Investigation of design perception, ergonomic and structural factors influencing vehicle seat comfort

James Devlin

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for the degree of Master of Philosophy

In collaboration with Stylex Auto Products Ltd

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Candidate Declaration

I hereby declare that:

1. I have not been enrolled for another award of the University, or other academic or professional organisation, whilst undertaking my research degree.

2. None of the material contained in the thesis has been used in any other submission for an academic award.

3. I am aware of and understand the University's policy on plagiarism and certify that this thesis is my own work. The use of all published or other sources of material consulted have been properly and fully acknowledged.

The data presented in this thesis was obtained in an experiment carried out by the researcher in Sheffield Hallam University. I played a major role in the preparation and execution of the experiment, and the data analysis and interpretation are entirely my own work. Any contributions from colleagues in the collaboration, such as diagrams or calibrations, are explicitly referenced in the text.

4. The work undertaken towards the thesis has been conducted in accordance with the SHU Principles of Integrity in Research and the SHU Research Ethics Policy.

5. The word count of the thesis is 20,636.

Signature

Name	James Devlin
Award	MPhil
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Faculty	The Art, Design and Media Research Centre
Director of Studies	Mark Phillips

Are you sitting comfortably?

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Abstract

The comfort of seating in vehicles is of importance to the user; the realisation of which, is strongly influenced by design perception, ergonomic and structural factors. The objective quantification and measurement of comfort, however, is as yet to be universally agreed upon, given that it is evident from the literature that there is no ‘gold standard’ for the measurement of comfort and that its evaluation is inconsistent (Pearson, 2009). During this study, electronic databases, hand searches and internet sources were used alongside physical testing with the aim of determining a robust method of analysis for seating comfort in vehicle seating, and to understand how much perception of a seat’s comfort affects and impacts upon user experience.

Testing to investigate this question was conducted through the construction of an adjustable modular test rig which allows participants to alter specific elements of the seating geometry, namely: seat base height, seat base angle, seat back height and seat back angle. Prior to the participants engaging with the rig, a baseline position was taken from additional informal participants. The first stage of the study sees participants rating their perception of the seats comfort in the baseline position. They are then invited to sit in the seat and make any adjustments they require within the parameters listed above to find their optimal position. The second stage of the study sought to validate this by presenting the same experiment to the participants, but with the initial baseline position changed for their optimal position.

During the testing phases, participants comments were recorded alongside the empirical data from their testing, to investigate links and the effect of the objective and subjective variables upon one another. So far, the findings indicate that the perception a user has of the seat prior to sitting in it has a significant impact on the user’s experience of comfort, however, they may still opt to change the seating geometry. This suggests that the factors influencing perception are affected more strongly by appearance elements such as seating surface and cushion material than by seating geometry, however, to what extent, is not yet known.

The thesis concludes by analysing the testing methodology through a set of varied theoretical tests and improvements. These are made to allow the methodology to be applicable in a flexible manner to inform design decisions in a commercial setting resulting in improvements of occupant's experience of comfort in in vehicular seating.

Contents

Chapter One - Introduction

1.1 Background

The comfort of seating in vehicles is of importance to the user, the realisation of which is strongly influenced by design perception, ergonomic and structural factors, however, an objective quantification and measurement method of defining seating comfort is yet to be universally agreed upon. It is evident from the literature that there is no 'gold standard' for the measurement of comfort in vehicle seating. It is also apparent that the method of evaluation is inconsistent (Pearson, 2009). Electronic databases, hand searches and internet sources were used to draw this conclusion.

1.1.2 Partnering Organisation

Stylex Auto Products Ltd designs, engineers and manufactures a wide range of automotive, leisure and marine seating and trim components. As an established business, Stylex has significant depth of knowledge about seating design and manufacture, with in-house facilities including textile cutting, laminating, sewing and wrapping. In addition to this, Stylex has many organisations that it works closely with, within the aforementioned industries, allowing development beyond in-house capabilities. As demonstrated later in this thesis, Stylex have been pivotal in accessing knowledge and contacts in the industry and have assisted research and development throughout the project.

The research in this thesis comes, in part, from a 30-month Knowledge Transfer Partnership (KTP). This UK Government funded programme aims to grow companies through innovation in the form of a KTP Associate who serves as a conduit to bring new capabilities and knowledge to businesses. In this instance, the KTP was between: Innovate UK, Stylex Auto Products Ltd and Sheffield Hallam University. The KTP sought to develop the company's knowledge around seating design and comfort; initially for use in the leisure vehicle market, but as research progressed it became apparent that the findings could be applied more universally across all the industries Stylex works with.

1.1.3 Context

It is apparent from the literature that the notion of comfort and its perception commences prior to the user having physical contact with the seat, therefore, comfort can be manipulated by visual design cues (Diels et al, 2014). Diels arrived at this conclusion after conducting a study in which 18 participants (9 male, 9 female) aged 20-30, were asked to sit in two covered seats in the same room and to rate their feelings of comfort on a 7 point scale. The study was then repeated with the seats uncovered, exposing the visual design. A short interview was conducted following each test to understand the reasons for the participant's ratings. Diels ventured that due to the subjective nature of seating evaluations, much of the perception rating and interview responses were reflective of the participant. This highlights the need to understand the consumer prior to investigation to be able to assess their influence and biases on appearance factors in future studies. Diels also noted that the effect of perceived comfort based on visual appearance was considerably greater for female participants. In concert with this evidence, ergonomic factors which can be objectively measured, play a pivotal role in seating comfort as evidenced by the spending, research and subsequent advances in automotive seating technology apparent in today's vehicles as discussed by Spormann Vehicle Seat Design, Development, and Manufacturing (Spormann, A. 2014).

As shown in a Mordor Intelligence market forecast (Mordor Intelligence, 2019) the automotive interiors sector is scheduled to grow by 6.73% between 2020 and 2025. Thereby showing market-driven development of vehicle seating is a prominent driver for automotive sales but the degree to which individual factors affect, influence and interact to determine overall comfort is largely unclear to those who manufacture seating.

1.2 Introduction to the Investigation

The rationale for this investigation is to confirm some historical propositions and to create a viable method for continued research thorough the creation of an appropriate testing methodology. The research will look at the three specified areas of seating comfort: design perception, ergonomics and structural factors. This will then provide a broad insight into how a user's understanding of seating comfort is formed, which in turn be used as a basis upon which a testing methodology can be applied. The results from this testing could then be used to inform the process of vehicle seating design.

1.2.1 Aims and Objectives:

Aims

To achieve a holistic understanding of perception, human factors and structural factors influencing user comfort in vehicle seating.

To produce an adaptable testing methodology through which understanding of the three key areas of design perception, ergonomic and structural factors relating to vehicle seating comfort can be measured.

To produce a framework through which it is possible to identify knowledge of human comfort in vehicle seating. The methodology should allow for the collection of data and propositions, to form a basis for designs that can deliver higher levels of user acceptance of comfort, both experiential and perceived (prior to interaction).

Objectives

Review existing literature on ergonomics, seating design, seating posture and the impact perception of design has on the user's expectation and experience of comfort.

Investigate and understand what is meant by occupant comfort.

Analyse how perception affects these elements.

Investigate and understand how structural factors in seat design impact user experience.

Build the learning from these elements into a testing methodology that can be used in academic and commercial settings.

Chapter Two - Literature Review

2.1 Introduction

To quote Smith (2006), ‘To date, the majority of questionnaires present in the automotive seating industry have been designed using questionable developmental methods with suspect statistical rigor’. Seating comfort does not currently have a universally agreed metric and as such can be measured using an extensive variety of techniques ranging across theoretical, virtual and physical. This chapter examines the varied literature and pertinent subject matter needed to inform testing methodologies and design proposals on this topic.

2.2 Existing Research

In 1982, an attempt to convert subjective data from participants to objective data was made by Kamijo et al (1982), who gathered specific data points including static pressure distribution characteristics, static load/deflection and vibration characteristics of commercial automotive seats. These were mapped against the subjective feedback results from the participants which showed approximate correlation on static pressure distribution but no other measured parameters.

Zhang, (1996) conducted a study to identify factors of comfort and discomfort in sitting. The aim was to investigate the ‘possible multi-dimensional nature of comfort’ with a view to understanding factors associated with comfort and unifying these into a model for perception of (dis)comfort. To do this, Zhang solicited descriptors of both comfort and discomfort from 106 office workers based on their experience of seating. The different descriptors collected were validated via a questionnaire and then grouped using a similarity matrix using pairwise comparisons of all possible pairs of descriptors to produce the most reliable data. Zhang went on to propose a conceptual model of sitting comfort and discomfort shown in *figure 1*.

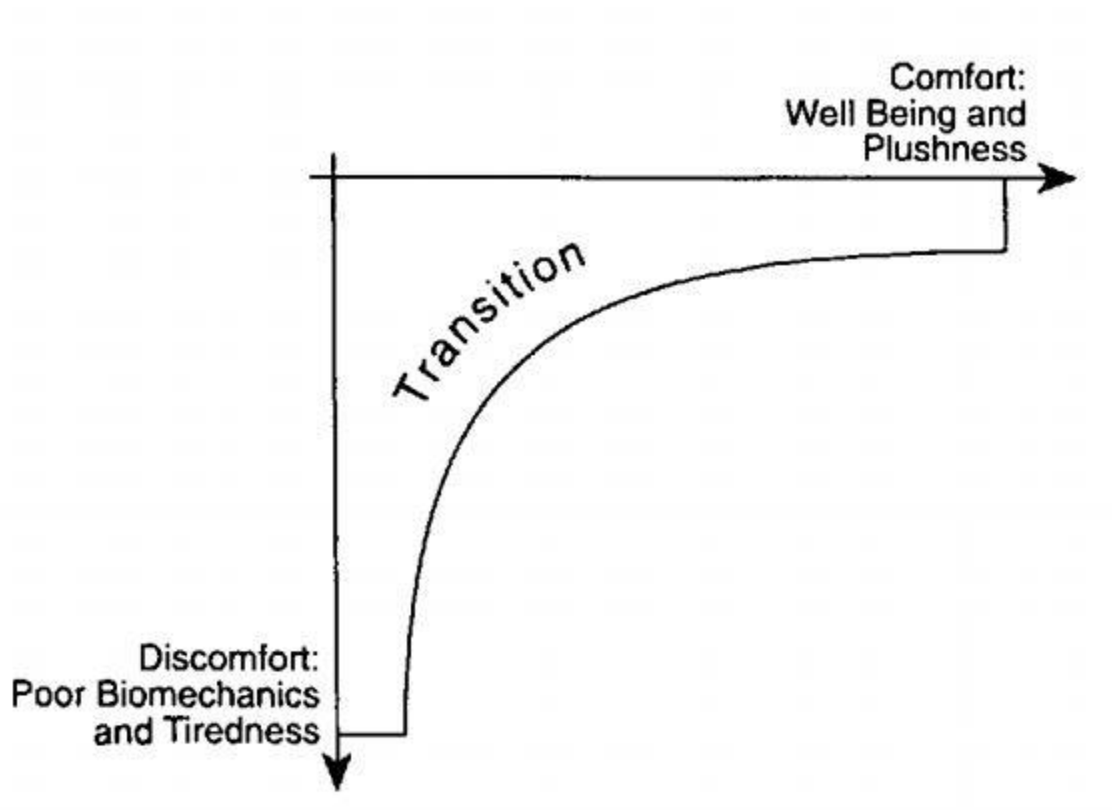


Figure 1 Conceptual model of comfort/ discomfort (Zhang, 1996)

Zhang concluded that ‘discomfort is associated with biomechanical factors such as joint angles, muscle contractions and pressure distribution that produce feelings of pain, soreness, numbness and so on’. The feelings of discomfort increase with time on task and fatigue. He commented that discomfort can be reduced through removing physical constraints, however, doing so does not necessarily produce comfort. Comfort, Zhang goes on to propose, is associated with feelings of relaxation and wellbeing which can be amplified by the aesthetic appearance of the seat or seating environment, however, unlike with discomfort, the absence of these feelings will not lead to discomfort as this requires adverse biomechanical conditions.

The above conceptual model illustrates the relationship and interaction of the two variables. Transition from one to the other is possible, for example, if discomfort is reduced comfort may be perceived and vice versa.

‘The Evaluation of Seating Comfort by the Objective Measures’ was a study carried out in 1997 by S.J. Park, where 72 male participants subjectively evaluated six automotive drivers’ seats over two periods of time. The first was an evaluation of first impressions of the seat in a non-driving environment where subjects were asked to evaluate the characteristics of the seat. The second was in a two-hour driving test where the subjects were asked to evaluate body discomfort. Discomfort was measured by providing the participants with a visual body map with specific body parts highlighted. Each area required the subject to rate their discomfort from 1 to 5. During these tests, body pressure distribution was also measured to give objective data which was then compared to the subject's feedback. It was found that there was a strong correlation between pressure distribution and the subjects' feelings of comfort; it was also noted that the seat with the best ratings of comfort demonstrated a symmetrical pressure map. Park went on to state that according to the results, it was statistically significant that overall seat comfort is related to the pressure ratio of hip and lumbar regions.

In a similar and complementary study entitled 'Evaluating Short and Long Term Seating Comfort', participants from Johnson Controls, a major automotive seat designer and manufacturer, were involved in a study comparing subjective assessments of short and long duration sitting comfort (Thakurta et al, 1995). Thirty six subjects evaluated five cars each over an 80-mile highway drive. Participants completed a comfort assessment questionnaire and were pressure mapped before and after the drive. Analysis was then conducted to compare the subjective results and the pressure maps over several defined areas of the body including the shoulders, lumbar, ischial tuberosity and thighs.

The study showed peak loading in the ischial tuberosity (protruding bones in the buttocks) region and reduced loading in other areas, but concluded that there was a nonlinear relationship between pressure and body part. They further concluded that the nonlinear relationship could be used as a model to define the way the body and the seat interact, suggesting that interaction between the variables is the key to occupant comfort. They go on to postulate that using only one factor may lead to incomplete conclusions about occupant - seating comfort. More research, they say, is needed to understand the complexity of the data.

2.2.1 Design Perception

A key factor affecting comfort that is particularly difficult to measure is perception, due to its subjective nature. Many papers have pointed out the limitations in subjective ratings in ergonomic studies of comfort but no definitive solutions have been identified (Maurin & Wang, 2013). In an article utilising such a subjective rating scale it was revealed that the most comfortable perceived posture for train seating was a more upright posture with the seat in whole body contact (Hiemstra-van Mastrigt, 2014). This article showed the benefits of using such a scale as a means to broadly analyse participants feedback and provides justification for the scales continued use.

The perception of an automotive seat's design was the subject of Erol's study (Erol, 2014), causing him to make the remark, 'When we consider seat design to offer optimal physical support, the differences between the perceptions of seat comfort can be manipulated solely by visual design cues rather than manipulating the physical structure of the seat'. He then goes on to reference Kolich(2008) who states that this proves that customers operate with an aesthetic bias, as investigated in his study that attempted to formulate the approach of measuring seating comfort.

A key publication by Sigrid van Veen and Peter Vink in 2006 investigated whether prior experience has an influence on the rating of seating comfort. The investigation focused on the influence of a sitting precondition on ratings of comfort over three points: first impressions, short-term comfort and discomfort. The study's aim was to assess the 25 participants to determine how sensations experienced prior to product use affected product evaluation.

Unlike many other studies, van Veen and Vink ensured that the participants were tested over two days at the same time of day to ensure consistency in results as it has been proven in a 2014 study by Bazley that people experience comfort changes throughout the day. The study's method was to desensitise participants to outside influences by having them sit in a chair in the same environment as they were to experience the seat which they were told they would be evaluating. The purpose was to remove the influence of previous activities and to desensitise them to the effects of the immediate environment. The participants were told that in the two sessions they would evaluate two different car seats, both of which were covered in a sheet to avoid any aesthetic bias. However, the experiment was actually conducted with the same car seat in both tests, but the initial seat was changed between a soft armchair and a wooden stool for which the order was changed systematically.

After answering questions on age, height, weight, how they got to the study and if they were experiencing any discomfort, participants were then asked to sit on the first seat (preconditioned) for 10 minutes and then to rate their discomfort again. They were then moved to the car seat and asked to evaluate their comfort after 30 seconds for first impressions and after 10 minutes, each evaluation was rated on a 9-point Likert scale (Rabe-Hesketh and Skrondal, 2010) and participants had the opportunity to describe their feelings with terms such as ‘I feel relaxed’ and ‘the chair is soft’ etc.

The results of the study showed little difference across the majority of attributes for both lengths of time. The only notable difference between the two tests was that participants reported higher levels of ‘softness’ when they had been preconditioned with the hard wooden stool. van Veen and Vink (2016) postulated that softness or ‘product tactility’ could be better evaluated after an uncomfortable precondition but stated that more research is needed to support his hypothesis.

In an interview conducted by Steve Snook (2003) with Andreas Wlasak the Director of Design at Johnson Controls European Advanced Product Design Studio, Wlasak stated that a critical design task is to seat four or five people in a smaller space. Wlasak went on to say that each centimetre that can be taken out of the seat is a big advantage in terms of achieving functionality and creating the perception that the customer is getting a 'grown up' car. This is an insightful statement as it could be inferred that the increase in space in the vehicle, afforded by way of reducing seat system volume, has a positive effect on the customers experience and thus a positive impact on their seating experience. His use of the term ‘grown up’ in context infers that the vehicle appears modern in its design and aesthetic. Wlaskak finished his thought by saying ‘It is an easy task to reduce seat volume at the expense of comfort, but this is not usually acceptable. After all, seats are meant to be sat in and drivers spend increasing periods doing just that.’ This second statement sheds a different light on his previous comment and suggests that the two elements of environmental perception and seating experience are separate, but still linked, and that one should not be sacrificed for the other.

This poses the question whether in a fixed vehicle size there is an optimum balance of seating volume versus 'free' interior space. This might be investigated by contrasting the needs and demands of ergonomics with psychological necessities and desires. It is also worth making the argument here that this question may be overly reductive due to the range of needs in both aforementioned realms of users combined with their subjective preferences.

These studies demonstrate that the user's design perception is a key factor in comfort experience and is already a consideration that the industry takes account of in the design of vehicular seating systems and seating environments.

2.2.2 Ergonomic Factors

One factor preventing the scientific community from a common 'comfort metric', noted in Gordon's 2012 paper on anthropometric change, is that there has been a growing obesity epidemic. The percentage of obese males in the US has risen from 10.7% in 1962 to 31.3% in 2006, which has a significant ergonomic impact on seating design and experienced comfort. Comparatively, this figure is estimated to be 35% based on studies conducted in 2014 (Flegal KM, 2015) meaning comfort measurement (and therefore optimal seating development) is not a static target. The transformation in the population's physical makeup acts as a 'shifting goalpost' for quantifying comfort in seating applications and the translation of this into a defined metric.

A 2012 study (Vincent et al, 2012) sought to analyse a set of variables from the study group and to use these to create accurate predictions of seat comfort based on participant ergonomics. The study sought to map the subjective seat comfort data from 30 participants to various measurements including participant anthropometrics and demographic characteristics and the objective pressure distribution at the body-seat interface along with different foam properties. The participants were asked to sit in the same seat eight times under four different configurations and to rate their comfort on a 5-point digital scale, from -2 which indicated 'very uncomfortable', to +2 for 'very comfortable'. Meanwhile, the seat base and back were being pressure mapped to gather objective data simultaneously; this was then mapped against participant data such as weight and height.

The different foam properties used showed a large effect on the subjective experience of comfort, the most significant factor of which was the indentation load characteristic (ILD), which is the measurement of load from foam when a specific sample size is compressed to a quarter of its natural thickness by a 50 square inch circular indenter. However, the anthropometric data was not found to have a significant impact on the results of the study although it did contribute to predicting average and maximum pressures on the seat cushion. The study also suggested that the seat back pressure has a significant influence on overall seat comfort and as with Park's 1997 study, a symmetrical pressure map received the highest comfort ratings.

One topic bridging the gap between ergonomic factors and comfort perception is analysing how sensitive the body is to pressure, which is a key element in the physical experience of comfort. This theme was investigated in 2016 by Peter Vink in an article called 'Sensitivity of the human back and buttocks: The missing link in comfort seat design'. The purpose of the study was to understand how sensitive different areas of the body were to the dimensions of the base and backrest of a vehicle seat to inform a theoretical guide for seat construction in relation to softness/flexibility of materials and components used.

To do this, a rig was created around a seat whereby a cylinder of 20mm diameter was slowly pushed into different locations on the seat until the participant reported that they were no longer comfortable. The pressure at the point where the participant indicated their discomfort was noted.

23 participants were selected for the study with ages ranging from 19 to 54, 8 female and 15 male each of whom had weight, body height, shoulder width, shoulder-buttocks height, lower and upper leg length measured. Participants were asked to wear just one layer of fabric between themselves and the seat, plus underwear. The participants were asked to sit in the seat represented below.

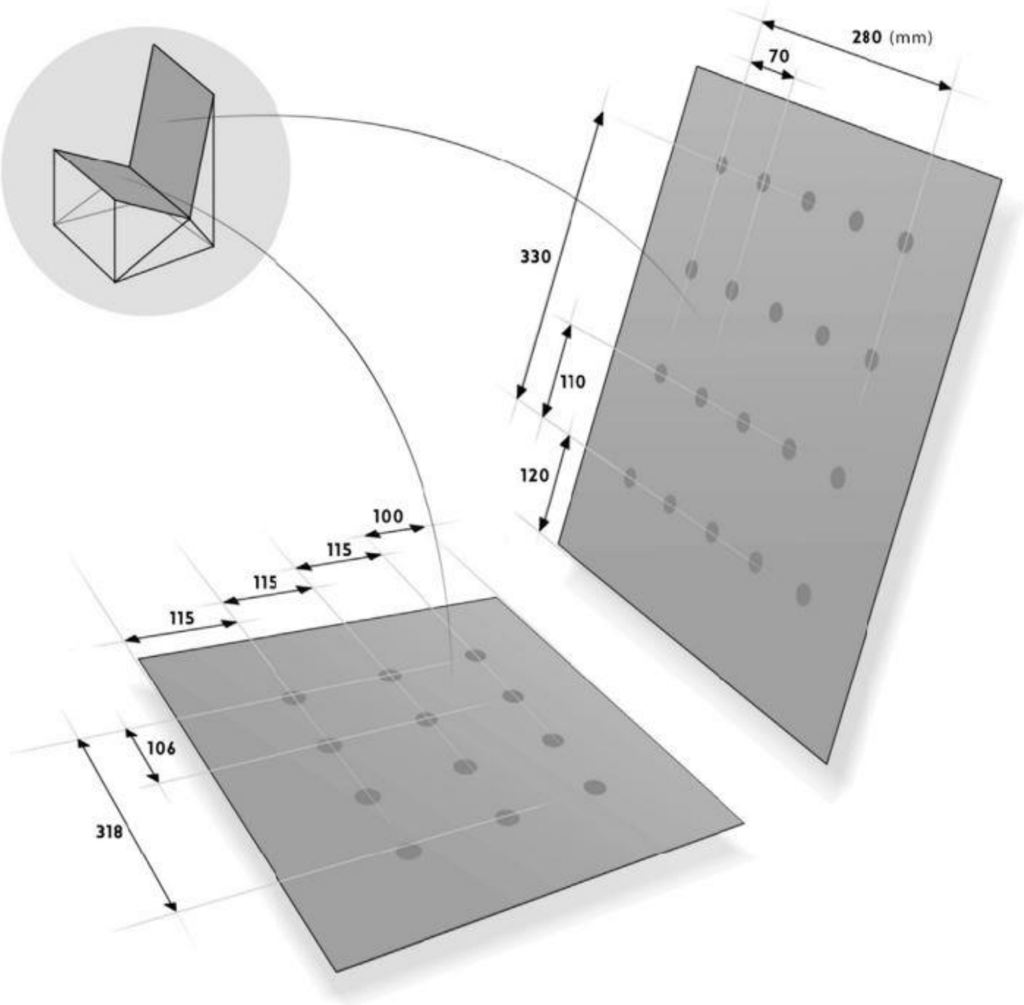


Figure 2 – Test rig with apertures for comfort pressure measurement (Vink, 2016)

As described previously, a cylinder was inserted into each aperture three times and pressure measured when it reached the point of discomfort for each participant. The results were then calculated and made comparable by dividing all back values for one participant by the average pressure value for the back, the same process was followed to give a value for the buttocks. Average values and standard deviations were calculated for each point and a formula developed which took each point and compared it with the four immediately adjacent points. Subsequently a t-test for paired samples was performed to check whether these differences were statistically significant ($p < 0.05$). Correlations were also calculated to investigate the relationship between sensitivity and BMI, sensitivity and age and sensitivity and obesity. Sensitivity and hip and shoulder width were also calculated due to these dimensions affecting pressure, as wider hips and shoulders are able to spread pressure over a greater area.

