel on the ground but it is sometimes uncomfortable because I am quite short. I am not used to having armrests but I like the option to have one, just on the left hand side. I wouldn't use it as a rest whilst using the steering wheel, but more of a resting point during driving, where my whole arm wasn't using the wheel. I like the lumbar support in the back; I am not used to feeling any support there and sometimes get low back pain over long journeys because of this.
18	I am used to driving vans and so I like the concept of driving higher up in a vehicle, I don't like to drive slouched down I find it all a lot more comfortable up here. I would be interested to see how it felt about a few hundred miles - At the moment it is very comfortable. The armrest on the right hand side is very much something that is further away from you, as I normally rest my right elbow on the sill of the door/window. The distance between this point and me often determines the position of the steering wheel.

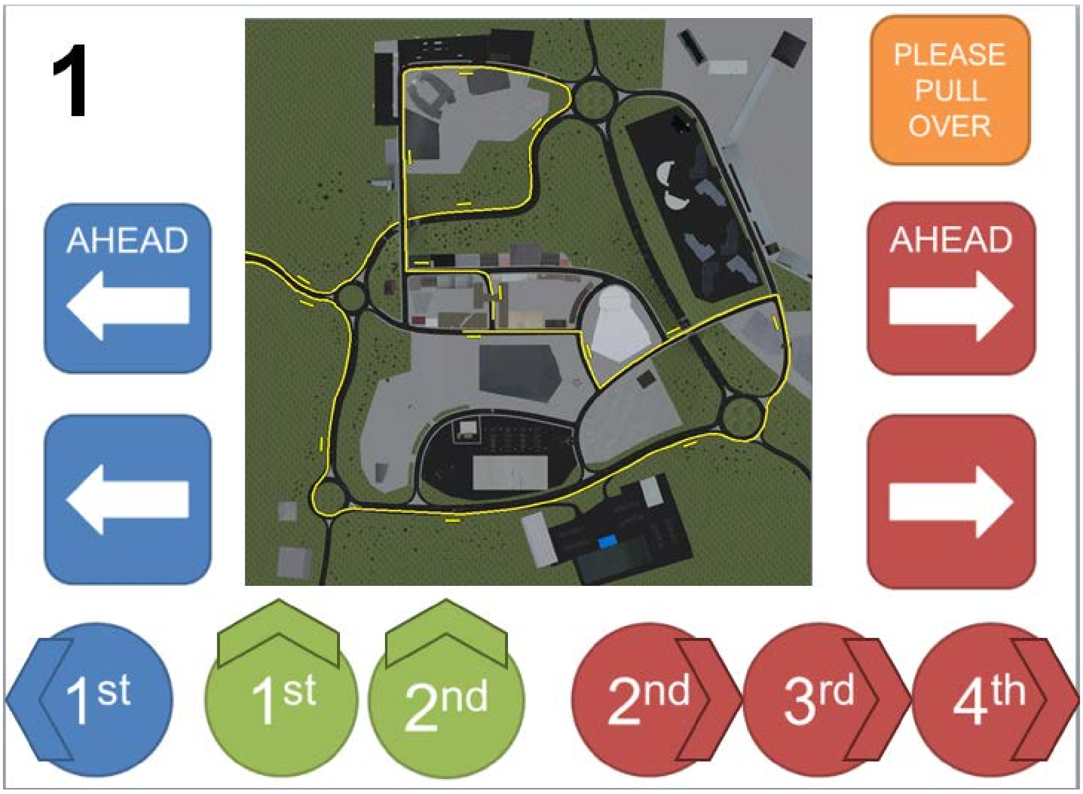
APPENDIX A11

- **Randomised order of driving scenarios.**

Participant	2nd Scenario	3rd Scenario	4th Scenario
1	Free Drive 1	Free Drive 2	Free Drive 3
2	Free Drive 1	Free Drive 3	Free Drive 2
3	Free Drive 2	Free Drive 3	Free Drive 1
4	Free Drive 2	Free Drive 1	Free Drive 3
5	Free Drive 3	Free Drive 2	Free Drive 1
6	Free Drive 3	Free Drive 1	Free Drive 2
7	Free Drive 2	Free Drive 2	Free Drive 3
8	Free Drive 1	Free Drive 3	Free Drive 2
9	Free Drive 2	Free Drive 3	Free Drive 1
10	Free Drive 2	Free Drive 1	Free Drive 3
11	Free Drive 3	Free Drive 2	Free Drive 1
12	Free Drive 3	Free Drive 1	Free Drive 2
13	Free Drive 1	Free Drive 2	Free Drive 3
14	Free Drive 1	Free Drive 3	Free Drive 2
15	Free Drive 2	Free Drive 3	Free Drive 1
16	Free Drive 2	Free Drive 1	Free Drive 3
17	Free Drive 3	Free Drive 2	Free Drive 1
18	Free Drive 3	Free Drive 1	Free Drive 2
19	Free Drive 1	Free Drive 2	Free Drive 3
20	Free Drive 2	Free Drive 3	Free Drive 1

APPENDIX A12

- **Driving simulation soundboard.**



APPENDIX A13

- **Long-term discomfort evaluation study information sheet.**

Loughborough University

Main Investigator: Jordan Smith

What is the purpose of the study?

The purpose of this study is to explore the long-term comfort of two separate driving postures in Light Commercial Vehicles.

Jordan Smith, Research Associate working for Loughborough University, will run this research. The research will be assisted and overseen by Dr. Neil Mansfield from Loughborough University.

Are there any exclusion criteria?

You must be between the ages of 18 and 65 and must have held a full driving license for at least one year.

Once I take part, can I change my mind?

Yes. After you have read this information and asked any questions you may have we will ask you to complete an Informed Consent Form, however if at any time, before, during or after the trials you wish to withdraw from the study please just contact the investigator. 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?

The long-term comfort evaluation will be split in to two trials; each with a different posture. You will be expected to attend both of these trials, which will be held at Loughborough University in the Environmental Ergonomics Research Centre Laboratories, James France building.

How long will it take?

Long-term discomfort evaluation:	Session 1	75 minutes
	Session 2	75 minutes

You will be required to attend each session on different days.

Is there anything I need to do before the sessions?

Read through this information sheet, fill out the medical questionnaire and sign the consent form provided.

What type of clothing should I wear?

For both trials you are advised to wear comfortable clothing and flat shoes e.g. sports shoes.

What will I be asked to do?

Long-term discomfort evaluation – 2 sessions

The trial will be split into two sessions, one in each different driving posture.

The respective driving rig will be mounted on to a driving simulator and participants will perform a series of driving scenario simulation tasks, each lasting approximately 10 minutes. After each driving scenario, a discomfort assessment will be conducted with the participant.

What personal information will be required from me?

You will need to complete a Health Screen Questionnaire, to ensure that there are no significant health problems.

Some of your body dimensions will be measured.

Will my taking part in this study be kept confidential?

The storage of data will comply with the Data Protection Act 1998. Any video and audio recording will be kept in a secure place and will not be released for use by third parties. All video and audio recordings will be destroyed within six years of the completion of the study.

What will happen to the results of the study?

The results of the study will be owned by Loughborough University and archived. A technical paper will detail the results of the study.

What do I get for participating?

Each participant will receive a financial reward for participation:
Long-term discomfort evaluation (attendance at both sessions) - **£20**

I have some more questions who should I contact?

If you have any further questions prior to, during or after the study trials, then please contact the main investigator (contact given at the top of this document). If there is a problem contacting the main investigator then please contact the academic supervisor for the study.