The key results of the study are helpfully summarised by the image in figure 3.

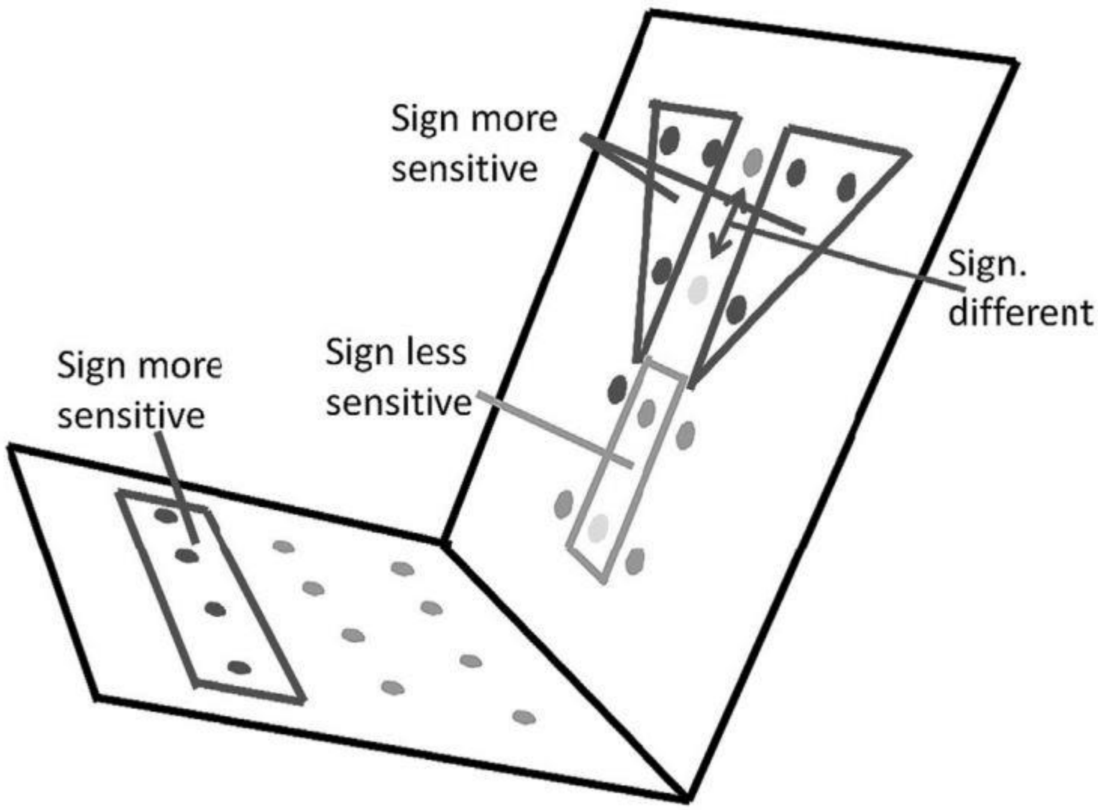


Figure 3 – Areas of differing sensitivity (Vink, 2016)

The areas with no results are those which could not be reached on all participants, however, on the 15 which could, showed no significant differences between participants.

A key result not shown through the above figure is that there was a significant difference between male and female participants, with females showing higher sensitivity values, however, all other measured correlations listed above showed little to no correlation.

As part of the discussion, Vink references Zenk et al (2012) and Hartung (2006) who suggest that pressure on the front element of the seat base where sensitivity is high should be around 6% of the total pressure on the seat; higher levels of pressure here increases occupant discomfort. Whereas less sensitive areas, further back on the seat, can tolerate pressures greater than 10%, especially the areas surrounding the ischiadicus tuberositas which can bear up to 50-65% of the load.

Brosh and Arcan (2000) showed stiffness of the seat, peak contact stresses and internal body stresses all substantially decrease during the process of sitting down meaning that creating a design based on this data could be ignoring the complete use of the seat.

Referencing himself, Vink also poses the point that seat aesthetics play an important role in seated comfort for the first 40 minutes whereafter physical contact has greater importance.

2.2.3 Structural Factors

Research in this area has primarily focussed on the reduction of discomfort, as opposed to achieving an optimised level of comfort (Erol T, 2014). Helander (2003) suggested that rather than comfort and discomfort being at two ends of a scale, they are separate, distinct experiences and are experienced in dissimilar ways. In a 2005 paper, Vink concluded that discomfort was more related to physical characteristics, whereas comfort was more related to experience, emotion, unexpected features, and luxury. Therefore, the causes and mitigating factors for each may well be different.

This can be shown as a theoretical model proposed by De Looze et al (2003) as pictured in *Figure 4.*

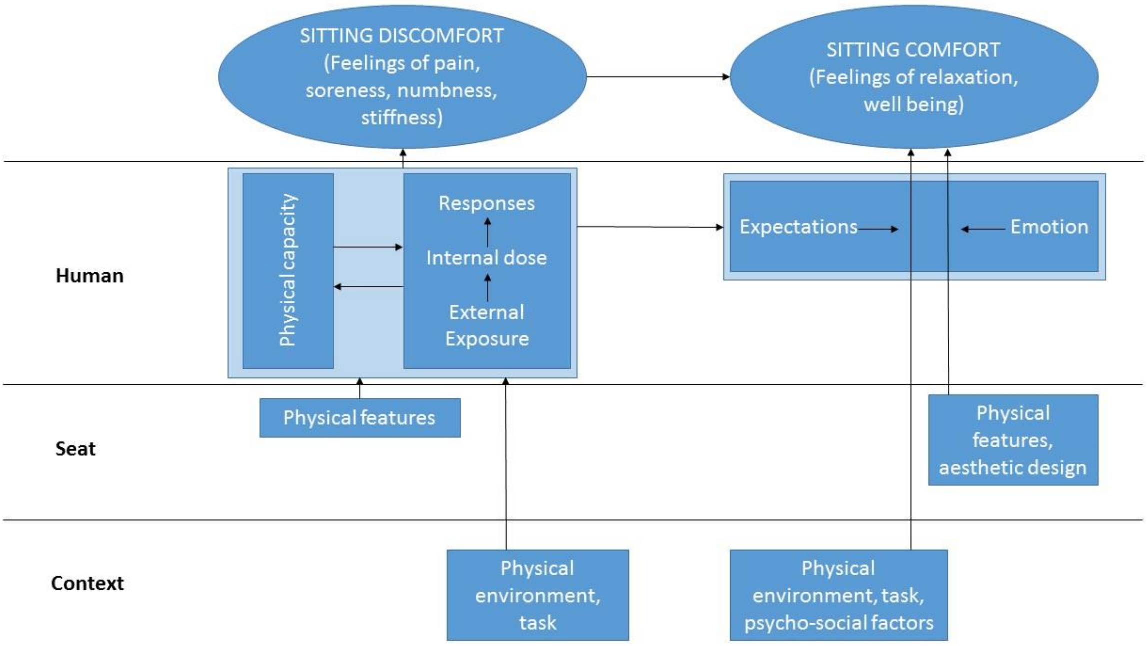


Figure 4 – De Looze's Theoretical model of comfort (2003)

Figure 4 represents the duality of (dis)comfort but bridges the gap between the two that we are experientially aware that exist. In this context, the term exposure relates to the external factors producing the individual's internal experience which is referred to as the 'dose'. The level and type of response to the dose is then subjective to the individual (Armstrong et al, 1993).

A 2003 study evaluated the performance of suspension seats under high magnitude vibration excitations (Rakheja et al, 2003). This was done by taking measurements from a wide range of environments and preloads on a suspended seat model, the environmental influencers such as vibrations were modelled on different vehicles such as buses and construction machinery. The study did not appear to draw conclusions beyond that the model created for the study was a valuable tool in simulating and assessing 'suspension performance under high magnitude excitations that induce repetitive impacts with motion limiting buffers'.

Examining structural factors in seating cannot be done thoroughly without considering foam composition. A study conducted in 2008 by Hiroshi Wada et al created a novel polypropylene glycol foam. They state that 'automotive seating foams were desired to have low resilience with keeping the low transmissibility at 6 Hz. Riding comfort mainly consists of three factors such as static property, dynamic property and durability'. The study also verified that the transmissibility at resonant frequency of the foam can be adjusted by changing the ratio of closed cells in the foam. The study found that the three elements of riding comfort in foams 'static property, dynamic property and durability' could be improved by reducing the number of monools (by-products) in the polypropylene glycol which increases the foam density and number of crosslinks. The ability to adjust the ratio of closed cells throughout the foam allows for the tuning and mitigation of transmissibility at resonant frequency.

In a study involving 12 subjects with extension-related lower back pain, Curran et al (2014) concluded that having the seat base angled forward resulted in greater discomfort both locally in the back and as an overall metric of body discomfort, as opposed to a flat seat base. The test was conducted using seats with and without a backrest. In this test, discomfort was measured subjectively by asking the participants to rate their discomfort on a 0-5 scale where 0 was 'no discomfort' and 5 was 'extreme discomfort'. Lower back discomfort and overall body discomfort were measured separately. The scale was applied to different areas of the body so that participants could record discomfort in 12 different areas of the body. The overall body discomfort score was recorded as a mean discomfort of the 12 body area scores. This investigation demonstrates that forward inclined seat bases have a detrimental effect to comfort for the specific subgroup of users with extension related lower back pain.

Within the realm of ergonomics, a key question was put by Andrew P Claus as the title of his 2009 paper, 'is 'ideal' sitting posture real?'; Measurement of spinal curves in four sitting postures. The study focused on the surface curvature of the spine and sought to understand if participants could imitate clinically 'ideal' directions of spinal curve in the lower back.

The curvature of participants' backs was measured by adhering 3D motion sensors to the skin so that the curvature could be translated into angles made by lines between the sensor's positions. The participants were asked to imitate pictures of people sitting in different positions and were then helped verbally and physically to reach the position. Measurements were taken in four different positions: slumped, flat, long lordosis and short lordosis. The lordosis is the curve at the base of the back often referred to as the small of the back; in this instance, long and short relate to the length of the back through which the curvature is evident, as defined in figure 5

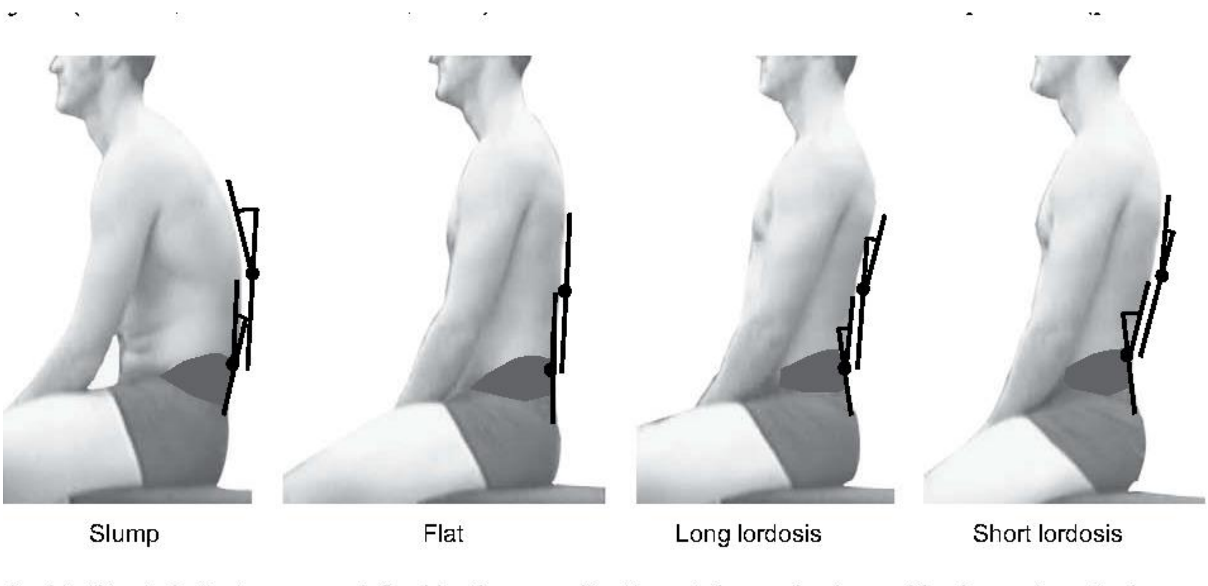


Figure 5 – Visual representation of sitting positions (Claus, Hides, Moseley and Hodges, 2009)

It was found that participants found it most difficult to replicate the short lordosis position with no participant able to do this from visual and verbal assistance alone, intimating that it was not a natural position for any participant to adopt while sitting.

Applying this to the idea of an optimum sitting position, it was noted that kyphosed (curved lumbar) position requires less muscle activity than upright postures, however, it may cause greater stress to articular and ligamentous structures. Upright lumbar positions, such as the long and short lordosis and flat positions, are around the mid position for lumbar joints and avoid end range stresses to ligaments - they are prone to bend, twist and shear.

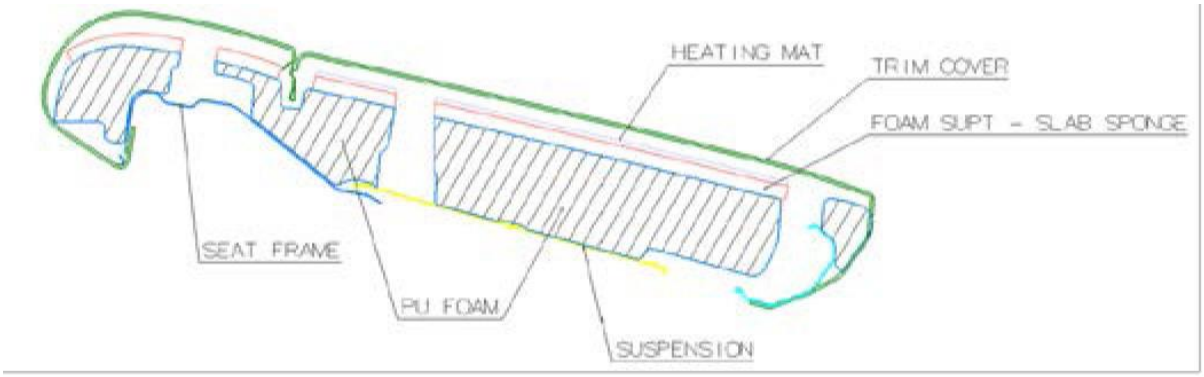
Although this test was inconclusive it was noted that the flat and long lordosis sitting positions are the most intuitive.

In 2016 Se Jin Park et al conducted an investigation into a method of reducing the amount of vibration that reaches the vehicle occupant by introducing a 'double walled 3D air-mat' in cushion into the seating system.

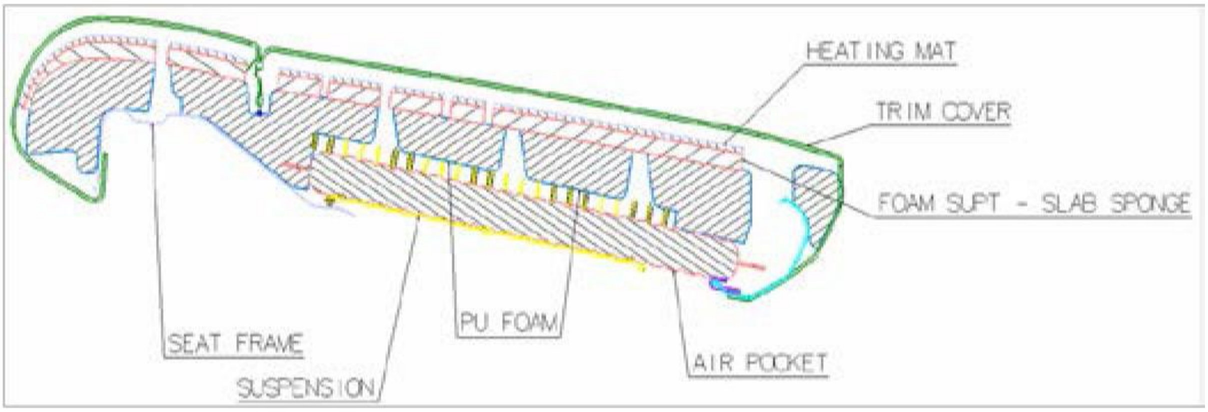
Park states that over long duration rides, vibration can cause muscle fatigue, back pain and other related injuries. The type of vibration experienced in vehicle transportation environments is whole body vibration which can come through the seat base, backrest and floor. Park states that reducing this exposure to vibration is one of the most significant ways to improve ride quality. Park also notes that another relevant physiological factor that has been shown to increase user comfort is uniformity of pressure distribution, especially around the hip area where it has been statistically correlated to local discomfort.

To evaluate the newly developed seating technology, a study was set up in two parts. The first part of the study saw three participants of body weights: 45kg, 70kg and 80kg, sitting in two seats, one with and one without the 'air-mat', for 5 minute periods while vibrations taken from a road profile were transmitted through the seat from a floor mounted actuator while the vertical accelerations were measured. The angles of the seat base and backrest were unchanged between participants and the pressure between the seat and participant were measured when subjects sat on the seats for 1 minute.

Figure 6 shows a section view of the two seats used in the test.



(a) Current Seat



(b) Newly Developed Seat

Figure 6 – Section view of 'current seat' vs seat with 'air mat' (Park, 2016)

The second study saw the developed seat installed in a car to perform road tests to evaluate ride comfort. Again, accelerometers were used to measure vertical accelerations. The subjects each had one run of 5 minutes driving the vehicle at an average speed of 90km/h, as with the first study the seat base and backrest angles were the same for all participants as was the air pressure inside the air pocket which was 0.027MPa.

The results from both studies were analysed, study one found that both the current seat and the development seat had root mean square values (RMS) of acceleration under 0.315m/s^2, which is the comfort level proposed in ISO 2631-1 (International Organisation of Standardization, 1997).

These were calculated as follows:

'Biometic DataLOG (model: MWX8; 8 channels) was used to collect the data from the accelerometers. Vibration Analysis Toolset (VATs) was used for time domain analysis of acquired acceleration data. The acceleration time histories were sampled at a rate of 500 Hz. Fourier analysis was performed using an FFT block size of 1024 points and a Hanning window. The band limiting filters (high pass at 0.1 Hz and low pass at 250 Hz) were used

with frequency weighting as recommended by ISO 2631-1 [4]. The whole-body vibration exposure parameters were calculated after applying weighting filters as per ISO 2631-1'

$$\mathrm{RMS}(m/s^2) = \left[\frac{1}{T}\int_0^T a^2(t)dt\right]^{\frac{1}{2}}$$

However, the weighted RMS values of the development seat were lower that for the current seat for all participants showing that the development seat isolated the user from vibration more effectively resulting in superior ride comfort as shown below.

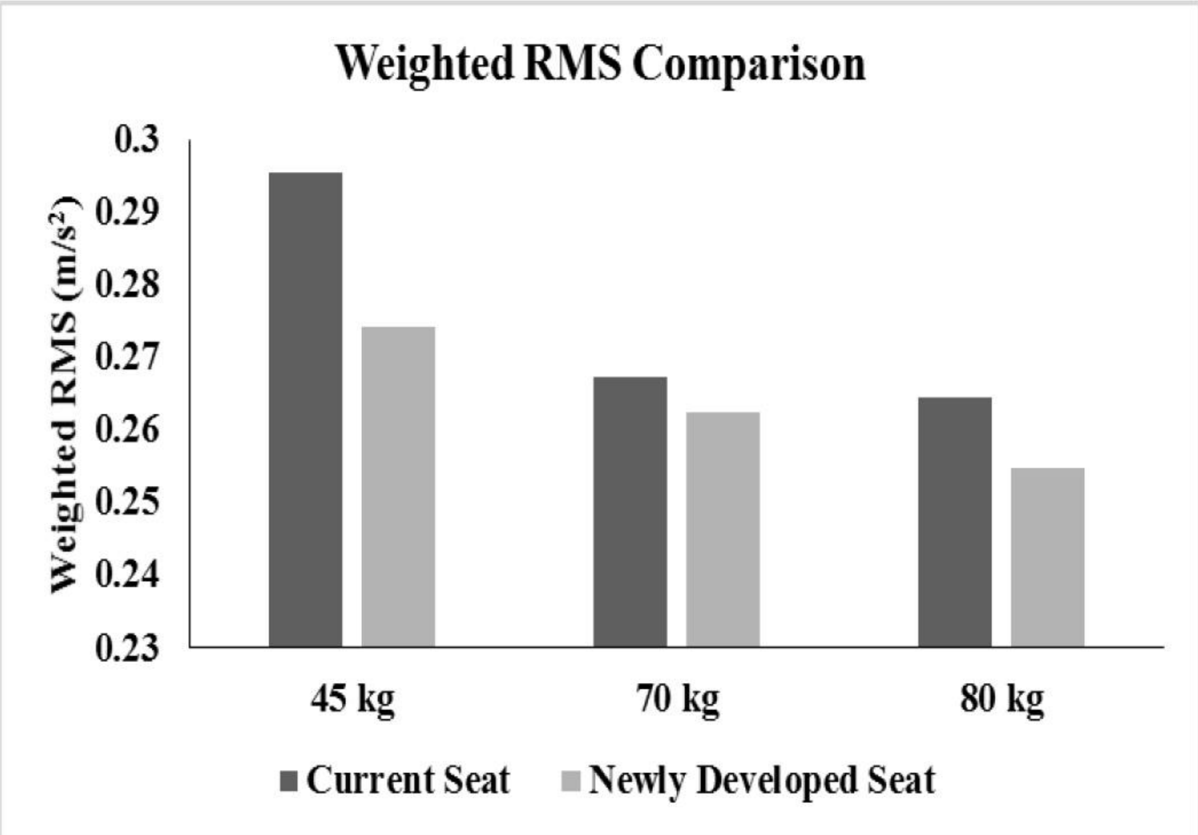


Figure 7 – Weighted RMS values for participants in current and newly developed seat (Park, 2016)

Another influential factor mentioned by Park, was the average pressure. Park casually mentions while discussing this point that pressure tolerance varies from person to person, but a threshold value of 0.427N/cm^2 has been used in past studies. This threshold value is the capillary pressure in the blood vessels which should not be exceeded. Both seats had average pressure values lower than the threshold value, but the development seat was the lower of the two resulting in a theoretically greater level of seating comfort; as shown in figure 8.