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 A14

- **Long-term discomfort evaluation study: Participant anthropometric data and driver background information.**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Range
Gender	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	
Age (yrs)	55	28	42	38	59	22	26	27	33	23	26	44	26	30	27	24	21	62	21	29	41
Experience (miles)	100k	1k	1k	40k	100k	1k	5k	1k	40k	1k	17k	1k	10k	1k	1k	n/a	n/a	50k	2k	20k	99k
Sitting Height (mm)	931	880	896	903	946	870	955	887	961	879	947	821	899	835	959	891	950	944	912	912	140
Shoulder Width (mm)	460	370	446	395	502	400	452	440	562	479	444	387	430	436	500	423	412	450	396	412	192
Sitting Hip Width (mm)	389	373	393	411	385	381	372	444	442	499	357	376	354	363	419	380	315	399	349	359	184
Knee Height (mm)	560	515	506	501	551	492	570	495	548	547	544	477	506	469	544	564	515	565	562	492	101
Popliteal Length (mm)	508	470	474	472	499	470	481	493	564	498	497	416	470	429	460	498	508	510	541	461	148
Seat Height (mm)	444	430	416	399	448	390	459	384	459	447	457	371	399	365	433	450	442	450	515	386	150
Leg Length (mm)	1060	901	975	944	1049	883	1014	978	1083	1053	1058	872	980	889	1053	1030	1054	1042	1127	931	255
Foot Length (mm)	255	232	254	232	255	229	285	223	275	240	262	229	246	228	259	245	248	257	248	230	62
Shoe Size	10	5	9	6	9	4	11	4.5	10.5	7	9.5	4	8	5.5	10	8	8	10	8	6	7

APPENDIX A15

- **Long-term discomfort evaluation study: Final seat positions for the elevated posture.**

Dimension	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Range
Heel Step (mm)	584	596	568	606	645	607	631	605	582	577	596	547	585	547	597	572	591	596	608	547	98
PH Gap (mm)	722	646	659	642	742	642	640	660	704	687	682	642	638	642	720	689	657	739	746	642	108

APPENDIX A16

- **Long-term discomfort evaluation study: Detailed participant verbatim.**

Participant	Verbatim
1	The whole set up feels good - my right thigh was uncomfortable by the end, I suppose, but it compares to normal driving. The discomfort I have now is nothing different that I experience in normal vans for an hour of driving.
2	Felt all OK. I didn't have any starting discomfort though, which I did have before.
3	It felt fine, yes. I didn't get any pains or aches. Perhaps the foam could have been slightly softer, but it isn't something that would cause pain, unless I was driving for a very long time.
4	My middle back ached a bit, just didn't feel like I was supported and I was wanting a bit more contact with the backrest of the seat, there. But generally, it's very good, I like it
5	Upper back, towards the end of the driving. I was just starting to notice it, but it isn't an unnatural experience compared with my van or the vans I drive around campus. It's a lot more comfortable than some I drive!
6	Feels fine. I always get fidgety when I drive for longer periods of time.
7	Couldn't really notice any difference. Cushion could be softer, perhaps.
8	Felt OK. My eyes went a bit dizzy at the beginning, but the seat and everything else feels OK.
9	The mental fatigue from the simulator is the worst bit - I started to feel slightly sick and dizzy by the end. The brightness of the screens could maybe do with turning down slightly.
10	I was getting a bit achy in my back; I get that when I drive normally. I felt supported but just getting aches as if I needed to adjust myself in the seat.
11	My bum was getting slightly numb by the end, wasn't a very soft cushion under that part of the seat, but other than that it all felt very comfortable and supportive. Felt intuitive and very normal.
12	My back began to slightly ache towards the end but other than that, it was very comfortable. I did get slightly dizzy towards the end, though. The simulator is very disorientating.