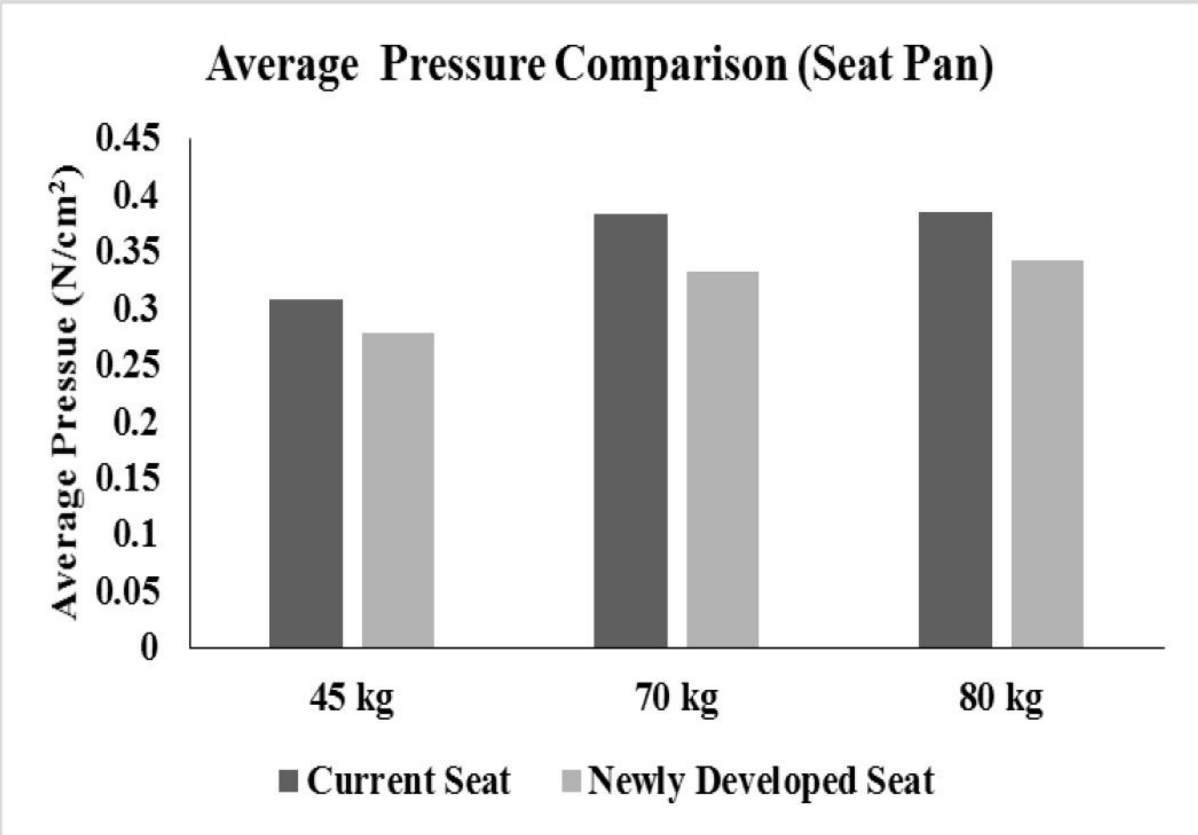


Figure 8 – Average pressure comparison for seat pan for differently weighted users between current and development seat (Park, 2016)

The second study looked into the whole-body vibration metric as measured while the participant drove on the roads. It was noted through the analysis of data that there was a decreasing trend of weighted RMS values observed when subject weight increased suggesting that different air pressure levels may be needed based on occupant weight. Results are shown in figure 9.

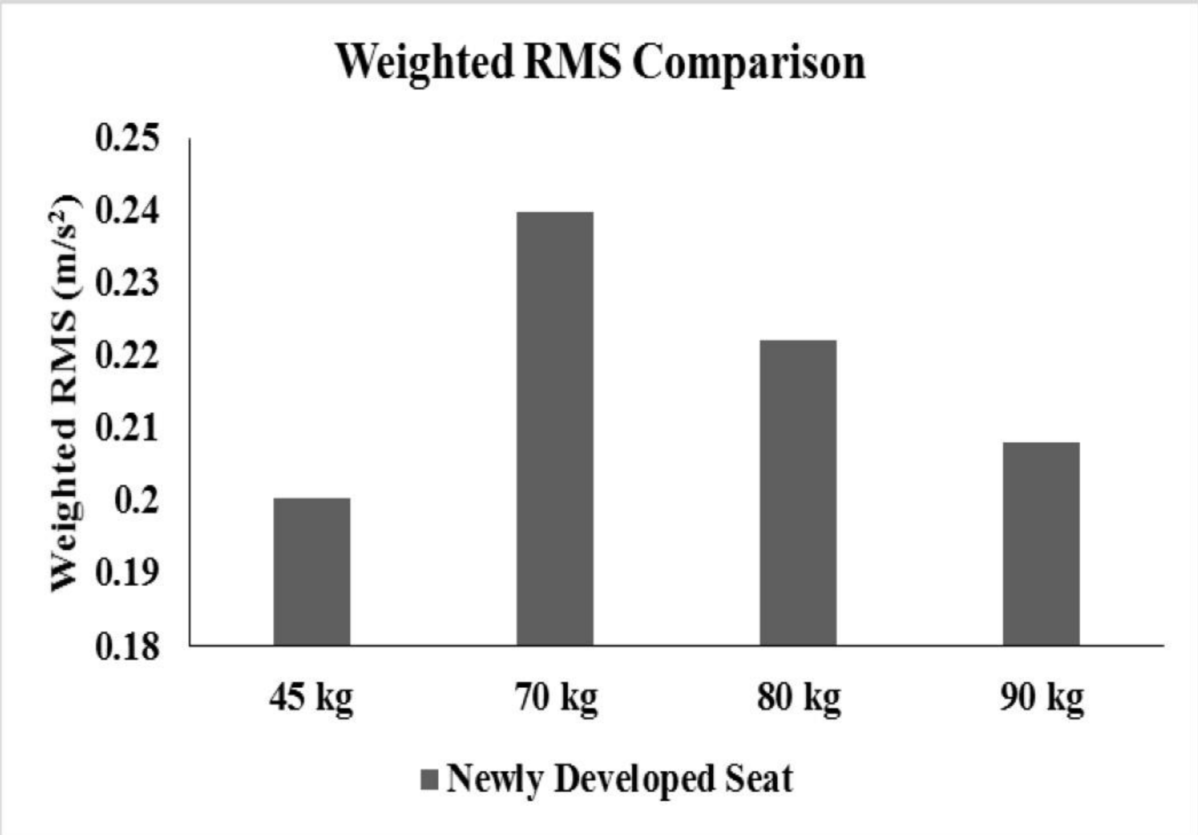


Figure 9 – Weighted RMS for whole body vibration vs participant weight for development seat (Park, 2016)

This paper evaluates the effects on occupant comfort for a newly developed 'double wall air-mat' seat cushion system against the current experience of occupant comfort afforded by current automotive seating. The studies show that the development seat reduced the amount of vibration exposure of the occupant and also reduces the peak interface pressure, resulting in theoretically increased occupant comfort. The study also suggests that varying air pressures based on occupant weight would yield an optimum pressure at which the occupant would experience greater seating comfort, however, this was not been studied.

In an insightful paper published in 2013, Singh linked the appearance of an automotive seat to the ergonomic factors and the perception of seated comfort by discussing the use of different types of upholstery fabric.

Singh starts his paper by discussing seating comfort as a subjective personal experience and that a seat that is perceived to be comfortable for one person may not be comfortable to another. He continues by saying that the notion of comfort is a relative one, in that it cannot be defined in isolation, only in relation to the experience of another seat.

To address this topic, Singh focused on seat surface grip, in other words friction produced by the upholstery fabric, stating that either too little or too much detracts from the occupant's feelings of comfort. The 'grip' of a fabric is proportional to the friction between it and the surface it is touching; the friction is defined by the coefficient of friction of the fabric. In relation to the feeling of grip on a fabric, Singh states that through first-hand analysis he notices 'discreet and prominent feeling difference' compared to variable density.

To investigate the effects of this, an experiment was designed to test the lamination layer the fabric is attached to with the goal of optimizing this variable. Lamination layer thicknesses were selected based on availability, manufacturability, trim development and assembly constraints with the same density; all samples were PU foams. These samples were then all topped with the same plain-woven top fabric to eliminate the psychological effect of colour and texture. The sample lamination thicknesses were 1mm, 3mm, 5mm, 7mm, 9mm and a non-laminated control was also included. The samples were then trimmed onto identical seats so that the only variable was the lamination thickness and the evaluations were done at one time over a single session so that environmental factors were consistent allowing for comparison of results.

Results were collected through the use of a subjective evaluation form asking participants to rate their experience from 0.0-5.0 over three areas: 1. Seat fabric feel, 2. Seat fabric grip, 3. Overall seat comfort. Subjects were selected from a wide spectrum of the vehicle using population to be as representative as possible. The breakdown of anthropometric data for the participants in the study is shown in figure 10.

	Weight (Kg)	Male %	Female %	Total Population %
1	40-50	6.66	6.66	13.32
2	50-60	13.32	6.66	19.98
3	60-70	19.98	13.32	33.3
4	70-80	13.32	6.66	19.98
5	80-90	13.32	….	13.32
	Height (Cm)	**Male %**	**Female %**	**Total Population %**
1	150-160	13.32	6.66	19.98
2	160-170	26.64	13.32	39.96
3	170-180	19.98	6.66	26.64
4	180-190	6.66	6.66	13.32

Figure 10 – Anthropometric data of participants (Singh, 2013)

The participants undertook subjective and objective comfort evaluation in a static vehicle condition. The study was conducted blind, so the subjects did not know what changes were made between seats. For the subjective evaluation of the seats, the participants were asked to undergo a pattern of predefined seated positions and movements shown in figure 11.

Sequence	Sitting / Movement Pattern	Measurement
1	Ingress / Egress (10 seconds interval per cycle)	10 cycles
2	Normal sitting	15 minutes
3	Steering wheel operation (both sides)	20 cycles
4	Pedal Pressing (all 3 pedals)	10 cycles
5	RH rearward turning (10 seconds interval per cycle)	10 cycles
6	LH rearward turning (10 seconds interval per cycle)	10 cycles

Figure 11 – Activities conducted by participants (Singh, 2013)

The results of this element of the study are shown in figure 5 relating to fabric feel.

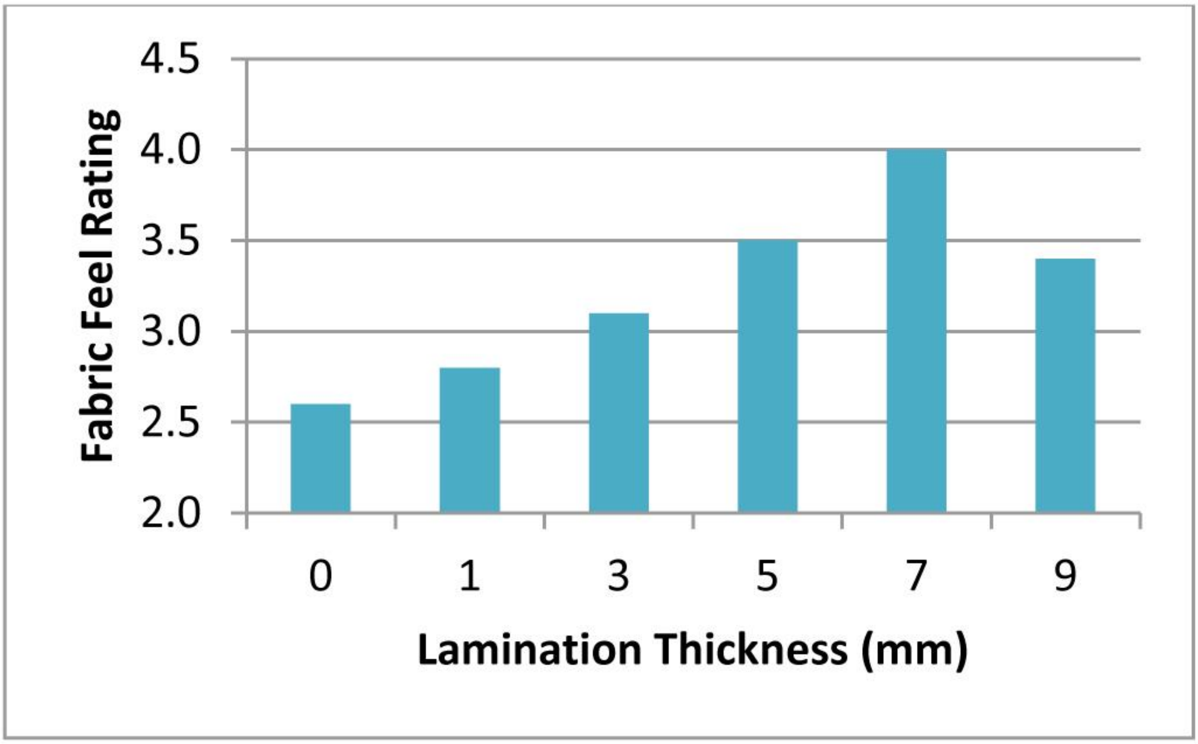


Figure 12 – Fabric feel rating vs lamination thickness (Singh, 2013)

The results of this test show that the effects of increasing lamination thickness are positive up until the 7mm peak and then start to decline.

Fabric feel was also analysed in relation to occupant weight. The fabric analysed was the 7mm laminated fabric on account of the higher comfort rating from the previous part of the test. It was found that the higher the weight of the occupant the higher their feeling of comfort in relation to fabric-feel for the 7mm lamination thickness as shown in figure 13.

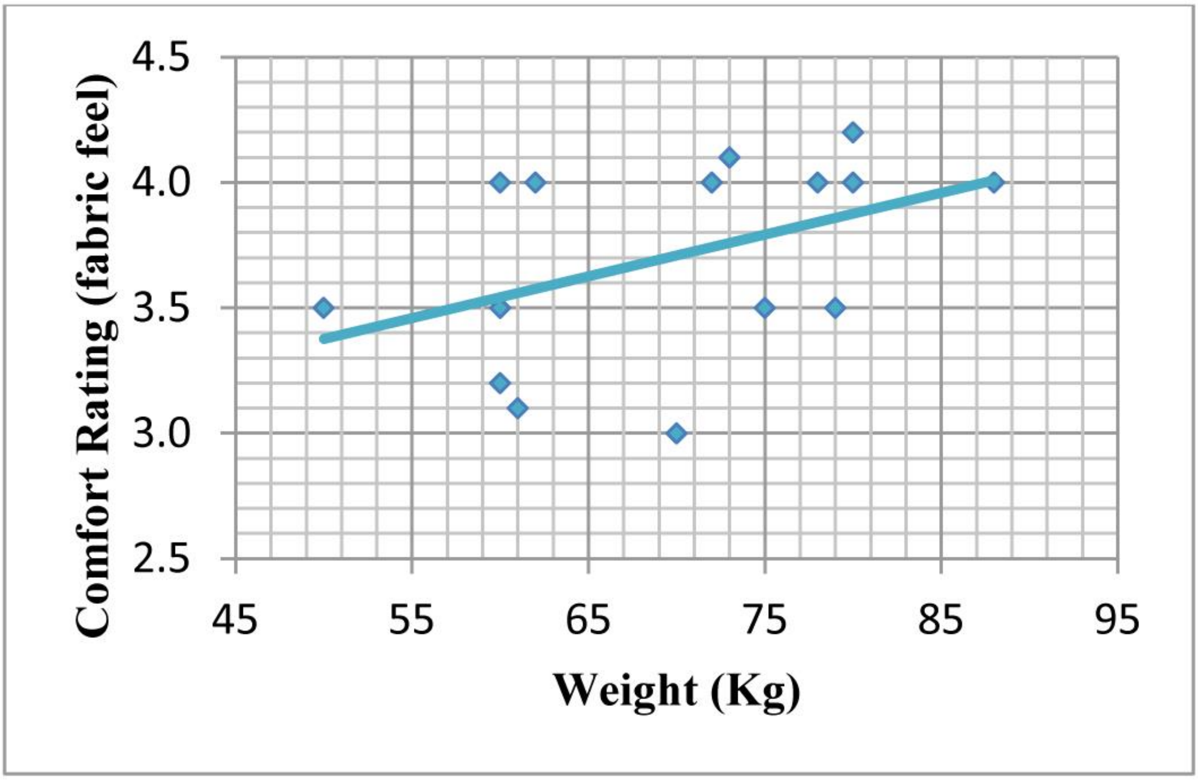


Figure 13 – Occupant weight vs subjective comfort rating for fabric feel (Singh, 2013)

Data was also analysed for overall seat comfort in relation to differing thicknesses of lamination. The results are shown in figure 7. The pattern of the data is very similar to the results from fabric feel versus lamination thickness in figure 5. The reason for this was revealed through the comments of the subjects who said that above 7mm the fabric grip was so high that it hampered subject ingress/egress and their ability to move while seated which detracted from the overall comfort of the seat. It was also stated that above 7mm lamination the seat began to look bulky and the amount of foam lamination started to hide seat contours meaning the seat appeared less comfortable to the participants.

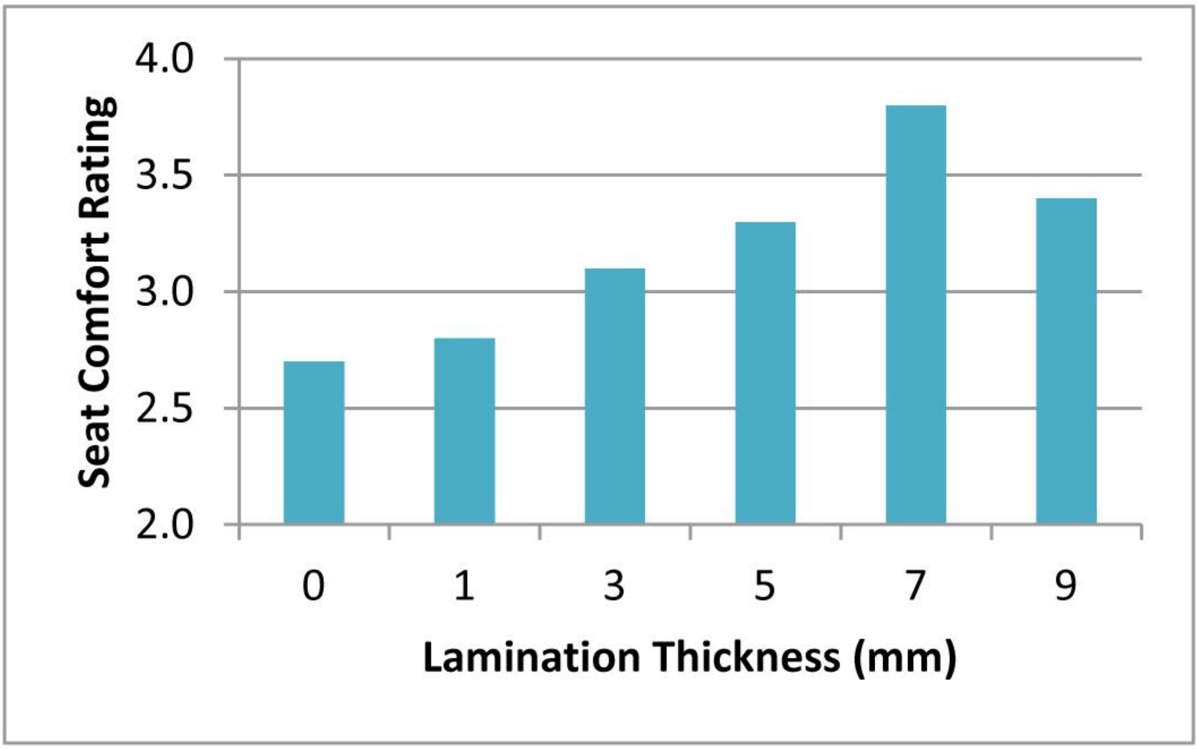
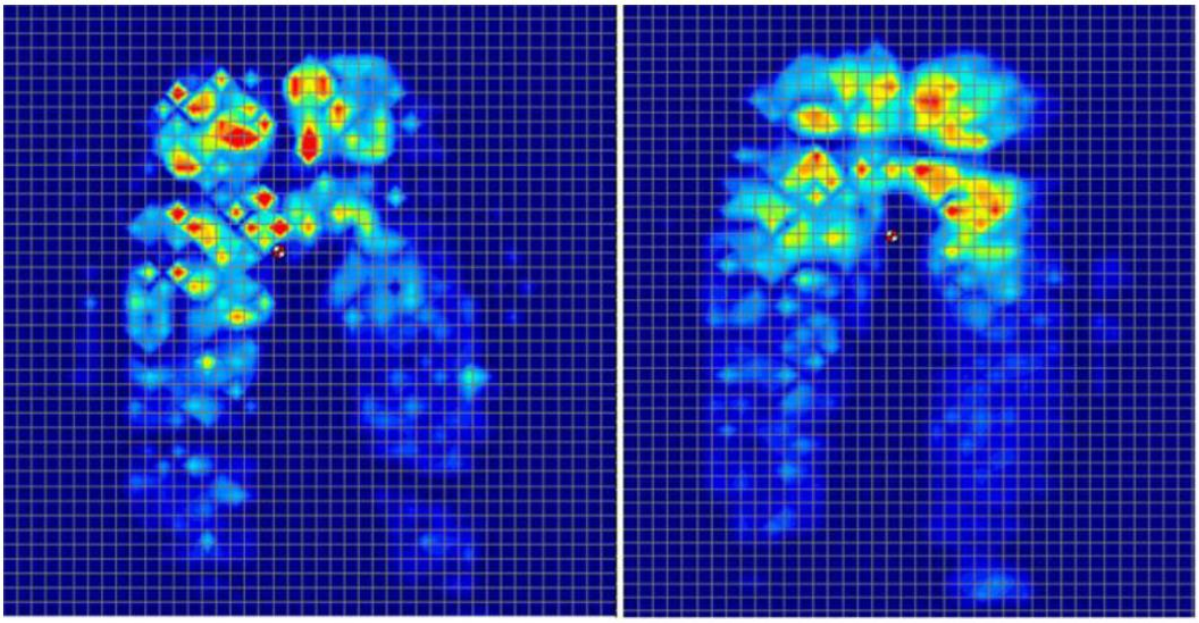


Figure 14 – Lamination thickness vs seat comfort rating (Singh, 2013)

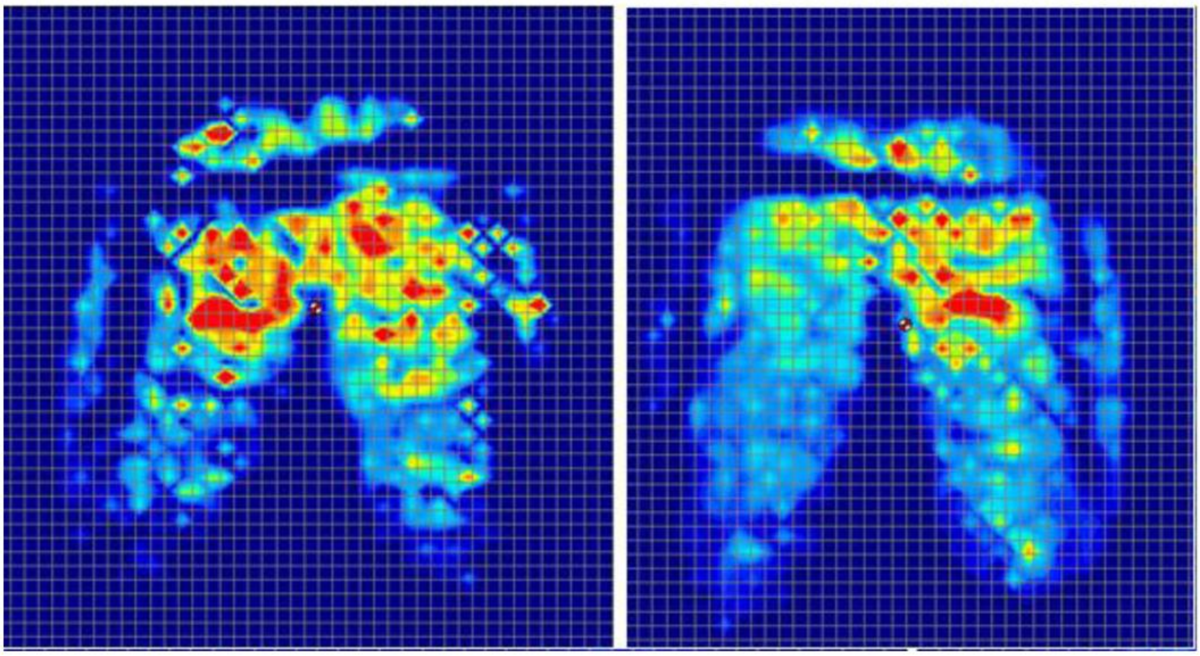
The second element of Singh's study focused on the objective data to gain a more complete picture of the subjective feedback. To do this, pressure mapping was deployed on two identical seats with the only difference being the lamination thickness, one at 0mm and one at 7mm, chosen based on the results from the previous studies.

The participants were asked to sit in the seats for 10 minutes while the pressure exerted on the seats were mapped and logged. The visual results of the tests conducted with a 50kg participant and a 75kg participant are pictured in figure 13 and 14.



Lamination thickness: 0mm   Lamination thickness: 7mm

Figure 15 – 10 Minute pressure map for 50kg participant for 0mm and 7mm lamination thicknesses (Singh, 2013)



Lamination thickness: 0mm   Lamination thickness: 7mm

Figure 16 - 10 Minute pressure map for 75kg participant for 0mm and 7mm lamination thicknesses (Singh, 2013)

The pressure maps in the figures show average pressures from the participant, red zones show higher pressure areas, whereas blue zones show lower pressure areas. The greater the size of the red and yellow zones indicates lesser comfort, as opposed to pressure maps which show a larger contact area but with fewer peak zones i.e. more evenly distributed pressure across the contact area represents a greater feeling of comfort. Figure 15 and 16 show that in both cases the use of 7mm lamination layer objectively reduces the number of high load areas and spreads the pressure across the subject in a more uniform manner.

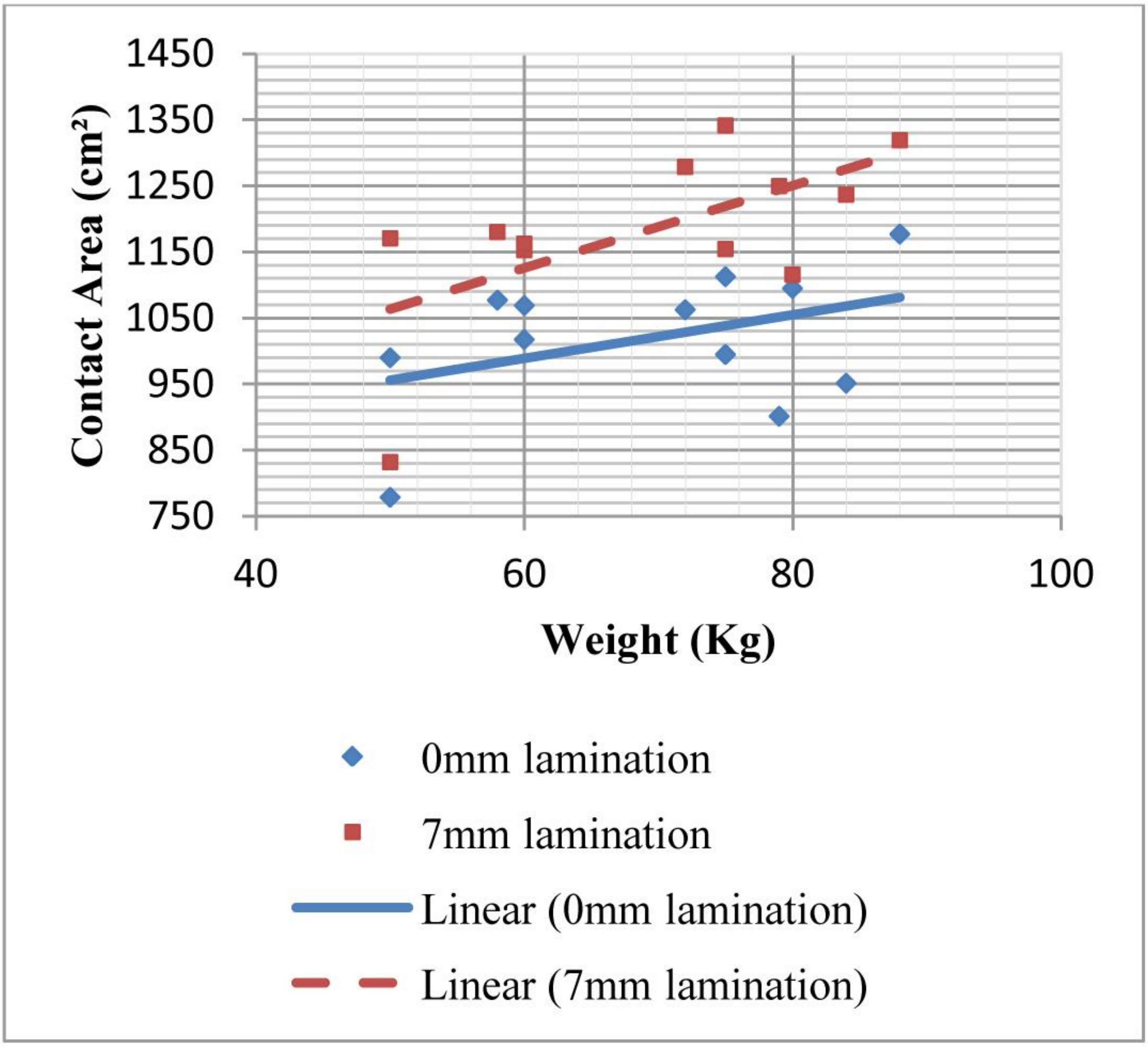


Figure 17 – Contact area vs subject weight for 0mm and 7mm lamination (Singh, 2013)

Figure 17 shows a plot of the test subjects weight vs the contact area from both parts of the study.

It can be seen that from the table that for any given weight measured the 7mm lamination increases the subjects contact area with the seat. The raw numerical data was also analysed and showed that for the participant of 50kg the 7mm lamination increased their contact area by 180.65cm^2; this figure increased for the 90kg subject who experienced a contact area increase of 285.49cm^2. It was then calculated that the average increase in contact area for 7mm lamination over 0mm lamination was 16.1%.

Further analysis was conducted to understand the effect of occupant weight on peak pressure for the two lamination thicknesses being studied. Considering the general rule that the smaller the peak pressure, the greater the comfort, it can be shown that for any particular weight the peak pressure decreases as the lamination layer thickness increases. As shown in figure 18.

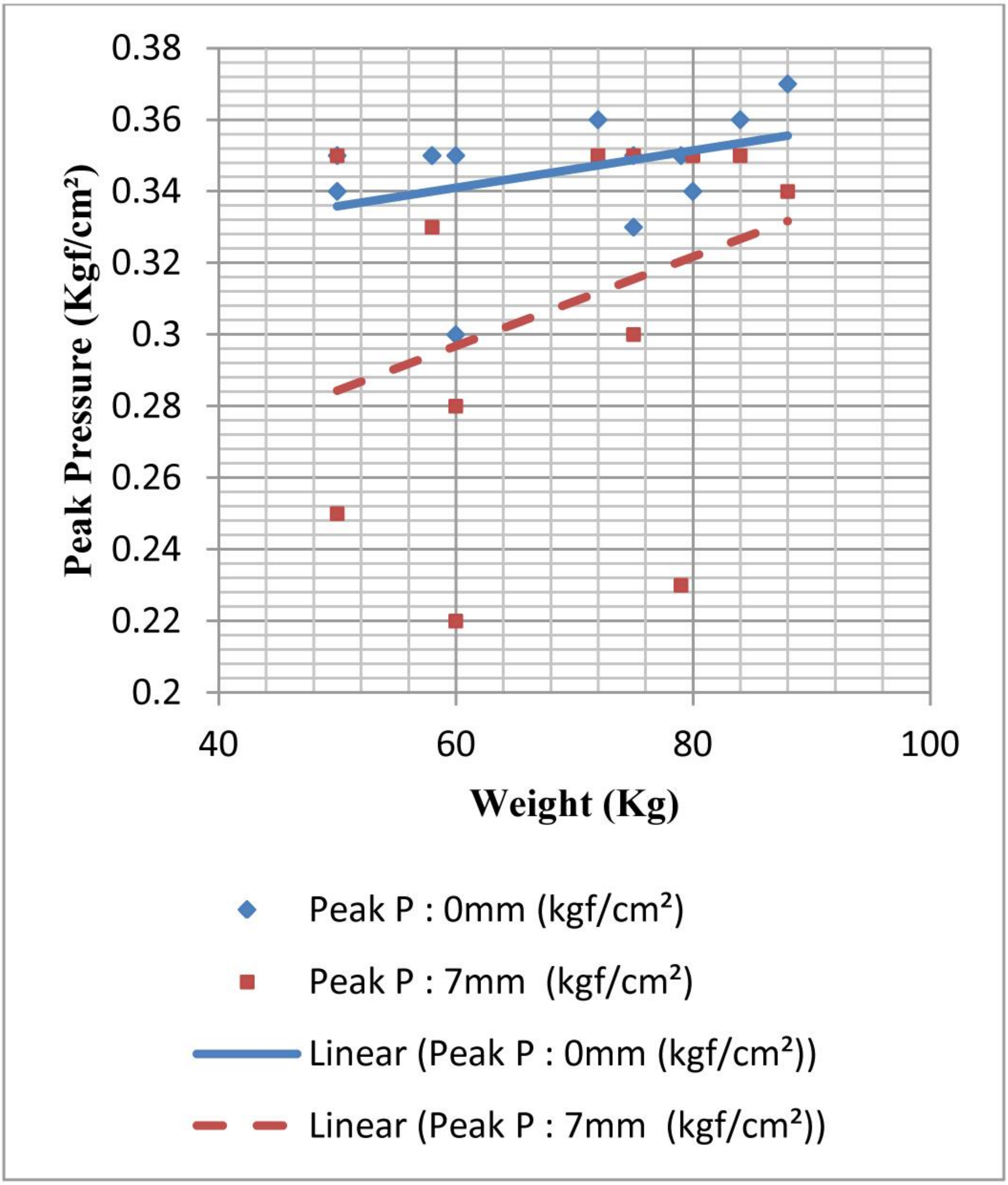


Figure 18 – Peak pressure vs Weight for laminated and non-laminated fabric seat covers (Singh, 2013)

The graph in figure 18 also shows that there is a 10.6% decrease in peak pressure when using 7mm lamination over 0mm lamination. This trend was also reflected in the data pertaining to average pressure with a percentage decrease in average pressure of 7%.

The conclusion of Singh's study relating to lamination thickness states that subjective and objective evaluation show that increasing lamination thickness has a positive effect up to a threshold value of 7mm (of the values studied) beyond which there is a decline in perceived comfort.

Chapter Three – Research Methodology

3.1 Introduction

This study is offered as an exploratory research study to more deeply understand the interplay between some of the primary elements that have been shown to affect users' experience of seating comfort. The investigation concludes with a summary and some guidelines based on the findings relating to the design for seating systems.

To study a topic as broad as design perception, ergonomic and structural factors influencing vehicle seat comfort, necessitated that the research project be conducted in stages, assessing each element to determine how design factors could provide a positive effect.

The rationale for choosing vehicle seating, and in the case of the test rig, dimensions and environment from a motorhome, is that the development partner Stylex Auto Products has a commercial interest in the development of seating technology and access to these types of vehicles. The access provided by Stylex also gives the opportunity to share the development results of the study, meaning that feedback can be obtained from those within the industry, potentially creating a valuable input for seating development that may ultimately lead to advancements being used commercially.

3.2 Research Ethics

Participants engaging in research studies must do so voluntarily, must be informed about the purpose and conduct of the research, must be treated with respect and must be properly protected. Participant preferences regarding anonymity and personal data must also be acknowledged and agreed.

Discussions about ethics and ethical approaches to research were held with the project supervisor as part of an ethical review, which determined that the study was able to proceed. A summary of those discussions is as follows.

Determining an appropriate cohort was discussed. The decision taken was that participants would be adults, recruited as representatives of a general population sample only, and not due to any particular health-related conditions (e.g. back problems). The initial group (which subsequently became the only group) would be drawn from Sheffield Hallam University staff who were not connected with the research study. The project supervisor, as Design Director of Design Futures, granted permission to involve staff and access spaces to enable the research to be conducted.

The nature and duration of the proposed testing and whether any of the tests would involve prolonged or repetitive testing was also discussed. The tests in this study would be short (no longer than 15 minutes) and would not be repetitive. Participants would also be reminded that they could stop the testing at any time. The core aim of the study was to identify comfortable seating positions and participants would be able to determine the most comfortable position, negating the risk of individual discomfort.

How to achieve informed consent for participation in the study and how the wishes of participants with respect to confidentiality could be recorded was discussed. Research documentation was prepared that included a participant information sheet and a consent form. These documents were written using clear and unambiguous terms to make them widely understandable to candidate participants. Following discussions with the project supervisor, it was agreed that unattributed comments would be used throughout (where letter coding would be adopted to differentiate between participants) and digital obscuration techniques of faces would be used to achieve anonymity in all images. A testing plan and draft script were submitted for review.

3.3 Health and Safety

As part of a responsible approach to health and safety, discussions took place with the project supervisor about risk assessment, including identifying potential hazards and ways that they could be mitigated. This focused on the test rig and considered production, assembly/installation and 'in use' by participants. Some of the potential hazards identified (and risk mitigations) discussed, included:

- Personal injury whilst operating CNC machines during production - create production files for physical part production by experienced technical staff

- Falling large panels during assembly - co-construct test rig with support from SHU staff
- Collapse/partial collapse during use because of a structural inadequacy - use 15mm thick structural plywood and pre-test
- Sharp/protruding corners or fittings causing hand injury - all external edges to be rounded (radiused), foam to be used on surfaces
- Entrapment/entanglement injuries in movable parts - adjustments to be made either by the researcher or by participants under the direction of the researcher and participants not permitted to be in lab space unsupervised
- Injury due to unqualified use - use 'do not touch signage' when not use/use only in secure lab space

3.4 Purpose

To understand the effect of changes in any of the three study areas of: design perception, ergonomic and structural factors, physical testing is required. This is necessary, firstly, as a way to determine a baseline user perception of comfort against which any changes can be measured.

In order to conduct tests, it was apparent, based on the researched data and data gathering requirement, that the seating rig needed to be a design that allowed for adjustments. The rig needed to allow for adjustment in height and angle of the seat base relative to the floor and the height and angle of the seat back relative to the floor or the seat base. The adjustments simulate the primary planes of motion that can be adjusted in vehicle seating.

When designing a simple rig, it was decided to model the basic dimensions from a bench seat used in the motorhome market as this is a core market for research partner, Stylex, and was thus able to provide foam and trimmed samples for initial testing. The rig would, however, be able to be adapted by use of profiled foams to be representative of automotive seating more widely.

3.5 Rig Design

The rig was initially designed and assembled using 3D CAD to ensure it was dimensionally accurate and that it would fit together appropriately. It was devised to be easy to manufacture and easy to modify during preliminary testing and to be able to achieve the finer adjustments that would be used in the participant-led element of the study.

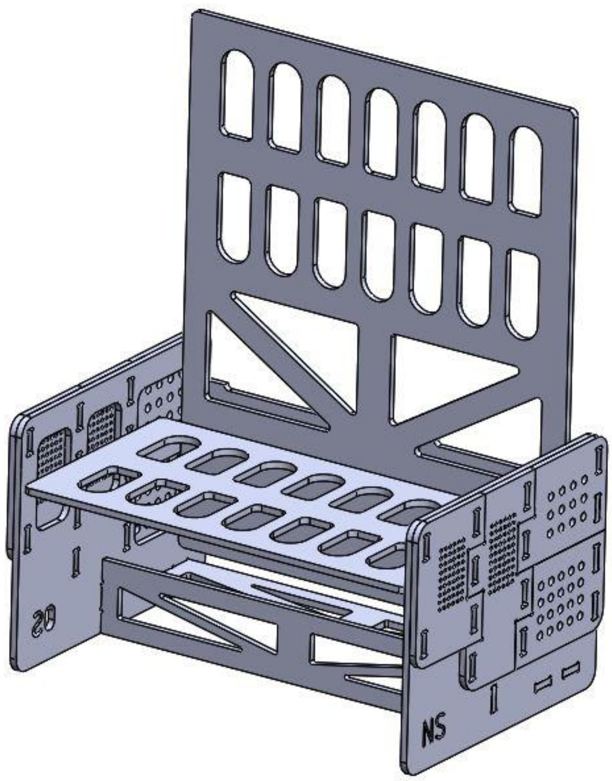


Figure 19 – Assembly model of seating test rig

So that the rig did not need to be completely dismantled (and to potentially require re-manufacture) when making adjustments to seat base and back height and angles, the holes where the support bars sit were milled into separate boards called hole boards. These elements can be seen in figure 20.

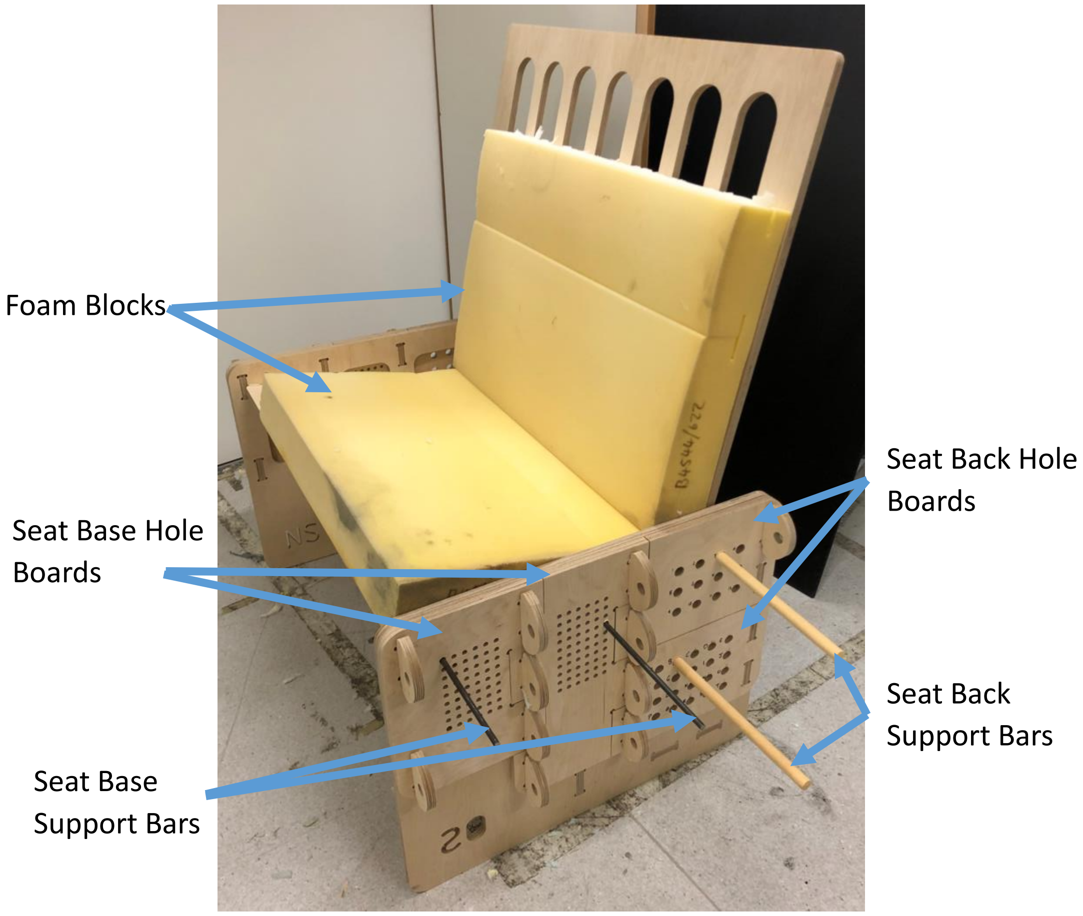


Figure 20 – Annotated Image of Test Rig

The benefit is that each board presents a range of positions for the support bars, allowing for a large range of adjustability which was helpful in finding the initial baseline ‘comfortable position’. Once this was established, finer adjustments could be made by creating a new hole board with holes in different positions based on feedback from the participant. By creating the rig in this way, individual boards could be replaced at any time to give the desired position quickly, and without needing to take apart the whole rig or to remove it from the test environment potentially improving the results. In figure 21 is an image highlighting one of the four hole boards on each side of the rig.