Participant	Verbatim
13	I really couldn't notice much difference to my van to be honest. I'm not used to having the luxury of adjusting elements of the seat and I am very light, so I didn't have much to complain about.
14	I have driven back this morning from Brighton which took 4 hours so I already have a relatively higher discomfort feeling for all of these body dimensions.
15	My bum was numb at the end, not as comfortable as my BMW but compared with vans, I couldn't notice an awful lot of difference. Felt supportive.
16	Buttocks were getting numb, nearly pins and needles; I get the same sort of sensation when I sit in my Nissan Micra for a 2-hour drive.
17	Started to feel uncomfortable by the end, I think I may have positioned myself slightly too high, for the underside of my thighs.
18	Steering sensitivity meant that I was leaning forward and compromising comfort for my shoulders specifically, and later my back, because I wanted to grip it tighter and be more on top of it. The posture itself didn’t lead to this discomfort.
19	My lower back felt like it needed a little more support towards the end, sitting more upright.
20	I felt very comfortable in this posture. Yes, I felt slightly fidgety by the end but nothing out of the ordinary.

APPENDIX A17

- **Lateral stability evaluation study information sheet.**

Loughborough University

Main Investigator: Jordan Smith

What is the purpose of the study?

The purpose of this study is to explore the sensitivity to lateral motion of three separate driving seats in Light Commercial Vehicles.

Jordan Smith, Research Associate working for Loughborough University, will run this research. The research will be assisted and overseen by Professor Neil Mansfield from Loughborough University.

Are there any exclusion criteria?

You must be between the ages of 19 and 65.

Once I take part, can I change my mind?

Yes. After you have read this information and asked any questions you may have we will ask you to complete an Informed Consent Form, however if at any time, before, during or after the trials you wish to withdraw from the study please just contact the investigator. 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?

The lateral stability evaluation will be split in to 3 trials, representing 3 separate seats. You will be expected to attend all of these trials, which will be held at Loughborough University in the Environmental Ergonomics Research Centre Laboratories, James France building.

How long will it take?

Lateral stability evaluation:	Session 1	20 minutes
	Session 2	20 minutes
	Session 3	20 minutes

You will be required to attend each session on different days.

Is there anything I need to do before the sessions?

Read through this information sheet, fill out the health screen questionnaire and sign the consent form provided.

What type of clothing should I wear?

The investigators will provide base layer clothing (various sizes) for participants to change in to for the trial itself and for all 3 sessions you are advised to wear flat shoes e.g. sports shoes.

What will I be asked to do?

Lateral stability evaluation – 3 sessions

The trial will be split into 3 sessions. In two trials, you will adopt an elevated driving position, established from prior research. In the other trial, you will adopt a benchmark driving position, based on an existing vehicle design.

The respective driving rig will be mounted on to a motion platform and participants will simply be asked to sit in a driving posture. Participants will then be subjected to differing levels of lateral motion replicating levels that are found in basic cornering whilst driving and asked to rate the sensitivity of the motion on a scale.

What personal information will be required from me?

You will need to complete a Health Screen Questionnaire, to ensure that there are no significant health problems. This questionnaire ensures that your participation in the trial will not adversely affect the results or your own health through participation. The results from this will be kept confidential along with the results from the trial itself and other personal information and will not be disclosed.

Some of your body dimensions will be measured to reference your driving posture.

Will my taking part in this study be kept confidential?

Your participation in this study will be completely confidential.

The storage of data will comply with the Data Protection Act 1998. Any video and audio recording will be kept in a secure place and will not be released for use by third parties. All video and audio recordings will be destroyed within six years of the completion of the study.

What will happen to the results of the study?

The results of the study will be owned by Loughborough University and archived. A technical paper will detail the results of the study.

What do I get for participating?

Each participant will receive a financial reward for participation:

Lateral stability evaluation (attendance at 3 sessions) - **£20**

I have some more questions who should I contact?

If you have any further questions prior to, during or after the study trials, then please contact the main investigator (contact given at the top of this document). If there is a problem contacting the main investigator then please contact the academic supervisor for the study.