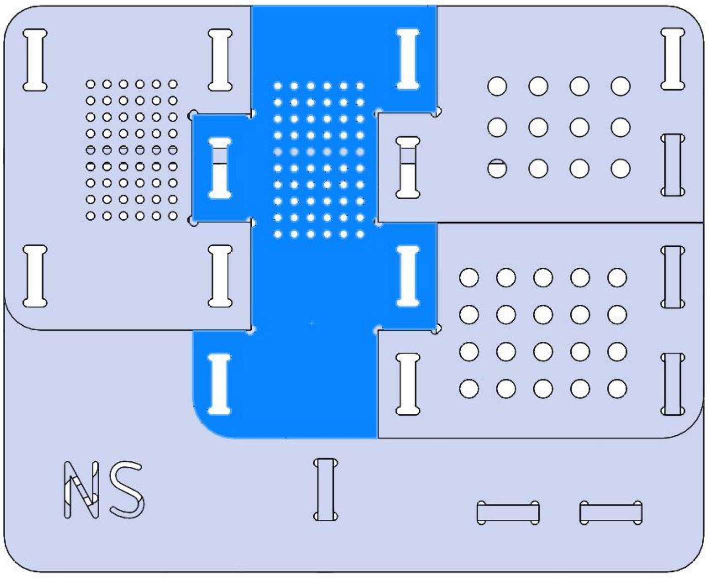


Figure 21 – Side view of rig base highlighting hole board

The highlighted hole board in Figure 21 is for the adjustment of the rear of the seat base, vertical holes allow for the height and relative angle to be adjusted and horizontal holes allow for finer adjustments of the seat base angle.

The test rig was manufactured by CNC milling using 12mm thickness plywood by Sheffield Hallam University technical staff.

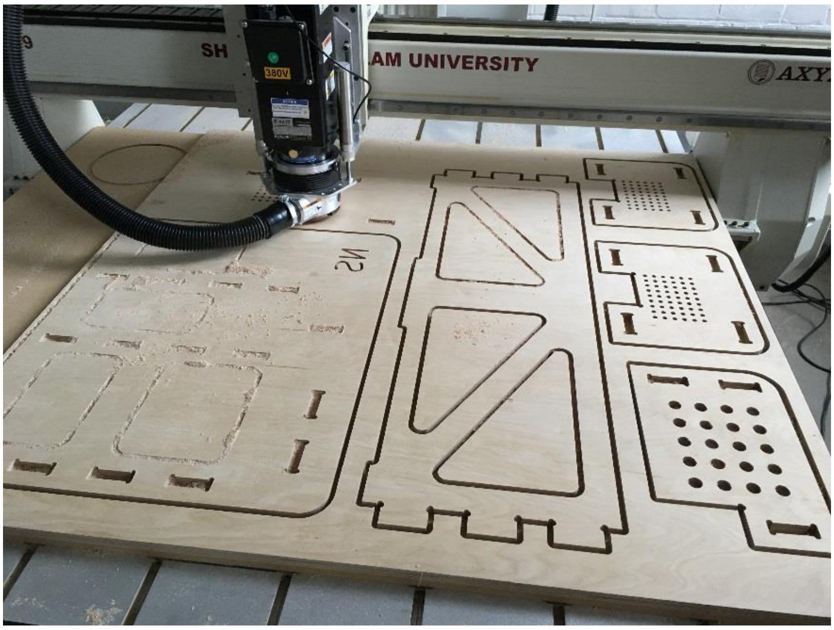


Figure 22 – CNC milling of seating test rig

Test rig is assembled using interference fit tongue and groove joints that can be seen in the above image. The hole boards are held in place using tab inserts as shown in the image below.

Figure 23 – Test rig prototype build

The rig was initially designed to be constructed using wooden dowel rods to provide support for the seat base in the same manner as the back rest however these were replaced by steel rods to provide additional support as the dowel rods did flex during some initial tests prior to participant engagement. Wooden batons were also added to the underside of the seat base to increase rigidity to be as representative as a vehicle seat as possible.

To simulate a vehicle environment, blocks of foam were added to the seat base and backrest. The foam used was RX33/135 which is the most widely used open cell polyurethane foam density in leisure vehicle seating applications. These foam blocks were not covered in fabric and left with a neutral tone so as not to influence the participants in any way. The studies detailed in the literature review showed that seating fabrics have a higher influence on comfort perception for females than males. In this setting it was impossible to eliminate entirely the effect of the seating surface visuals leaving the seat uncovered reduced the effect of fabric influencing the participants' results. The exposed foam surface creates higher friction between the participant and the seat meaning that slipping would be minimised. Through the literature review this was seen as a positive feature of seats meaning that the user required less effort to remain in a comfortable position.

3.5.1 Testing Rig Dimensions

This section provides a concise summary of the testing rig, its main features, and key dimensions to enable it to be replicated, and the experiments conducted in this thesis to be repeated.

The test rig was designed using the key dimensions of the commercial customer's seat (that Stylex was working on at the time this research was conducted). The customer has not been named in this study, but the dimensions are freely available in the public domain. The project work and its immediate commercial impact have been concluded.

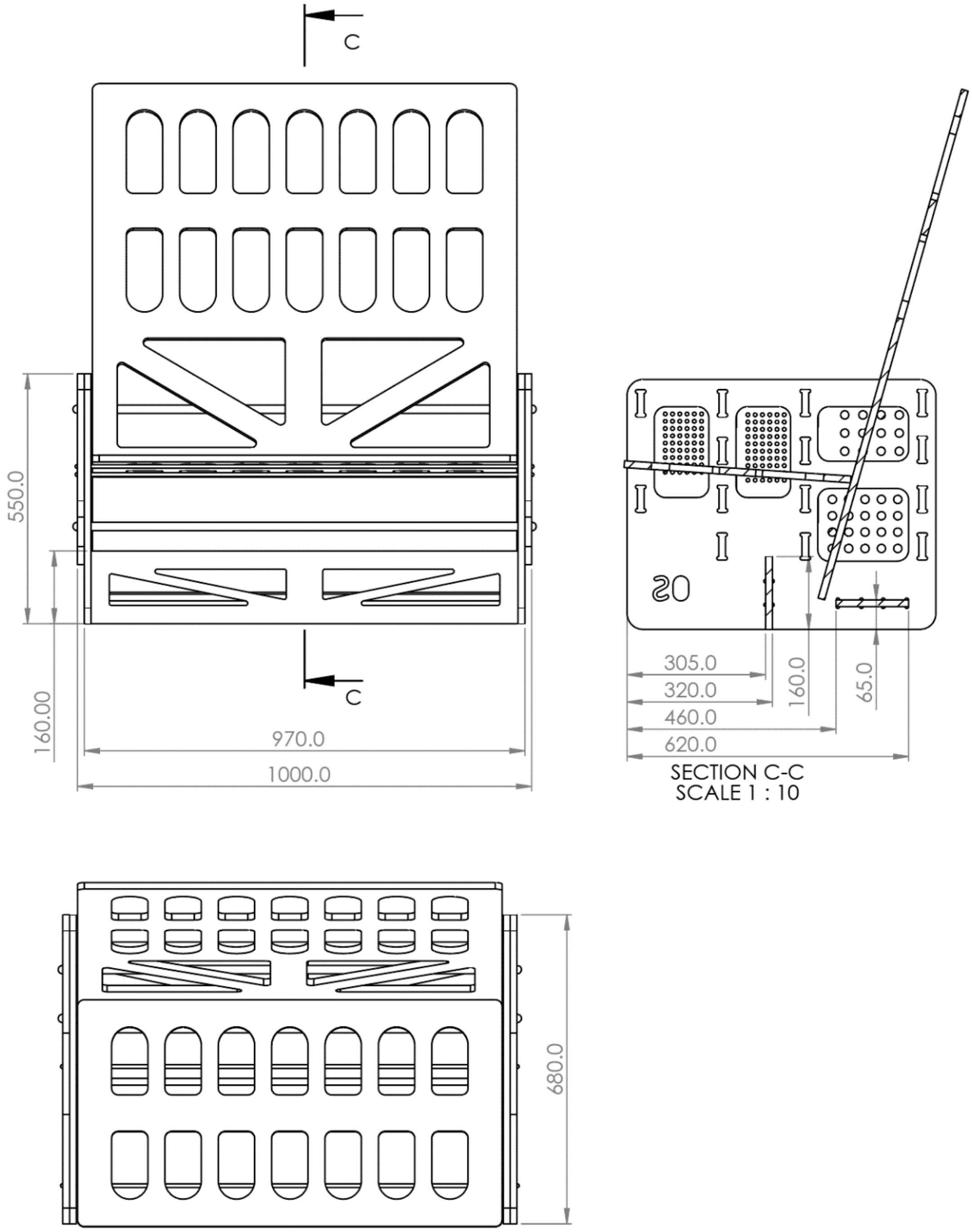


Figure 24 – Test rig dimensions

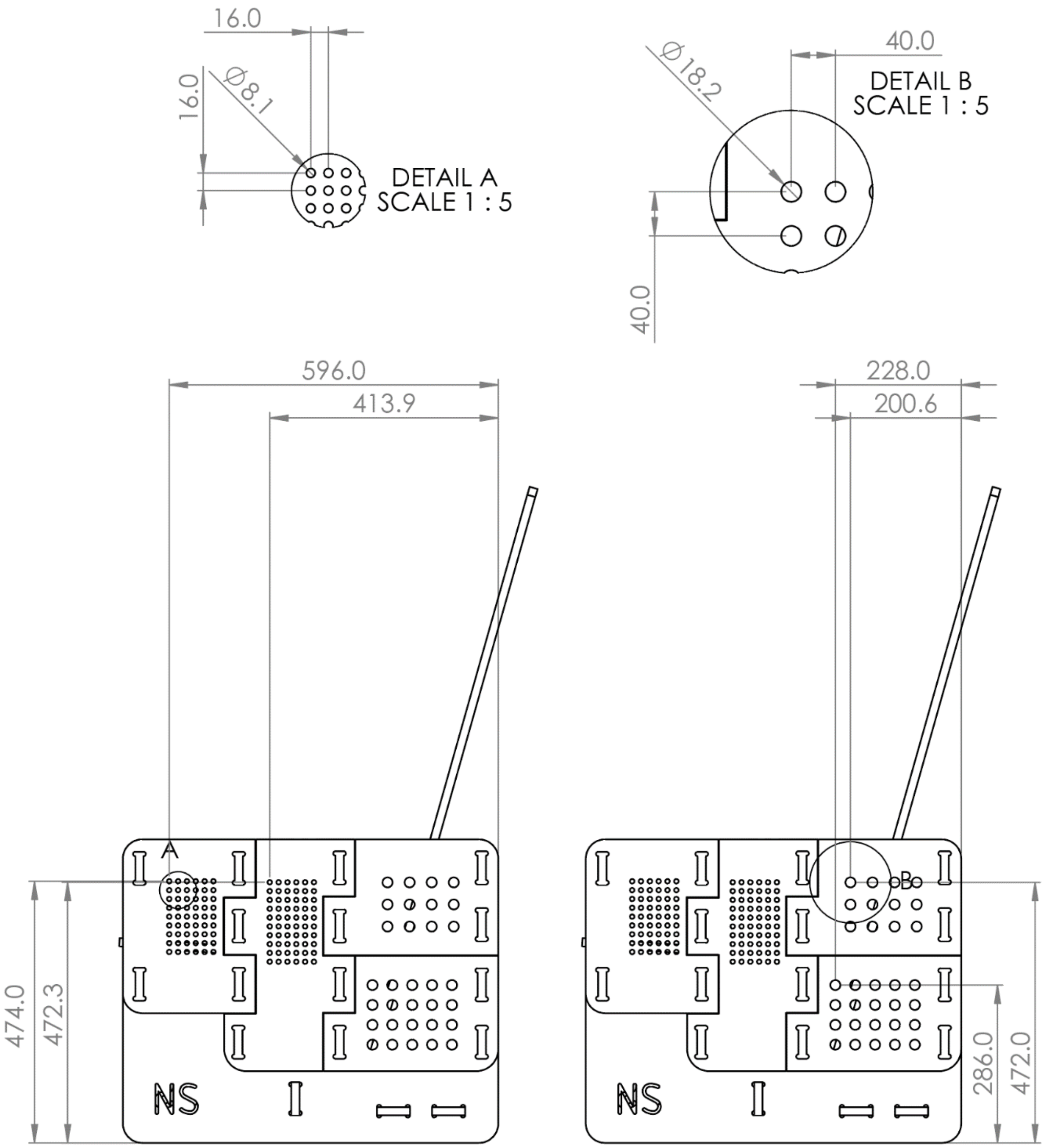


Figure 25 – Test rig dimensions continued

Figure 24 and 25 show the overall dimensions of the testing rig. These dimensions replicate the seating area of the commercial vehicle being studied at the time, however, the extremities of the dimensions have been altered to accommodate the elements of the rig which allow for adjustment to the seating angles. The dimensions of the surfaces that the participants come into physical contact with when sitting in the seat are that of the commercially available vehicle, for example, seating surface width and depth.

The foam used on the rig surface is an untrimmed (no fabric covers) version of the foam used for the vehicle this test rig replicates. The foam density has also been replicated to give a clear like-for-like comparison and to make the results of the study as relevant as possible to the intended application.

The dimensions of the seat base foam were also based on from the foams intended for use in the vehicle. Due to the high cost of a set of foam inserts, a minimal number of development inserts were produced by the company to reduce development costs. Therefore, the sample used for the seat base in the testing is a trimmed down version of a larger sample set. The original test foam set had a second layer of developmental foam applied to the bottom of the original white pad which was removed and then the foam trimmed to the specified width. The trimmed side of the foam pad was placed intentionally to face the wall to help to avoid influencing the participant.

The seat back foam was not available for development, so a substitute foam of the same grade as the seat base was used. This was trimmed to the maximum available height to best reflect the back rest height and profile of the production vehicle within the available resources.

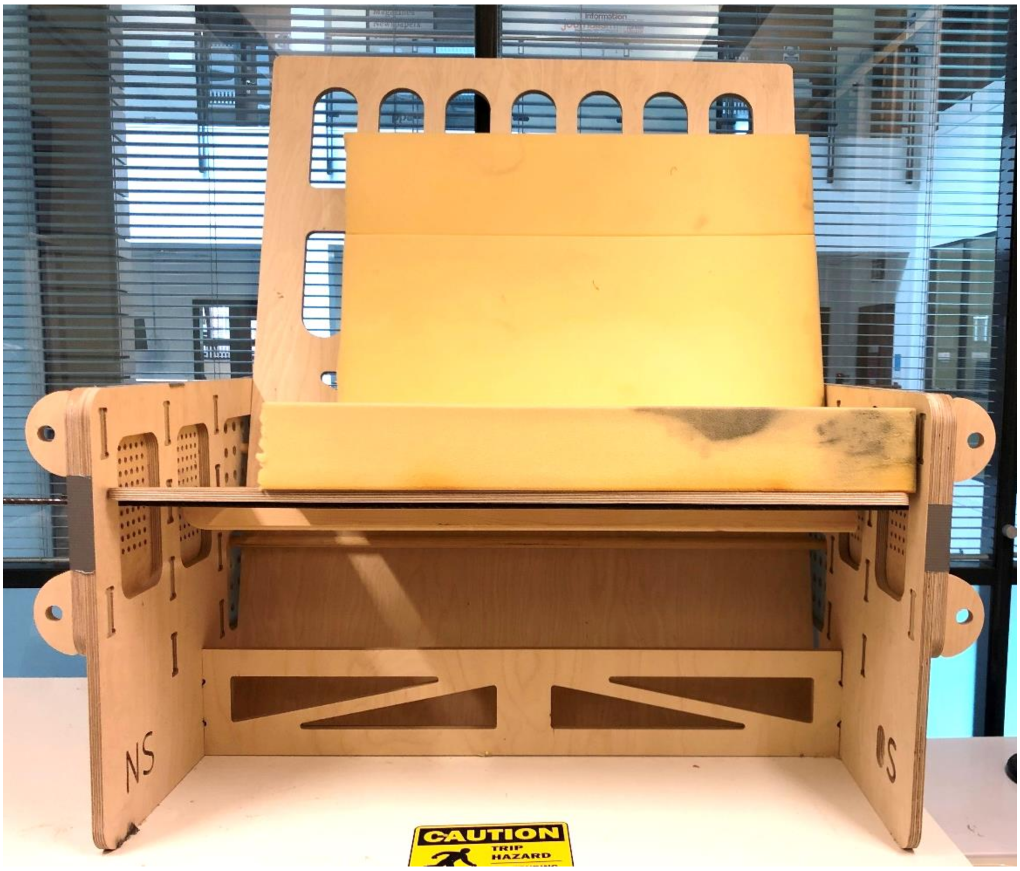


Figure 26 – Test rig foam front

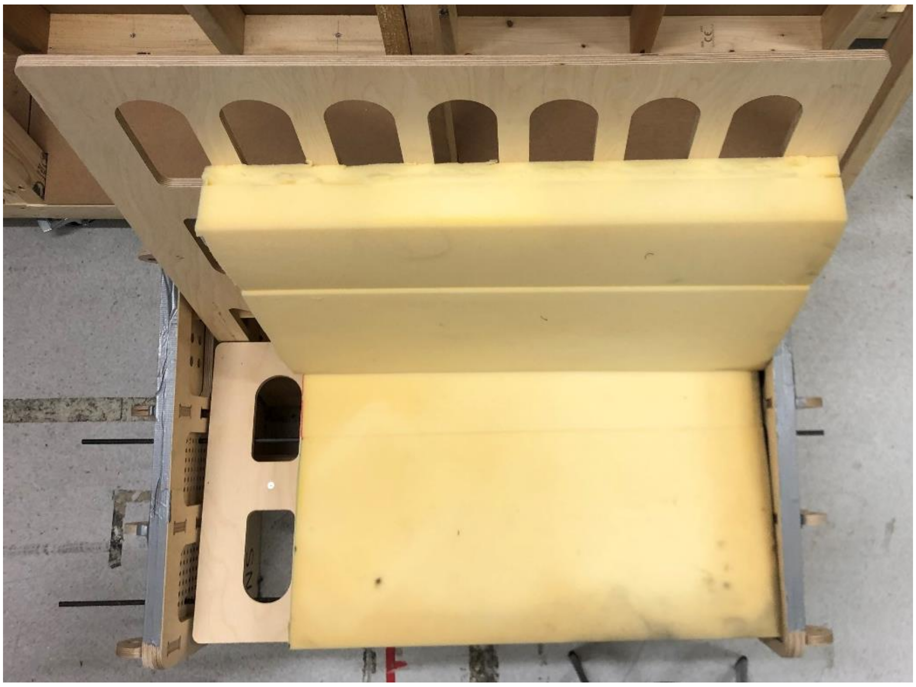


Figure 27 – Test rig foam top

Figure 26 and 27 show test foam placed on test rig.

Seat base foam dimensions: 760mm x 550mm x 100mm

Seat back foam dimensions: 775mm x 550mm x 100mm

The test rig is designed to allow participants change the height and angle of the seat base and seat back. To enable this to happen, 'hole boards' were used as shown in figure 28.

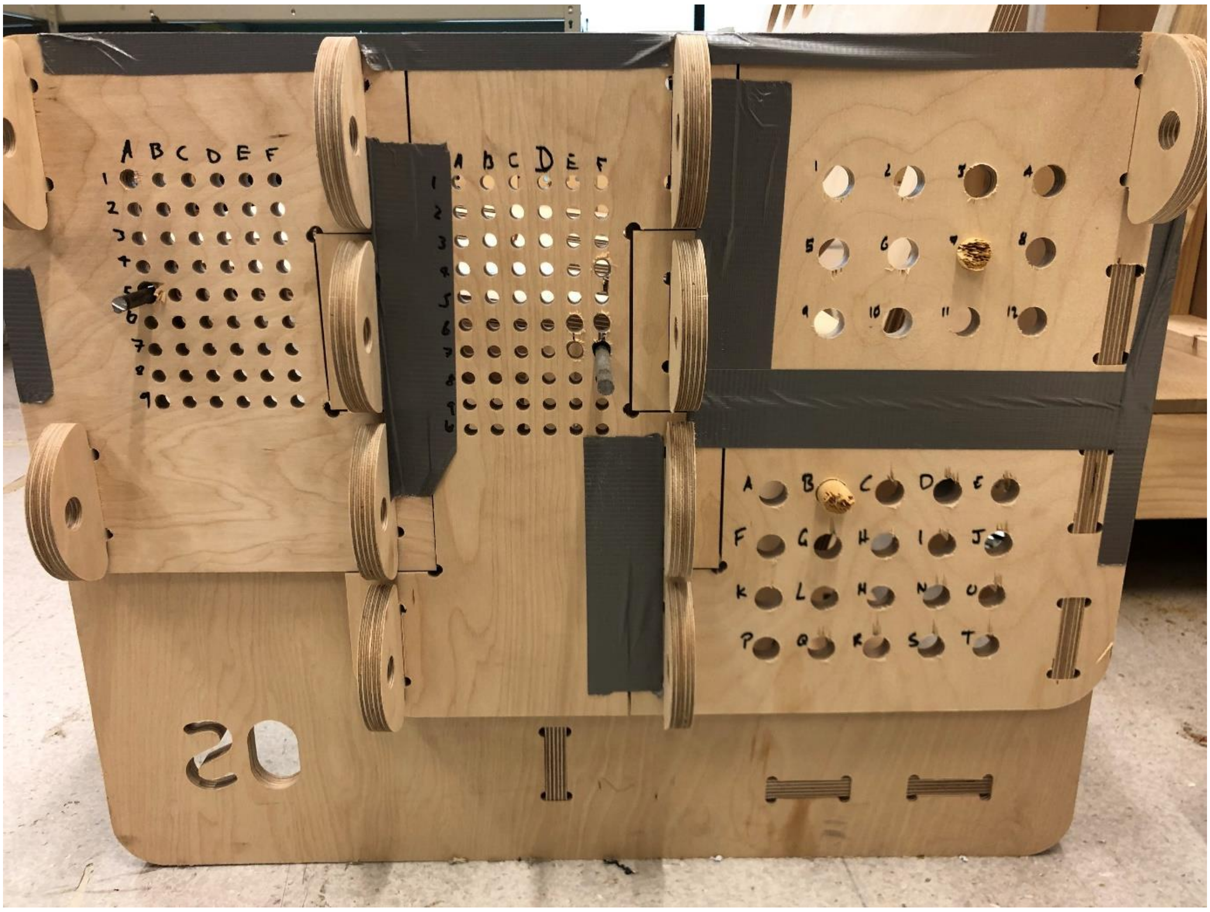


Figure 28 – Hole board labels

The holes in the hole boards are marked with a letter and number coordinate system as shown in figure 28. This gives a six-character positional reference. For the example in figure 28 this would be, A5, F7, B7.

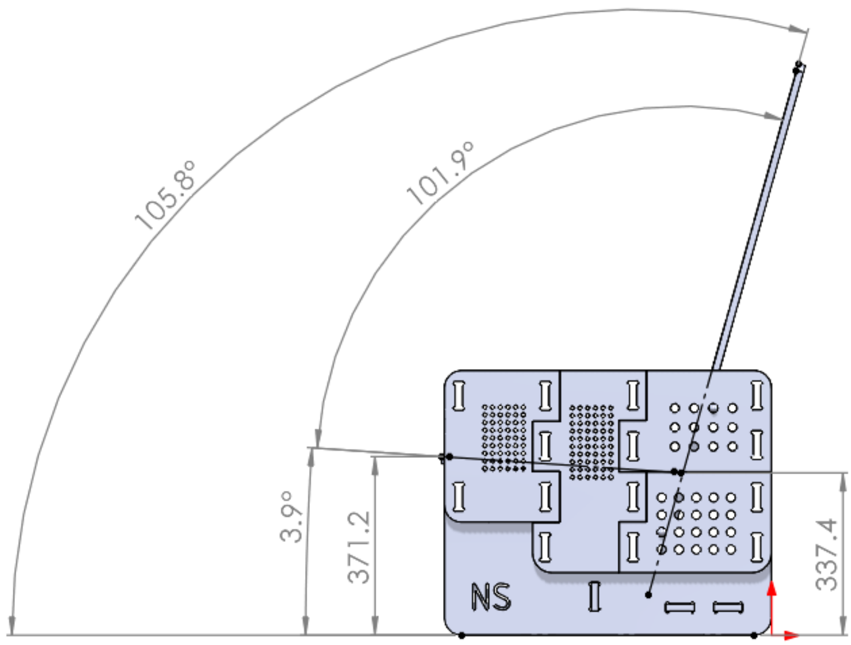


Figure 29 - Seat base hole boards in position A8, F9

In figure 29 the seat base hole boards are set to A8, F9. These figures make noting the positions of the supports easy and can be simply translated into measurement data by referencing the CAD model. The example in figure 29 corresponds to a seat base angle relative to the ground of 3.9 degrees, a front height of 371.2mm and a rear height of 337.4mm. This data can then be combined with the measurements of the board and foam to give a front height of 471.2mm, rear height of 437.4mm and an angle relative to the floor plane of 3.9 degrees.

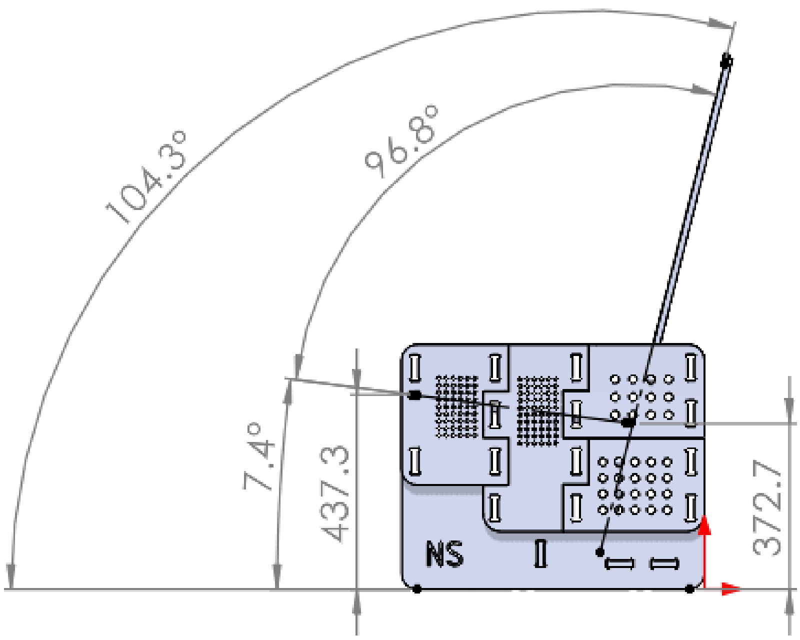


Figure 30 - Seat base hole boards in position A4, E6

Figure 30 is another example of a seat base position with the supports at A4, E6. This corresponds to relative seat base angle of 7.4 degrees, seat base front height 437.3mm, seat base rear height 372.7mm. Again, this data can be combined with the uncompressed measurement data of the foam to give 537.3mm, 472.7mm with the same angle of 7.4 degrees.

The seat back coordinates work in a similar way, but due to the reduced number of support locations required each position has an individual signifier, either a number or a letter as shown in figure 28.

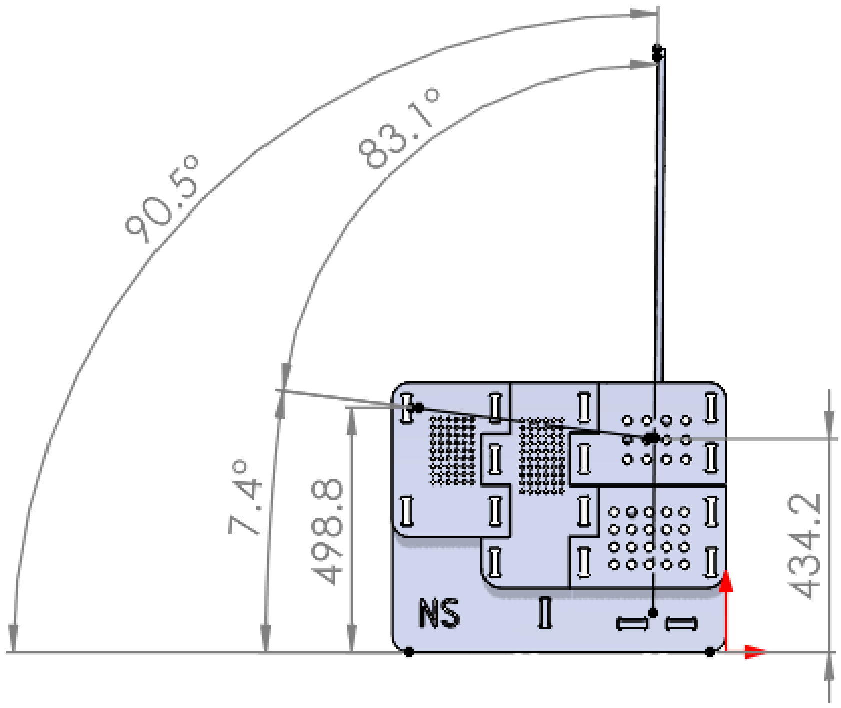


Figure 31 - Seat back hole boards in position C5

Seat back position in figure 31 is C5. Using the same method as used with the seat base, this translates to an angle of 90.5 degrees relative to the floor plane.

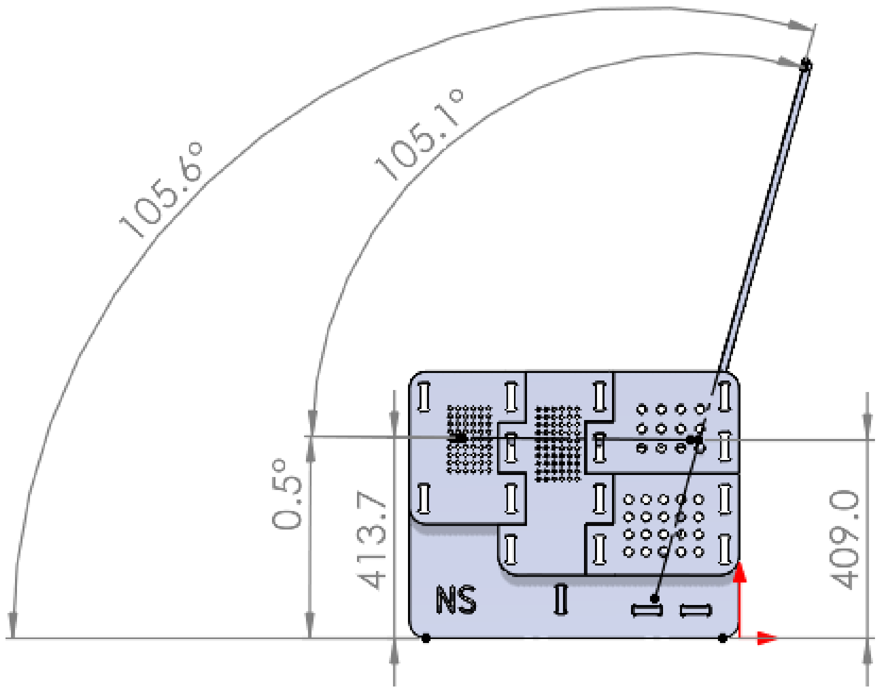


Figure 32 – Seat back hole boards in position I12

Seat back position in figure 32 is I12. Using the same method as for the seat base this translates to an angle of 105.6 degrees relative to the floor plane.

Another relevant calculation that could be used in the analysis of the positions of the two elements is to measure the angle relative to one another.

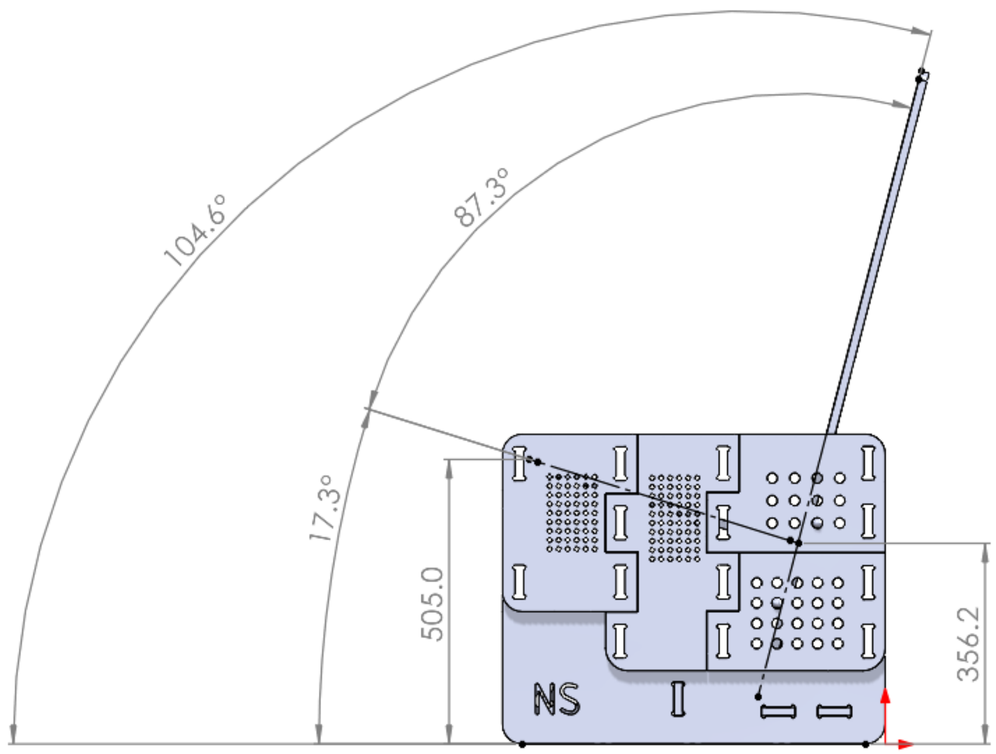


Figure 33 – Rig in position D1, C4, G11

In figure 33, the test rig set up with the seat base hole boards at D1, C4 and the seat back hole boards at G11. The relative angle between these elements is 87.3 degrees.

3.6 Testing Plan

Through the literature review, it is clear that in addition to the collection of results, the validation of them is critical to their accuracy. Due to the nature of the research suggested through this project, it is important to validate results of perceived comfort against the experiences of comfort of the participants individually. It is also demonstrated through the literature review that participants' perceptions do not always accurately reflect their experiences but do have an influence over them. To aid determining what effect perception has over reality, a third stage of the test will be necessary using a baseline seating position formulated from the results of the previous two investigations.

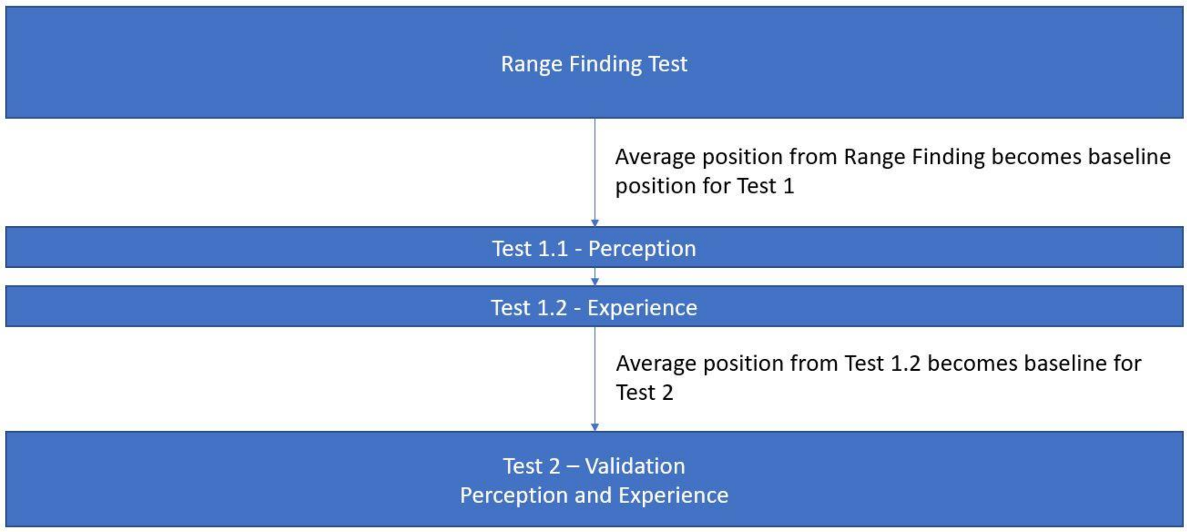


Figure 34 – Testing plan

The experimentation plan was as follows:

Initial range finding exercise was conducted to obtain a baseline for a comfortable seating position using employed staff within Sheffield Hallam University; the group was spread across the 18-65 age demographic. This was a semi-formal session in which participants were asked to adjust the seat into a 'comfortable travelling position for use in a vehicle' this statement is intentionally non-specific as it allows for each participant individually to interpret it as they feel is most appropriate and that best meets their requirements. This element of the research, although not part of the main study results, will give an insight into participants perception of the idea of setting this seat up for vehicular travel.

Each of the initial participants was allowed a period of time in which to make changes to any element of the seat geometry allowed by the rig as they see fit. This means that the full range of seat base height, angle, seat back height, angle and their relationship to each other and the floor is open for adjustment according to user preference, using the standard hole boards attached to the rig. This does result in an opportunity for the participant to suggest that their optimal position may be between the available adjustment increments, however, at this early stage this is not important. Once they have established this position, each element of the set up was recorded and tabulated and the user's sex and height noted. These two elements have been chosen as other experiments reviewed in the literature review demonstrated that sex has an influence on the perception of seating comfort due to the appearance of the seat and height having an effect purely based on ergonomics and anthropometrics.

Once tabulated, the results were averaged to give a theoretical 'mean comfortable seating position' referred to as the baseline position which is used as the position for the start of the investigation. At this point, it may be pertinent to note any anomalous results that may need to be discounted when averaging the results.

Through the literature review it has been shown that a key point in achieving good results and understanding them accurately in context, is the need to validate the results observed. The testing methodology used here incorporates this without explicitly telling the participants that this is what is happening, to avoid influencing the results.

Individually, and in isolation from one another, each participant was taken into the testing environment and shown the rig set up at the previously defined baseline position. The participants were not told the rationale for the seat's initial position, again, to avoid influencing the participant's response. The participant will be asked to rate how comfortable they perceive the seat to be, on a 1-9 scale with one being 'not at all comfortable' and 9 being 'supremely comfortable'. For this study, a Likert scale is used to avoid the typical reversion to centre trend found in results taken using scales with a centre point. The nomenclature of the scale is based upon accessible terms used to describe comfort. The rating was made by the participant without the ability to physically interact with the seat. The purpose of this rating is to be exclusively a visual assessment. To ensure continuity of appearance of the seat the wooden frame of the rig had two blocks of foam placed on top of it, one for the seat base and one for the back rest, to ensure that the overall effect of the seats appearance always reflects a flat planar face relative to the angles of each element and reduce the number of possible variables. The foam used was a typical automotive grade polyurethane foam. Results from each participant were recorded.

The second element of the investigation allows the participant to interact with the seat. Firstly, to sit in the seat in its baseline position and to rate their comfort using the 9-point Likert scale. Once participants have given their results, they were then invited to change any element of the seating geometry available to them e.g. seat base height seat base angle, seat back height and seat back angle, if they wished to, with the intention of making the seat optimally comfortable for them. They were assisted in making the changes, but changes were only made through participant instruction, to ensure maximum efficacy in the results. There is no time limit for the participants in this part of the study; participants define when they have found what they consider to be the most comfortable seating position. If a participant suggests that their optimal position is between two positions as defined by the standard hole boards, they were swapped out to allow for the participants perceived perfect position to be realised. Once the participant had completed any adjustments they wished to make, the results are recorded. This process is repeated for all participants individually in isolation.

To control the second element of the investigation, the testing was conducted in a room with consistent temperature and lighting. The participants were asked to remove any coats or thick layers of fabric that may have an influence on their experience of the test rig. It is also important to note that the time at which the test was undertaken by each participant was noted so that when repeated during the following section it can be conducted at the same time. This control is based on the 2014 study by Bazley which indicated a potential for participant experience of comfort to change throughout the day.

The final element of the study mirrors the initial set up phase and is designed to validate the previous phase and to help to understand the weighting of perception on comfort experience. The optimal seating positions from all participants are averaged in the same way described in the first part of the test. The seat was then set to this average optimum position, the hole boards on the sides hidden to avoid influencing the results, and the initial test repeated with participants individually asked to rate their perceived comfort of the seat prior to interaction and then to sit in the seat and rate its comfort. The participant was requested to sit in the seat in its current geometry for a minimum of 20 seconds and a maximum of 1 minute, prior to giving their rating, to give them time to experience their own physiological response to the seating position. It is noted that up to 1 minute of sitting in a seat is not directly representative of the experience of sitting in a vehicle seat, however, as shown through the literature review, the initial responses to a seat have a strong bearing on the users experience of overall comfort. All ratings are taken on the same 9-point scale.

The purpose of this final element of participation is to understand the gap between individual optimal position and average optimal position and how much effect perception has on comfort.

Chapter Four - Testing

Tests were carried out according to the testing plan; the experiments are detailed in the sections 3.6.1, 3.6.2 and 3.6.3 with the overall results summarised in section 3.7.

4.1 Range Finding

Seven adults from across a range of ages and heights, including male and female participants, were individually asked to enter the room with the testing rig. They were shown the seat and how it could be adjusted according to the parameters of the study. They were asked to adjust the seat (with help to create the desired adjustments) to their most 'comfortable traveling position for use in a vehicle'. This definition remained identical across all participants in order to control the experiment. The participants were also informed about the ways that the rig could be adjusted; this was read from a script to avoid influencing the participants.

Figure 35 – Participant sitting in rig

A grid system was used to quickly and easily measure the position of the changeable elements as pictured in figure 36.

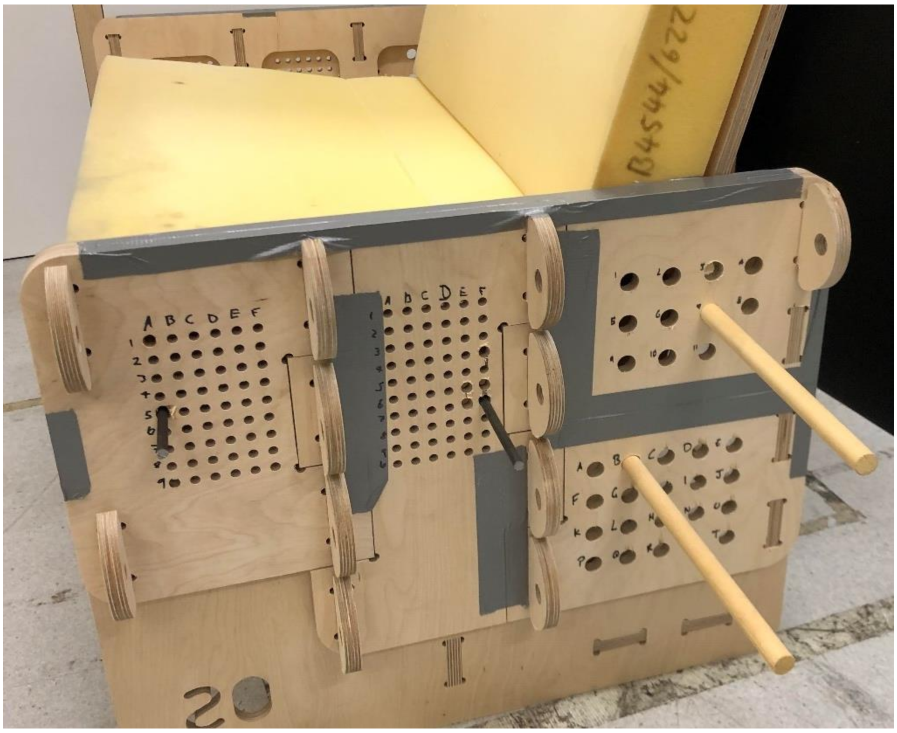


Figure 36 – Grid system to determine hole position

All participants are anonymised and represented with a letter from A-G. The results of the range finding exercise are shown in table 1

Table 1 – Participant range finding results

Participant	**Sex**	**Height**	**Seat Base Front**	**Seat Base Rear**	**Seat Back Lower**	**Seat Back Upper**
A	Male	189cm	A4	F6	B	7
B	Male	179cm	A5	F7	B	7
C	Male	175cm	A5	F7	B	7
D	Female	161cm	A6	F7	C	3
E	Female	166cm	A5	F6	B	7
F	Male	177cm	A5	F7	B	7
G	Female	169cm	A5	F7	G	3

Notes were also taken of the relevant comments made by each participant during the range finding exercise and included with consent.