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 A18

- **Lateral stability evaluation study: Participant anthropometric data and driver background information.**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Range
Gender	M	M	M	M	M	F	F	M	M	F	M	F	M	F	M	F	M	F	M	F	
Age (yrs)	24	21	55	32	26	23	29	28	28	48	22	47	27	43	27	36	27	42	40	49	
Sitting Height (mm)	897	974	904	902	799	855	915	859	933	906	908	919	976	893	903	872	855	924	901	899	177
Shoulder Width (mm)	445	495	424	456	430	372	433	500	468	405	423	411	505	487	411	439	452	411	435	441	133
Sitting Hip Width (mm)	358	411	378	429	354	344	440	419	399	385	400	425	418	383	405	408	372	421	489	407	145
Knee Height (mm)	502	578	551	503	506	480	503	544	533	448	509	524	523	494	451	478	570	534	478	522	130
Popliteal Length (mm)	451	514	465	432	470	404	450	460	472	419	458	455	511	436	367	417	481	445	422	465	147
Seat Height (mm)	430	480	450	424	399	410	403	433	445	385	414	441	493	407	393	390	459	440	415	426	108
Leg Length (mm)	991	1207	1101	985	980	874	976	1053	970	849	948	998	1179	915	875	923	1017	990	925	942	358

APPENDIX A19

- **Lateral stability evaluation study: Final seat positions for the elevated posture.**

Dimension	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Range
Heel Step (mm)	586	668	604	582	585	547	573	597	608	547	566	585	679	582	547	557	591	583	547	581	132
PH Gap (mm)	655	735	695	667	638	642	682	720	701	642	671	697	750	700	642	641	675	634	642	714	116

APPENDIX A20

- **Lateral stability evaluation study: Detailed participant verbatim for the elevated posture seats (EPS1 and EPS2).**

EPS1 Seat	How well do you feel supported by the seat?	Do you require any additional support from the seat bolsters?	How well do you feel supported by the backrest?	Do you require any additional support from the backrest bolsters?	Any further comments regarding your comfort/stability?
P1	I feel completely confident in the seat.	I fit quite well in the seat.	I feel supported in the seat.	It needs to be narrower, bolsters are quite soft.	The stability is okay.
P2	The seat base is a little too short for my legs.	Perhaps a little bit more support would be good, higher up the thigh.	Feel upright, would prefer more lumbar support.	Feels ok with the backrest bolsters.	It feels quite comfortable.
P3	It's a fairly comfortable seat.	Bolsters could be a little firmer to support me more.	Feels fine.	They are okay as they are.	It was quite comfortable, felt relatively secure.
P4	I feel secure in the seat.	It feels about right for me.	It did feel secure and comfortable.	It was good, I felt encased by the bolsters enough.	I think it is comfortable.
P5	I felt secure.	That's fine for me.	I could feel the sides.	No, any more would start to get in the way of my arms.	The seat pad feels shorter than I am used to, but quite soft and comfortable.
P6	Feels quite supportive, sides could be harder.	I would want them slightly closer to me to feel them more.	Supported well with the bolsters when tilting.	Position is fine for me.	The backrest is quite long and the headrest was above my head but feels OK
P7	It feels quite secure and good and comfortable for me.	I like to be hugged by them so would want them closer.	Felt good, but I could do with a little more lumbar support.	Again I would like to be hugged more, didn't notice them too much.	It feels OK but it could hug me more generally.
P8	It feels quite soft and comfortable.	I would like higher positions of the bolsters, to support me more.	I don't tend to sit this upright whilst I am driving – feels average.	I feel I need to feel them hugging me a bit more.	Strange and different sitting this upright, I am not used to it.
P9	I felt secure and comfortable.	The seat pad feels a little flat, more support would be good.	Slipped a little when tilting, but comfortable.	The support is fine.	I feel quite upright, feels comfortable.
P10	Feels quite good, a little firmer would be good I like a firm seat.	Probably about right for me.	Feels good for me,	Perhaps a little more support to encase me.	It's quite good, a little firmer would be good for me.