Participant A:

- 'The back feels too straight, it needs more lumbar support'
- 'This is a pretty comfy angle (referring to A4,F6,B7) but the back needs to be slightly taller'

Participant C:

- 'This angle (referring to A5,F7,B7) cradles me more [it] feels like I'm more in the seat'

Participant D:

- 'This position (referring to A5,F6,B7 during experimentation) seems good but too high, it's digging into the back of my knees'.
- Once adjusted to final position (A6,F7,C3): 'This is much comfier than before, but I think the angle of the foam behind my knees needs to be more curved'

Participant F:

- ‘Now that the seat is more level (referring to A5,F7, B7) I feel like I could sit here for longer, I feel like the softness of the foam helps that, if the seat was harder I think I’d want it tipped back more’

4.1.1 Analysis of preliminary results

The aim of the range finding exercise was to provide a baseline position from which to start the primary and validation testing. The position was to be an approximate average of the demographic selected as part of the range finding exercise. To this end, the participants were selected to include people of varying height and sex, and although selection was not controlled by physical characteristics, they do embody a representative range of end users of vehicle seats.

Seat Base:

The seat base showed the greatest variation in results, specifically in the front position, which controls the height of the front of the seat base and the angle of the seat base in combination with the seat base rear position.

The changes loosely correlate with participant height - the taller the participant, the lower the number. This signifies a higher position on the rig; this holds true for the participants that were shorter having a lower position on the rig. Participant D noted this in her comments with the front of the seat ‘digging into the back’ of her knees. Upon lowering the seat base front position, the participant stated that it was ‘much comfier than before’.

The seat base rear position varied in only two cases, the first being for the tallest participant to maintain the seat angle but to raise the seat base and the second was for participant E to bring the seat base angle closer to parallel with the floor. In the remaining participants results, the seat base rear position stayed at F7.

Seat Back:

The seat back position saw less variation between participants with all but two concluding that the angle B7 was the optimal.

The first of the two angles outside the average B7 position was participant D who settled on position C3 which creates a subtly more upright angle, this was combined with the lower seat base position for this participant. The second, participant G, concluded that position G3 was the most comfortable. This is an extremely relaxed angle, and one that no other participants results were in the same range as during their experimentation. This suggests that this result, while considered the most comfortable for participant G is unlikely to be a universally agreed up on comfortable position.

Creating a baseline:

In line with the testing plan, an average position from the results of the preliminary test can be drawn for use as a baseline from which to conduct the primary and validation testing later in the plan.

In this instance the preliminary test results are closely aligned with only slight deviation making the creation of a baseline position a simple process. From these results a baseline position has been determined by taking the modal value as shown in table 2.

Table 2 – Participants Baseline Positions

Participant	**Seat Base Front**	**Seat Base Rear**	**Seat Back Lower**	**Seat Back Upper**
A	A4	F6	B	7
B	A5	F7	B	7
C	A5	F7	B	7
D	A6	F7	C	3
E	A5	F6	B	7
F	A5	F7	B	7
G	A5	F7	G	3
Average	**A5**	**F7**	**B**	**7**

The results give a baseline position of:

A5,F7,B7

This position was used as the position the rig will be in at the start of the primary test.

4.2 Primary Test

To clearly show the results, the following primary test has been divided into two sections. Part 1 is the perception element i.e. before the participant has any physical interaction with the seat, part 2 is the participants physical interaction with and adjustment of the seat. Each element allows the participant to provide a rating meaning that at the end of the primary test each participant will have two ratings of 1-9.

Participants for the primary element of the test were planned to ensure that there was an even number of representatives for each variable i.e. male/ female and that a range of heights were used to provide a broad spread of data. The participants for this stage of the testing were not the same as those used in the baseline group to ensure that there was no influence on the results. Participants were selected based on those willing and able to participate in the test programme. From this group, twelve individuals representing the best possible spread of sex and height, were selected. Using a participant information sheet and consent form (in line with Sheffield Hallam University ethics processes) participants were informed of what they would be expected to do, what information was required from them and told that the results would be anonymised. In addition, participants were advised that if at any point they were not happy with the proceedings of the test or they wanted to pull out for any reason that they could do so without giving a reason.

4.2.1 Primary Test Phase 1 - Perception

As with the range finding exercise, the participants were brought into the test room one at separate times and in isolation from each other so as there could be no communication between those participants who had experienced the test and those who had not. This was to avoid exchange of any information that may influence the test results given by each participant. To further control the inputs to the participants during both elements of the test, a script was used. All participants were made aware that all results would be anonymised throughout all stages of the study. For part 1 the script read as follows:

'This is the first of two phases of the primary test in which you will be assessing a seat for seated comfort in the context of vehicular seating. During this phase of the test you will enter the test room, where there will be a white wall set up across the middle of the room with the test rig against it. When you see the test rig, it will have two foam pads on which are representative of a soft seating surface; they do not have a fabric cover. Please primarily pay attention to the geometry of the seat. This means: the height and angle of the seat base and the seat back. At this stage of the test, please do not interact with the test rig, you may walk around it to view it from different angles but please do not touch it. When you have had sufficient time to look at the test rig, please give a rating of comfort on a 1-9 scale where 1 is 'not at all comfortable' and 9 is 'supremely comfortable'. Once you have given the figure that you are happy with, this will conclude the first part of the experiment. '

Participant list and results shown in table 3

Table 3 – Participant list and results

Participant	**Sex**	**Height (cm)**	**Perception Rating (1-9)**
A*	Female	166	7
B*	Female	157	7
C*	Male	188	5
D*	Female	162	8
E*	Male	173	7
F*	Male	177	8
G*	Male	181	8
H*	Female	166	8
I*	Male	190	7
J*	Male	178	7
K*	Female	160	7
L*	Male	174	6

* Denotes participant is different from baseline test participant of the same letter

Below are some participants comments on during this phase of the test that are relevant to the study:

Participant A*:

- 'The foam looks soft'
- 'The front of the seat base looks too high, like it might cut off circulation to my legs'

Participant B*:

- ‘I like it when I’m tipped back in a seat so it kinda (sic) holds me, looks like this one will do that’

Participant C*:

- ‘The position of the seat base looks comfortable but the back looks too upright’
- ‘I’m not sure about the flat surface of the seat, if it’s soft and spongey it might be okay but if it’s firm then I think it will be uncomfortable’
- ‘There doesn’t seem to be any support for the lower back, I’d also be concerned that it would push my head or shoulders too far forward’

Participant D*:

- ‘Looks comfy’

Participant E*:

- ‘Looks like you will sink into it, so I reckon it’ll be comfortable’
- ‘If it was going to be used in a vehicle it might need to be shaped a bit more to stop you slipping out of it when you go round a corner’

Participant F*:

- ‘That foam looks like it would be warm to sit on, which would be good on a cold day but might be too hot on a warm day’

Participant G*:

- ‘Looks like it’s at a good angle but the foam looks quite flat and might not give much support to my lower back which is something I often notice in seats’

Participant H*:

- ‘Looks soft’

Participant I:

- ‘Looks too upright on the back’
- ‘The base looks too low for someone my height’
- ‘I think it could do with an arm rest’

Participant J*:

- ‘I like that the seat back doesn’t go too high and it usually pushes my head forward which is uncomfortable on my neck’

Participant K*:

- ‘Seat looks a bit high; I think it’s going to dig into the back of my legs and be uncomfortable if I sit in it for more than five minutes’
- ‘It might be more comfortable if it had armrests’
- ‘The back of the seat looks kinda (sic) high’
- ‘I guess it’s only a test seat but there is no material on it which I think would change my opinion of how comfortable I thought it was going to be but I guess it depends on what material it was’

Participant L*:

- ‘Looks comfortable but could do with being reclined a bit less, I like the seat to help support good posture’

4.2.2 Primary Test Phase 2 – Experience

The second phase of the test was conducted directly after the first part for each participant so when participant A* had given their answer to the perception question, they were then asked to complete part 2 of the test.

The second part of the test was to allow the participant to sit in the seat and adjust it to find their optimal position. As with the first part of the test, the participants were briefed using a script to ensure that that there was no variation between the information each participant received. The script for the second part of the primary test was as follows:

‘Are you happy to proceed to the second stage of the test? [Participant response assumed positive for script] As with the first part of the test, you will continue to assess the seat in the context of vehicular seating. In this stage of the test you are required to find the most comfortable seating position for you, by adjusting the following variables: Seat base angle, Seat base height, Seat back angle and Seat back height. [At this point a physical indication will be given to the participant as to which elements of the rig can be adjusted and in what way] I will be here to assist you with any adjustments you wish to make but will only make adjustments based on your direction. If you find that your most comfortable position is between two of the predefined locations on the hole board, please let me know and they can be changed to meet your request.

You have as long as you require to find the most comfortable position in the seat, when you have found this position please indicate this to me and I will note down the chosen position.

While I am doing this, please take a few seconds to consider how you would rate the comfort of the seat against the same criteria as the first test, on the 1-9 scale where 1 is ‘Not at all comfortable’ and 9 is ‘Supremely comfortable’.

[Once positional notation and rating have been recorded] This concludes the test, thank you for your participation.’

Figure 37 – Participant during experiment

Table 4 containing the results taken as part of the experiment, participants remain consistent from the first stage.

Table 4 – Participant results stage 2

Participant	Sex	Height (cm)	Perception Rating (1-9)	Seat Base Position	Seat Back Position
A*	Female	166	8	A5,E8	B7
B*	Female	157	9	A6,E8	B7
C*	Male	188	9	A4,F5	B3
D*	Female	162	9	A5, F7	B7
E*	Male	173	8	A4,E5	B7
F*	Male	177	9	A4,F6	G7
G*	Male	181	9	A5,F7	B7
H*	Female	166	8	A5,F6	G11
I*	Male	190	8	A4,F6	B7
J*	Male	178	7	A5,F6	G7
K*	Female	160	8	A6,E8	G7
L*	Male	174	8	A5,F6	B7

As with the range finding exercise, the above results have been averaged to create a more controlled 'average comfortable position'. This has been defined as A5,F6, B7 but was only exactly selected by one participant during the primary test.

The average comfort score across all participants when allowed to edit the geometry to their individual preferences was 8.3. This was compared to the average position as defined above through the secondary phase in section 3.6.2.2.

4.2.3 Initial Conclusions from Primary Test

The results from the second stage of the primary test show a narrow range of seating geometries despite the broad range of participant anthropometrics, suggesting that it may be possible to have a position that although not the optimal for all participants, could be very close.

It is also insightful to see the differences in individual elements such as seat base angle between participants where the seat back position remains the same. An example of this is participant A who opted for a seat base position A5,E8 and participant D* whose response was A5 F7. In these instances, the results both come from female participants who had a

4cm difference in height meaning that the variation is likely to come from a non-measured physical variable or from participants perception to their experience of comfort when in the seat.

Two participants, H and J, did not improve their scores of comfort whilst all others increased them, with six participants rating their comfort at 9 out of 9. All six of these participants did not, however, agree on the positions of each element of the geometry. Participants D* and G* agreed not only with each other, but also with the initial results of the range finding exercise, specifying the same positions on the test rig. During the experiment, both participants made changes to their seating position in an attempt to improve their comfort experience in the seat, however, reverted to the original position claiming that it was the most comfortable. Although these participants only make up just under 17% of the overall results, their position seems to represent the average comfortable position.

One of the outputs from this element of testing was to determine an 'average optimal position' from the results. This was done in two ways, firstly by taking the results as full sets and selecting the set with the highest number of occurrences as defined below. This method sees sets of results used rather than individual positions as they interact with each other. Taking each position in isolation could theoretically end up with the final resultant position of the seat being one that no participant selected and at an angle that would not be considered comfortable. Despite this risk, results were also analysed in isolation and then compiled - the risk previously stated was significantly mitigated by the fact that the results were very close in proximity meaning that the average position calculated in this way may give a more accurate representation of the results gathered.

4.2.4 Result frequency and optimal position calculations

Positional Results by Sets

The results in table 5 where the whole set match exactly have been highlighted in yellow.

Table 5 – Positional results by sets

Participant	Seat Base Position	Seat Back Position
A*	A5,E8	B7
B*	A6,E8	B7
C*	A4,F5	B3
D*	A5, F7	B7
E*	A4,E5	B7
F*	A4,F6	G7
G*	A5,F7	B7
H*	A5,F6	G11
I*	A4,F6	B7
J*	A5,F6	G7
K*	A6,E8	G7
L*	A5,F6	B7

This data shows that there is only one set that overlaps entirely with another, A5,F7,B7 meaning that using this method this result becomes the 'average optimal position'.

Positional Results by Individual Results

The most common results that match for each data element have been highlighted in the same colour in table 6 to show the most chosen hole board positions by the participants.

Table 6 – Positional results by individual results

Participant	Seat Base Position	Seat Back Position
A*	A5,E8	B7
B*	A6,E8	B7
C*	A4,F5	B3
D*	A5, F7	B7
E*	A4,E5	B7
F*	A4,F6	G7
G*	A5,F7	B7
H*	A5,F6	G11
I*	A4,F6	B7
J*	A5,F6	G7
K*	A6,E8	G7
L*	A5,F6	B7

Analysing the data in this manner gives a slightly different result of A5,F6,B7 for the seating position.

These two positions are extremely close, meaning that both methods lead to a very similar conclusion of position. For the secondary phase of the test, the position of A5,F6,B7 has been selected due to the high number of occurrences and its close proximity to the result of analysing the results via sets.

4.3 Secondary Test (Validation)

The secondary test is designed to validate the results from the first test. The purpose is to conduct the same test without the variable of being able to change the position of the seat. The same participants were used during the second part of the test as for the first part, to achieve an accurate comparison. To further reduce the amount of influence that the adjustability offered in the first test made, the position of the rods in the hole boards was covered for this test. This also prohibited the participants knowing the position of the seat for the second stage of testing in case this had an influence on their feedback. The seat was set in the ‘average optimal position’ of A5,F6,B7 as defined in the first stage of testing.

Participants were then asked by use of a script to observe and rate their perception of seating comfort and then to interact with the seat by sitting in it but not adjusting it. As with the first element of the primary test, the participants were asked to provide their comfort rating after a minimum of 20 seconds and a maximum of 1 minute on the same 1-9 scale that has been used throughout the study.

The script for the participants was as follows:

‘This is the only phase of the secondary test in which you will be assessing a seat for seated comfort in the context of vehicular seating. During this phase of the test, you will enter the test room, there will be a white wall set up across the middle of the room with the test rig against it. When you see the test rig please pay attention to the geometry of the seat; this means the height and angle of the seat base and the seat back. At this stage of the test, please do not interact with the rig, you may walk around it to view it from different angles but please do not touch it. When you have had sufficient time to look at the rig please could you give me a perceived rating of comfort on a 1-9 scale where 1 is ‘not at all comfortable’ and 9 is ‘supremely comfortable’. Once you have given the figure you are happy with please sit in the seat, take 20 seconds to 1 minute to evaluate your level of comfort on the same scale and then give me a comfort rating. This will conclude the second and final element of the testing.‘

Due to the global Covid-19 health crisis it was not possible to conduct the second stage of testing via the method outlined in section 3.5. This decision was taken following a risk assessment and consultation with project supervisors Mark Phillips (Design Director - Design Futures), Prof Graham Cockerham (Emeritus Professor of Engineering Design) and Dr Becky Shaw (PhD Lead/ Postgraduate Research Tutor – Art and Design Research Centre at Sheffield Hallam University). It was decided that an alternative approach should be adopted, without the requirement for face to face contact.

It was agreed that by using virtual results, based upon the previous results, and indications from the literature review would represent a valid approach to produce an original testing methodology with which to analyse these results and to draw meaningful conclusions.

In table 7 are virtual results (created based on the previous results and knowledge of trends shown through the literature review) for the second stage of testing to demonstrate the testing methodology:

Table 7 – Second Stage Virtual Results

Participant	**Sex**	**Height (cm)**	**Perception Rating (1-9)**	**Interaction Rating (1-9)**
A*	Female	166	8	8
B*	Female	157	8	8
C*	Male	188	8	8
D*	Female	162	8	8
E*	Male	173	8	9
F*	Male	177	7	8
G*	Male	181	8	8
H*	Female	166	6	8
I*	Male	190	8	7
J*	Male	178	8	8
K*	Female	160	7	7
L*	Male	174	9	9

Chapter Five - Results Analysis

Virtual analysis

The results from this element of testing show a link between the perceived rating of comfort of each participant and the interaction rating. In eight out of twelve cases the rating remains the same from perception to experience, in three of the twelve cases it increases when the participant interacts with the seat and for participant L it decreases.

These results show that in an overwhelming majority in the cases studied, the user's perception of a seats comfort does not change following their initial sighting of it. Although only one seat was used (which the users had already sat in) the results still varied from their initial perception ratings even though the range finding exercise happened to predict the results of the second stage of the primary test.

The one result where a participant gave a higher perception rating than their experiential rating was in the instance of participant I who was a male participant with a height of 190cm, whose result during the initial stage of testing saw a higher frontal position on the seat base. It is important to note that participant I was the tallest participant involved in the experiment and so represents the outer most point on the height distribution range. This in turn means that he will be unlikely to find the 'average optimal position' as comfortable as his personal optimal as it will diverge more significantly than for other participants.

The link between perception of comfort and experienced comfort appears to be strong as shown through these results. This testing method has also shown that it is possible to determine a seating position in which the majority of people, as represented by this study, will perceive to be comfortable prior to sitting in it. Despite the final result being the same as the result of the range finding exercise, it has value in confirming the position as a more widely accepted seating geometry that people perceive as comfortable.

The remainder of this chapter seeks to conclude the research as gathered up to this point and to suggest how the research could be continued (as a separate research study to this MPhil submission) when safe to do so.

5.1 Influence of Results on Emerging Test Methodology

Perception of a seat has an influence on the comfort experience by the user whilst sitting in it. One way to create a more comfortable seat is to create the perception of comfort to the user prior to their physical engagement with the seat, thus influencing their experience. As investigated through this study, the geometry of the seat is a significant factor in the perceived comfort rating and experience of the user. Based on the comments made by participants through all stages of the investigation, other factors that affect the users' perception of comfort in a seat are: the texture of the seating surface, the contours of the seating surface and the overall appearance of the seat e.g. if it appears to be a luxurious seat or to have specific comfort enhancing features. This is a reductive and subjective list based upon the participants' feedback during this study, however, it is logical to reason that the subjective nature of comfort will be made up of diverse facets in differing amounts depending on the individual. This means that although there will be some seating features that may be widely perceived as comfortable, there will be no 'one size fits all' design for a comfortable seat.

This thesis set out to determine a testing method for investigating design perception, ergonomic and structural factors influencing vehicle seat comfort. The results are not only illuminating for their value as part of the test, but also as a method for understanding the testing method. As discussed previously, they have helped to highlight some of the issues associated with the process and pointed to techniques where the testing strategy could be improved. However, they have also shown that the system is a helpful tool to understand the complex and interlinked variables of perception, ergonomics and seating geometry, as defined in the aims of this project. This testing methodology could, therefore, be used to test similar variables across different settings that value this level of in-depth information, such as seating features e.g. bolsters, seating fabrics and a wide range of geometrical changes.

Through the commercial link with Stylex Auto Products, who design seating solutions for the automotive and leisure sectors, this methodology is likely to be a valuable asset in assessing consumer opinion during the development phase of the design process. Using a testing strategy such as this, could have significant commercial and financial benefits, especially when applied to a larger sample group of the specific target demographic of the product (e.g. older adults for leisure vehicles)

It would also be possible to modify this research approach to focus on different elements of the seating design, such as seating surfaces e.g. textiles, seating surface form e.g. curvature of the seat, seating features e.g. bolsters and seating build and finish e.g. types of material used throughout the product. This could be achieved by changing the variable in the initial and subsequent stages of testing, from seating geometry to the desired element of study. The testing methodology is a framework to help the user understand the effects of perception of a specific element on a sample user base and give insight into its impact on user experience.

5.2 Possible limitations/ Experimentation Method Improvements

On reflection, there are a number of ways in which the experimentation method could be developed and improved which are discussed in this section.

Due to the fact that the user was asked in front of the experimenter to make the adjustments to the seat, there may have been a desire to rate the comfort of the new seating geometry as more comfortable than it was as, as participants may not want to appear that they did not know what they were doing and wanted to make it seem as if the adjustments they had made created an improvement. It could also be argued that the geometry defined in the range finding exercise was the most accommodating to the greatest number and so the test was inadvertently asking participants to make changes, if any, moving away from this position by setting it as the default position. This also poses the question of whether or not the testing environment should have been the participant alone and unobserved to avoid potential influence from the observer. The environment may have also benefited from the position markers being covered (this would have required the design of a new rig) so that the user could create changes without knowing what the baseline position was.

It is possible that better results could have been obtained if the test rig was initially intentionally positioned at an uncomfortable angle meaning that it would be unlikely for any participant to find the baseline position the most comfortable. This would have eliminated or seriously mitigated the feeling of having not achieved anything by the participant if they stated that the most comfortable position mirrored the default position of the rig at the start of the study.

Another element not addressed through this study that does have a significant influence on user comfort in vehicle seating, is the length of time spent in the seat and the physiological and psychological effect that has on the users experience of comfort. This could be achieved by elongating the second element of testing or by building in an additional testing phase which simulated the sitting environment and duration more thoroughly, allowing for the variables being studied to be analysed over a longer period and their effects measured.

In hindsight, although addressed through the preliminary study details and in the script for the study, the test rig should have had a generic cover applied to the foam to more closely simulate the seating environment it was attempting to represent. This may have made the rig appear to be more like a vehicular seat like to the participants and so helped them to think of the seat in the right context.

5.3 Revisions to Experimentation Methodology

Conducting the experiment using the theoretical methodology devised from the literature review and understanding of the industry's demand for specific relevant information has allowed for any defects in this methodology to be highlighted prior to the system being used in a commercial context. Using the lessons learned through this process, the methodology can be refined to create a more efficient process. Below are the details of some changes made to the original approach, based on the learning experience above.

Range Finding:

This stage of the test was initially illuminating and had the intention of finding a good baseline for the start of the process. In the case study above this process produced the final result, using a process like this an outcome of this nature is always possible, even likely. Although this element of the process was intended to be helpful it runs the risk of pre-empting the initial stage of testing. This could happen by putting the participant in a position where they feel they are expected to change the seating position to find a more comfortable one and may have a reluctance or bias to return to the original position and admit that this was the most comfortable. Were this not the case, the value that it adds to the results gained through the experiment is very minimal, its benefit is limited to the initial visual appraisal by the participant at which point there would be merit in this being conducted on a seat with geometry that differs more significantly to the final result although this is not necessarily predictable. Due to these factors this element of the test would be removed. This, however, presents its own problem in that the seat does need to be positioned prior to the start of the initial test. However, by making this a randomised position this serves to blind the person conducting the experiment and serves to remove the potential bias.