EPS1 Seat	How well do you feel supported by the seat?	Do you require any additional support from the seat bolsters?	How well do you feel supported by the backrest?	Do you require any additional support from the backrest bolsters?	Any further comments regarding your comfort/stability?
P11	Felt stable. The foam feels comfortable and soft.	Any higher would feel like bucket seats which I don't like.	Felt comfortable.	They are in a good position.	It's comfortable; I could drive this quite happily.
P12	Felt quite secure and the seat feels comfortable.	Okay for me.	I like it because it is upright.	I didn't notice them that much, but must have offered enough support.	Seat feels quite short, but I got used to it and I like being this upright.
P13	The width is small for me, felt quite flat.	Offered me good support, perhaps a little wider for me.	Good support but didn't encase me.	Felt ok, a bit more bolster support would be good.	Felt ok, could improve slightly but I felt secure.
P14	I felt like I was flying off the seat, I was not comfortable.	I didn't feel like I had any support, needed them to be right against my thighs and harder support.	I didn't have any support from the backrest when moving.	I would like to be hugged more with harder support for when I move sideways.	Generally didn't feel the shape of the seat suited my body.
P15	Felt okay for me.	The bolsters on the side of my hips needed to be harder or bigger I think.	Felt okay for me.	The bolsters were OK, didn't really feel them too much.	Tilting to the right felt more uncomfortable, don't know why.
P16	I felt stable, and it was comfortable.	A little higher/more support on the thighs was needed to be perfect.	Relatively stable, felt ok.	A little bit narrower would have given me more support which I probably needed to be perfect.	It is more upright than I am used to, but feels comfortable.
P17	Felt pretty stable.	I could have done with the bolsters coming higher up my thigh.	Backrest felt ok, quite comfortable.	They felt fine for me.	I think overall it was very comfortable; it could have been a little more rigid though, to make me feel more secure when tilting.
P18	Could do with more support on the sides, felt very comfortable though in terms of softness.	Needed more support to brace against.	Comfort was okay.	Same as the seat, something to brace against.	It's a comfortable seat.
P19	It felt comfortable, didn't move that much.	A little more support perhaps on the thighs.	Felt fine for me.	Felt okay.	I felt very comfortable.
P20	The seat was comfortable.	The sides could be raised a little higher but I felt secure for the most part.	Less stable than the seat base, maybe more support needed, something harder.	A little too close, but they could do with being harder.	Seat is a little short, but feels ok. Might be different after driving for a long time.

EPS2 Seat	How well do you feel supported by the seat?	Do you require any additional support from the seat bolsters?	How well do you feel supported by the backrest?	Do you require any additional support from the backrest bolsters?	Any further comments regarding your comfort/stability?
P1	I feel completely confident in the seat.	I'm always aware that I have room to move and I have sufficient support from the bolsters. I fit quite well and wouldn't want them closer.	Probably even more than the seat pad.	It could be slightly narrower to fit me but I like that I have freedom to move a little, room to fidget.	The stability is good, it feels fine, and my ratings are all low. As soon as you feel the bolsters you feel secure during the tilt of the platform.
P2	Relatively secure, a little too short for my legs.	No additional support is required for me.	A good lumbar support which is great as I usually get lumbar discomfort when driving.	Perfect for me, although the lumbar pushes your back forward so my shoulders aren't supported as much by the bolsters.	Slightly more comfortable than the EPS1 seat.
P3	It's nice and firm and I like a firm seat.	Feels perfectly fine.	Supported me adequately.	They are okay as they are.	Seems quite comfortable, I didn't feel unsafe and I would be happy with it.
P4	I feel secure to the seat; the texture of the material makes the posture adhere to the seat.	It feels about right for me.	It did feel quite secure. Whichever angle I was at I felt in the same position in the seat and only when it stopped did I notice some movement.	Perhaps a little bit closer to my back, inbound.	I think it is comfortable; I felt like I was stuck to it whilst moving.
P5	Feels firm and very secure.	That's fine for me.	I could feel the sides (bolsters) which helped with feeling secure.	No, any more would start to get in the way of my arms.	The seat pad feels shorter than the EPS1 seat, but that doesn't feel wrong.
P6	Feels quite supportive, ridged at the side which is good.	I wouldn't want them any further away, possibly slightly closer.	Supported well with the bolsters when tilting.	Slightly wider as my arms come in to contact with the bolsters.	I feel like my shoulders are off the backrest and not supported, the backrest is quite long and the headrest was above my head.
P7	It feels quite secure and good for me.	The bolsters are okay for my size I think but I like to be hugged by them.	Felt good, but I could do with a little more lumbar support.	They could come forward a little bit so that I felt more hugged by them.	I think this feels more secure than the EPS1. I like the material, it's soft. I would like more bolster towards the hips/buttocks on the seat pad.
P8	It felt okay; it feels harder than the EPS1 which feels more secure.	They are okay for me, perhaps a little higher as I am used to those seats.	Average, I don't tend to sit this upright whilst I am driving.	They could come forward a little more.	Strange and different sitting this upright, I am not used to it.

EPS2 Seat	How well do you feel supported by the seat?	Do you require any additional support from the seat bolsters?	How well do you feel supported by the backrest?	Do you require any additional support from the backrest bolsters?	Any further comments regarding your comfort/stability?
P9	I felt secure, it is quite rigid and firm which helps.	Feels okay but I would like the bolsters a little higher for more support, feels a little flat.	Felt secure, quite firm again and I didn't slip at all whilst tilting.	The support is fine.	Lumbar is more prominent in this seat, makes me feel higher and more upright.
P10	Feels quite firm and good.	Probably about right for me.	Feels quite good actually.	I wouldn't want any more.	It's quite a firm seat but I like it and it feels supportive.
P11	Felt stable. The foam is more rigid which made me feel more secure.	Any higher would feel like bucket seats which I don't like.	Lumbar could be slightly lower.	They are in a really good position.	It's too hard; I would prefer softer foam for longer driving.
P12	Felt quite secure, I don't mind that it's hard but wouldn't like for a long journey.	Okay for me.	I like it because it is upright, lumbar is a little too prominent for me.	I didn't notice them that much, but must have offered enough support.	Seat feels quite short, but I got used to it and I like being this upright.
P13	The width is small for me, but surprisingly felt secure and comfortable.	Offered me good support, perhaps a little wider for me.	Good support but quite rigid so it didn't encase you.	A bit more support needed further forward during the last few tilts.	Offered me more support than the EPS1 seat I think.
P14	I felt like I was flying off.	Closer to me and higher up as I didn't feel like I had any support.	I didn't feel any support from the back with the kind of movement there was.	Would be better with more support closer to me to grip the occupant more.	Generally didn't feel the shape of the seat suited my body.
P15	Felt okay for me.	The bolsters on the side of my hips could have been bigger giving more support.	Felt okay for me.	The bolsters stopped me from moving too much during the tilting.	Tilting to the right felt more uncomfortable like I was turning more.
P16	I felt very stable actually; I didn't feel like I was sliding off.	A little higher/more support on the thighs.	Stable for me.	A little bit narrower would have given me more support.	It is more upright than I am used to.
P17	Felt pretty stable.	A little higher towards to the posterior.	Yes it was fine for me.	They felt fine for me.	I think these seats would be more comfortable with a ridge in the middle, like a saddle.
P18	I have felt seats with more support around the thigh – feel pretty comfortable though.	Just a little more to curve around the thigh to brace against.	Comfort was okay.	Similar to seat base, a little more support curve around the upper shoulders to brace against.	I was aware my head wasn't resting back; it's not a bad seat.
P19	I didn't feel like I moved at all.	They were fine for me.	Felt fine for me.	They feel perfect for me.	I felt very comfortable.
P20	Fine because of the raised bolsters at the side.	They are ok for now, would need to test again after a long journey.	Less stable than the seat but general okay.	A little too close for me.	I find the front edge of the thigh slightly digging in to the underside of my thigh.