Primary Test Phase 1:

This stage of testing is for the participant to visually evaluate the seat and is the first opportunity they have to see it. This element of testing was successful, and the use of a script encouraged consistency across all participants. One modification to this stage would be to actively encourage participants to share their thoughts on the seat as they observed it. This did happen naturally to a degree during this phase and the participants comments were noted down, but actively asking participants to comment would give a better insight into the process of perception each participant went through. It would also allow for an understanding of the priority of perception for individual seating elements, meaning the experimenter could track the order of perception of significant elements.

Primary Test Phase 2:

This stage of the test is to allow the participant to interact with the seat and modify its geometry to suit their taste and then provide a rating of this. An area of improvement would be to allow the participant to sit in the seat which they have just provided a visual rating on and then provide an experiential rating which would give slightly more data. However, by doing this there is the same risk as the range finding element in that if the participant rated the seat as looking uncomfortable and then were to find that they were comfortable sitting in it, they may be less likely to contradict themselves and this could also have an impact on their willingness to change the seating geometry. A solution to this would be for the participant to be asked to write down their rating on a sheet of paper which was not visible to the experimenter, anonymised and placed into a ballet type box until all participants had finished this stage of the experiment thus removing the perception of pressure.

A further improvement that could be made to the process would be to have a rig which was more easily and quickly modifiable. Although it was not difficult to change positions on the test rig it was more time consuming than on that of a traditional car seat and so may have created an obstacle to participants wanting to make changes and experiment with their position. The test rig did, however, provide the opportunity to modify the relevant variables meaning that they system by which the testing was carried out was valid. Nonetheless, it could be improved by a mechanical redesign of the to create a more robust and easier to use system with which the participant could interact more easily on their own or in some cases ask for assistance with.

Secondary Test:

The purpose of the secondary test was to provide a method of validation for the primary test and additional insight into the process and influence that perception has on the participants experience of comfort. As mentioned previously, these results had to be simulated (due to the COVID-19 pandemic) to allow for the analysis of the system to take place. Although this meant that lessons could not be learned from the physical process of conducting this stage, there is value in assessing the process using virtual results. The test rig in this instance was set to the 'average optimal position' as defined by the first stage of testing, and the hole boards dictating the seats position covered. Participants were asked to rate the seat visually on the same 1-9 Likert scale as has been used throughout testing. They were then asked to sit in the seat and give another rating on the same scale as to their experience of comfort. Because each participant had already seen and experienced this seat, their perception rating will have been influenced by previous experience, however, it is still a valuable metric to track. The additional experience served to make their perception ratings and experiential ratings closer in the majority of cases. The participants were not informed of the specific position of the seat in this stage of testing to avoid influencing their ratings. Again, using a system of anonymised participant filled out questionnaires rather than asking the participant for their rating would have reduced the likelihood of bias from the experimenter or participant result manipulation due to the experimenter's influence.

Finally, the setup of the experiment that was carried out saw the test rig in a basic replica of a seating environment from a leisure vehicle from which the test rig measurements were taken. The context for the investigation was loosely set through the initial script but to remove more variables and help participants visualise the seat in its intended context it would be better if the rig was designed in such a way that the environment it occupies was more representative of the final intended environment.

5.4 Further Development and Next Steps

Based on the above analysis of the results from the investigative study some key topics were introduced these are:

- Seating texture
- Seating form
- Seating features
- Seating build and finish quality

To address these topics whilst taking into account the feedback from the participants detailed earlier in the study, it was decided that an investigation into the fabric and visual surface condition of the seat would be needed. Although the investigation into this is not complete, a road map to achieve investigation into these elements is laid out as a proposal for further study in the following chapter.

Chapter Six – Seating Technology

As mentioned previously, due to the impact of Covid-19, face to face testing was not possible. The research was continued by analysing the testing conducted up to this point and creating virtual results which were used to advance through the testing methodology. Although this element of the testing methodology was not going to be physically conducted, trial tests were going to be made in order to validate the approach being advocated. As this was not possible, the following testing programme is based upon the testing that was possible to conduct, the lessons learned, and results gained.

During the early stage of testing, a participant commented on the seating surface and another on the appearance of the seat itself, this led to the investigation as to how the seating surface could influence comfort. Although physical testing was not possible in the following sections, developmental strides are made into a method of testing the influence these elements have.

These theoretical test plans use the above methodologies with small adjustments to allow them to be used on a wider range of variables.

6.1 Seating Surfaces

6.1.1 Definition

The seating surface is the element(s) of the seat that come into contact with the user when sitting in the seat. Typically, this will be the fabric on the seat base, seat back and head rest, elements may be included or excluded based on the seat such as arm rests. Different seating fabrics and coverings have different properties which can be used to influence the user’s perception of the seat and their experience when using it.

6.1.2 Examples

In figures 38 and 39 are some examples of automotive seating surfaces

Figure 38 – Textile Automotive Seat Upholstery (WikiHow, 2019)

Cloth or textile upholstery used in automotive seating applications.

Figure 39 – Leather Automotive Seat Upholstery (Genesis Motors LLC, 2020)

Leather seat upholstery with design stitching and perforation.

6.1.3 Test Method

The testing methodology and revised testing methodology described and demonstrated previously in this body of work can be modified to suit the testing of seating surfaces. The key elements of the test programme would remain the same. Below is an outline of how the test would be conducted for researchers trying to understand the effect of perception and user experience on comfort of different fabric types for an automotive seating application.

Scripted set up:

At this stage, the experimenter would need to set up the test with the participant, explaining to them all that is expected of them and setting the scene with relevant information such as the context. As mentioned previously the optimal location for the test rig would be in a representative final environment for the seat being developed to give the most accurate, relevant results, in this case in a car. In the absence of this, as with the test conducted previously, the environment should be mentioned in the script to help the user visualise the final environment.

Primary Test Phase 1:

The primary stage would run in much the same way as the test demonstration but instead of having a range finding exercise to determine an initial position a baseline seating surface e.g. a plain automotive fabric should be used. The banality of this fabric would be important in this specific application to avoid the effects of priming as mentioned in the literature review. The participant would then be asked to rate the seat on the defined scale in the same way as in the initial test.

Primary Test Phase 2:

The second element of the test should also rely on the instructions being given using a script as defined in the methodology. The participant would then be asked to sit in the seat and give the rating according to the test plan. In this example of seating fabrics, this first stage will be significant due to the highly visual nature of the variable being tested. The participant would then be invited to swap the seating fabric for other pre-made covers to find the one they perceive to be the most comfortable. This, as with the previous example, would be a combination of visual perception and user experience.

Secondary Test:

In this example, the second stage of the test may be used as validation, but due to the visual nature of the variable it may not be required. If it were to be used, the 'average optimal' seat cover selected by the participants would then be shown to all the participants and they would be asked to rate their perception and experience of comfort with it. It is important that the participants are not given access to their previous results at this time in case they cause a change in the feedback in the second stage.

Results:

Results would be collected digitally during the test and collated into the tables as demonstrated in the physical trial of this method earlier.

6.2 Seating Surface Form and Features

6.2.1 Definition

The term seating surface form in this context is used to refer to the curvature of the seating surfaces rather than the wider appearance of the seat. The primary study in this paper addresses the topic of seating geometry through the main planes of movement for vehicle seats, the form would be an element of the seat that in most vehicular seats is not adjustable. Seating features are elements that are created as part of underlying structure of the seat that are typically evident in the final seating design. Elements such as bolsters, lumbar support and arm rests are all examples of seating features. Whilst they are not required in a seat, they are often used to improve the appearance, comfort perception and user experience.

6.2.2 Examples

Figure 40 – Bolstered seat (Takawane, 2019)

Automotive seat with bolsters on seat base and backrest.

Figure 41 – Automotive seat with cover partly removed (Indiamart, 2010)

Seat with partly removed cover showing the individual PU foam structural elements and tiedown (places where the cover is anchored to the underlying seat structure) points.

6.2.3 Test Method

Scripted Set Up:

As with the previous example, the experimenter would need to set up the test with the participant, explaining to them all that is expected of them and setting the scene with relevant information such as the context if not physically available. At this stage, the experimenter would need to explain the focus of the study and what can be adjusted during the second part of the first stage. The participant will be asked to record all their personal scores digitally as a method of anonymising their results to the experimenter during the test.

Primary Test Phase 1:

The primary test first stage would be the participants first opportunity to see the seat and provide a perception rating on the nine point scale of the seat in its baseline position without any physical interaction by way of digital input via a tablet.

Primary Test Phase 2:

Part two involves the participant sitting in the seat in the baseline position and providing a comfort rating after 20 seconds. They are then permitted to make changes in line with the variables being studied, in this example they would be permitted to change the angle of the seat base and back bolsters in relation to the respective seating element and the distance between seat set of bolsters. Once the participant has found what they would consider to be the most comfortable position for them, they would input their comfort score digitally.

Secondary Test:

The secondary test would take the average position of all of the participants 'optimal positions' and apply this to the test rig. The participants would then be asked to provide a perception rating of this set up in the same manner as the first stage of the primary test and then to sit in the seat and provide another comfort experience rating of this set up. These results would all be taken digitally and anonymously.

Results:

Results would be collected digitally during the test and collated into the tables as demonstrated in the physical trial of this method earlier. The larger the sample size of participants the more detailed the data could be. This study is a trial of the methodology to demonstrate its utility, its intended user is likely to make a greater investment of time and cost and therefore the scale of the study could be greatly increased.

6.3 Seat Build and Finish

6.3.1 Definition

Seat build and finish in this context refers to the overall feeling of solid construction and the quality to which the seat is finished to the user. An extreme example of how this might be different between two seats is the difference between the feel of a folding garden chair and a Chesterfield lounge chair (as illustrated in figure 42 and 43). Although both are adequate for sitting in, there is a distinct difference to the user in appearance, build quality and experience. In many ways, this overlaps with the previous two points but has been split from them in order to take a more holistic view of the seat in this instance.

6.3.2 Examples

Figure 42 – Folding Garden Chair (Wuyi HangHang Leisure Products, 2020)

Folding garden chair for reference of low perceived and experienced build quality and finish.

Figure 43 – Chesterfield Lounge Chair (DJC Electronics, 2020)

Chesterfield lounge chair for reference of high perceived and experience build quality.

6.3.3 Test Method

Scripted Set Up:

This element would remain in the same format as the previous example with the specific information pertaining to this test. Details of what this would contain are in the subsequent sections.

Primary Test Phase 1:

The initial observational rating in this instance would be conducted as with the previous examples where the participant is presented with the baseline seat and asked to record a perceived comfort rating.

Primary Test Phase 2:

The second part of this stage in this instance would be conducted in a different manner due to the nature of the variable being analysed. Seat build and finish encapsulates a number of variables, meaning that it is not feasible to have one test rig that could be changed. Whilst it may be that each of the individual variables may have been studied in its own version of this test, the notion of build and finish is a holistic notion, and so requires all variables to be studied at the same time. Therefore, instead of having a test rig that could be manipulated, there may be a number of different seats or rigs set up to represent the different permutations of the seat(s) being investigated.

The process for the participant, however, would be much the same as previous tests where they would record their experiential comfort score of the baseline seat having sat in it for 20 seconds. They would then find their 'optimal comfortable position' but in this case, it would their 'optimal comfortable seat' from the range they are presented with. The physical experience for the participant would be different from previous tests detailed in this chapter but the methodology remains the same.

Secondary Test:

The secondary test would see the participants presented with the seat most selected as optimal in the first stage. They would then be asked to provide a perception of comfort score and an experiential comfort score which would be recorded by the participant privately.

Results:

The results can be analysed in the same manner as the previous test owing to the consistent nature of the testing methodology.

Chapter Seven - Discussion and Conclusion

7.1 Discussion

The purpose of this body of work was to create a testing methodology that could be used to investigate, design perception, ergonomic and structural factors in vehicle seating. The process of developing the model of testing was based on a broad review of academic and industry research and testing methods used to analyse similar aspects of vehicular seating.

Taking insights from this review, a test strategy was devised that allowed the user to conduct a trial experiment using this methodology. This was facilitated by Sheffield Hallam University where a test rig allowing for the modification and study of specific elements of seating geometry was built. The rig allowed for modification in each variable selected for study.

The trial experiment was run using a group of participants to load test the process and give insight into the real-world outcomes of a theoretical test design. This test, despite not being safe to conclude due to COVID-19, proved that it was capable of producing meaningful results that could give insight into the effects of design perception, ergonomic and structural factors in vehicle seating.

The physical creation and trial of the testing equipment and strategy proved valuable in highlighting areas for improvement which would have been overlooked if this pilot study had not been performed. These areas included the understanding that the range finding exercise may have had a negative impact on the participants' responses during the test and that the results would have benefitted from the participants being able to anonymously note down their responses during the experiment.

The methodology was then adapted to incorporate the lessons learned through this, and theoretically applied to three different variables that may be tested in relation to vehicular seating. During this phase, it was clear that some adaptation of the test plan would be needed to provide the best results possible, but that the core programme would remain the same. This flexible approach to the touchpoints of the study results in a methodology that can be used widely to understand and validate user perception and experience in vehicular seating applications. Additional lessons were learned through this exercise and applied to the base methodology to improve the results, such as recording the participants age as well as sex and height to give an additional relevant metric through which the data could be analysed.

Hands on testing augmented the development of the testing methodology. The additional rigour of creating an environment where testing was possible and conducting the experiment provided significant additional information not considered in a theoretical test set up.

7.2 Original Testing Methodology

Through this testing programme, the original methodology (as developed in theoretical form from the literature review) has been modified based on the lessons learned. Below is the final structure as proposed in this thesis.

7.2.1 Preliminary Set Up:

During the preliminary set up phase a number of key elements, based on the seat or seating element being tested, need to be established. Below is a list of the critical points that need to be addressed, these points represent the minimum number of elements that must be defined prior to the start of the experiment.

- Final seating environment
- Final user demographic
- The test seating environment
- The test participant demographic
- Participant metrics
- The test rig(s)

- The variables to be tested
- Outcomes sought (what is to be analysed)

Defining these points allows for the testing plan to be implemented as they define the parameters of the test. Points such as the test rig need to be able to accommodate the variables needed during the research. Participants should be selected from a representative demographic or across representative demographics to promote correlation of test results to real world experience.

7.2.2 Scripted Set Up:

A script is required for use with participants prior to the first stage of testing to ensure that they have all the information they need to complete the test in the required manner. It is crucial that a script is used and adhered to, to guarantee that all participants are given exactly the same information in the same manner thus reducing the chance of bias unintentionally or otherwise.

7.2.3 Primary Test Phase 1:

The first part of the primary test is designed to measure the participants perception of comfort in the seat under analysis. They will have been asked to rate the seat according to the 9-point scale prior to interacting with it and note down any of their initial thoughts on the seat or seating element in question, depending on the test parameters. The purpose of this is to understand what their initial impressions are and, therefore, to provide insight into what the user notices and in what order, and how it influences their comfort rating.

All results are recorded digitally as a method of anonymising the results to the experimenter during the experiment. The participant will have been made aware that during the analysis phase of the test their score will be linked with the metrics of their body as requested at the start of the experiment e.g. sex, height and age. Other personal information will not be used as part of the experiment to remove links to specific individuals and their responses.

7.2.4 Primary Test Phase 2:

The second stage of the primary test records two specific data points along with any additional verbal feedback or notes the participant provides. This stage of the test is focused on the participants first physical interaction with the seat. The first data point is their initial reaction to the seats comfort in its baseline state i.e. without making any modifications to the seat over that which they observed in the first part of stage one. This rating should be recorded between 20 seconds and one minute after the participant sits down to give them time to collect their thoughts on the seat, decide on a rating and then record it. The time scale on this element is short to promote the participant feeding back their initial response to the seat.

The second element of part two is the participants opportunity to interact with the variable in question on the seat and find their optimal set up. Once this has been done, the position and comfort score is recorded. All comfort scores use the same 9-point scale as defined previously.

7.2.5 Secondary Test:

The secondary test seeks to examine the response of all candidates to the most commonly selected version of the variant being studied. This stage of test is underpinned by the demographic of the participants in the study being representative of the final users to give a result which is common with the final users of the seat.

The test rig should be set up in the most common optimal position and participants asked by use of a script to give their perceptive score as with the first part of the primary test and then to sit in the seat and record their experiential score as with the first element of the second part of the primary test. Alongside the numerical ratings participants are also able to make comments on their thought and opinions during the process.

This is the conclusion of the participants involvement in the study.

7.2.6 Results:

Results from all stages of the test will be a participant's metrics and a set of comfort scores which will be single digit ratings on the comfort scale. Each one will have been given in a specific situation and may be bolstered by additional participant comments giving reasoning or insight into the reason for their score or comments on their thoughts during the process.

Depending on the variables being measured, different elements of the testing results may be more important than others. The testing methodology does not give prescriptive feedback on data gained, but presents a framework through which to consistently and rigorously collect relevant information across a wide range of variables.

The data collected is subjective to the individual participant and their experience but when paired with the anthropometric data gives significant insight into trends across data sets once compared. The results are dependent on the data collected, which was defined at the start in the preliminary set up; changing the amount or type of information gathered at this point allows the test method to produce data that is specifically relevant to the variable in question. Equally, due to the flexible nature of the methodology, it is possible to add and remove measurement parameters to decrease the amount of time and resource research of this type takes to conduct.

7.3. Conclusion

At the outset of this project the initial aims were as follows:

- To achieve a holistic understanding of perception, human factors and structural factors influencing user comfort in vehicle seating

- To produce a flexible testing methodology through which understanding of the three key areas of design perception, ergonomic and structural factors in vehicle seating comfort can be measured.

- To produce a framework through which it is possible to identify human comfort in vehicle seating. The methodology should allow for the collection of data and suggestions to form a basis for designs that can be deployed to deliver higher levels of user acceptance and comfort, both real and perceived prior to interaction.

In essence, to understand what factors influence comfort, a structure designed to measure these and a process of data collection that can be used to inform design strategies for future vehicle seating.

The above testing methodology incorporates the learning and understanding gained through the literature review into the way humans experience comfort in vehicle seating. This was then broken down into three areas which were used as the basis for the development of the testing methodology, these are:

- Design Perception
- Ergonomic Factors
- Structural Factors

The methodology addresses each of these factors through its process of analysis of variables in seating, the output of which is subjective data linked to ergonomic data and seating structural data that can be used to inform the design of future seating.

Clearly this is a complex issue and a methodology that allows a researcher to balance these three factors identified against each other will produce the best results. This methodology has the opportunity to do so and is a feature which distinguishes it from other testing methodologies. This methodology allows for the influence of these factors to be identified and incorporated into seating design. The methodology can also be run multiple times focusing on different variables of the same seat, yielding a complete set of results which can be used to inform design decisions.

Finally, this design methodology is an ideal process to be used in a commercial setting as it requires a small amount of initial set up work, and can be conducted by one experimenter who is able to tailor the test to focus on the variables of interest. This flexibility and ease of use are critical characteristics in the vehicle seating design in a commercial setting. A testing methodology such as this combines the requirement for data from three key and interconnected areas of seating design with a cost effective and resource-light process that yields valuable research data and insights. This is a powerful tool for any company seeking to critically inform their design process that could lead to desirable and differentiated product offers in today's highly competitive automotive markets.

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Appendix

Appendix A - Participant information sheet

Participant Information Sheet

Investigation of design perception, ergonomic and structural factors influencing vehicle seat comfort

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Introduction
I would like to invite you to take part in a research study. Before you decide to do so, I would like you to understand why the research is being done and what it would involve for you. Please take time to read the following information carefully. Please ask me if there is anything that is not clear or if you would like more information. Please take time to decide whether or not to take part.

Which organisation is sponsoring the research?
The research is being sponsored by Sheffield Hallam University as part of our Post Graduate research programme in Art & Design.

Overview of the research study
This study is designed to create and test an investigative methodology with which to inform the design and development process for vehicular seating.

Legal basis for research for studies
The University undertakes research as part of its function for the community under its legal status. Data protection allows us to use personal data for research with appropriate safeguards in place under the legal basis of **public tasks that are in the public interest.** A full statement of your rights can be found at https://www.shu.ac.uk/about-this-website/privacy-policy/privacy-notices/privacy-notice-for-research. However, all University research is reviewed to ensure that participants are treated appropriately and their rights respected.

Why have I been invited?
I am interested in talking to people who use vehicular seating, this can be from any demographic as I am seeking the broadest range of participants available. If this applies to you, I would be pleased to invite you to take part in the research study.

Do I have to take part?
It is up to you to decide whether or not to take part. This document describes the study and explains its purpose, and what will happen to the data collected. If you **do** decide to take part, you should keep this sheet. You will be asked to give your consent to take part in the research before you take part in discussions online. You can withdraw at any time during the online exercise, without giving a reason and without prejudice, before submitting any responses or information, or you can decide not to answer a particular question. After submission, information is processed in such a way that it becomes anonymous so your identity cannot be determined.

What will taking part involve?

If you decide to take part, you will be invited to respond to some questions regarding your perception and experiential comfort of a seating rig. These will be recorded on a 1-9 scale which will be fully explained to you and you will be free to make any additional comments on your perception and experience of comfort during the process.

How often will I have to take part, and for how long?

I envisage two 30 minute sessions on one day, however, if you would like to continue to be involved with the group or with any projects of particular interest, we would welcome further discussions.

Where will this take place?

The research session/s will take place at Sheffield Hallam University in the C3RI building on Arundel Street.

What are the advantages and possible disadvantages or risks of taking part?

Whilst we don't envisage any benefits to the participants, we hope that the information we obtain from the study will help to increase our understanding of seating comfort and design perception which will be helpful in developing the testing methodology which is the aim of the project. I hope that these insights will lead to informing design proposals that, if produced, may help to improve vehicular seating comfort in the future. The research team do not foresee any disadvantages or risks involved in taking part.

How will my information be kept?

All the information collected about you during the course of the research will be kept strictly in accordance with the Data Protection Act (1998). You will not be able to be identified in any reports or publications without your specific consent.

Will anyone be able to connect me with what is recorded and reported?

All information that identifies you will be removed from any reports or publications. We typically use a coding system that only identifies people involved in research by coding, e.g. 'Participant A', by gender and by age group, e.g. 34-45. If you agree to any images being used as part of the research, your identity will be anonymized (obscured).

Who will be responsible for all of the information when this study is over

Mark Phillips, Design Director, Design Futures, Sheffield Hallam University

Has this research study been ethically reviewed?

This research study has been reviewed in line with Sheffield Hallam University's Research Ethics Policy.

How can I find out about the results of the study?

I will contact you and ask if you would like to receive summaries of the design project outcomes. If you do, I will send a summary of the project outcome.

Contact for further information

If you would like further information about the research, please contact the project supervisor/s, using the contact details at the end of this information sheet. Details of who to contact if you have any concerns, if adverse effects occur after the study or if you have any complaints, are also provided at the end of this information sheet.

Next Steps

If you do decide to take part in the research, please follow the instructions in the email invitation.

Research team details:

Researcher/s:
James Devlin, Research Student, Sheffield Hallam University

Supervisor/s:

Prof Graham Cockerham, Professor of Engineering Design, Sheffield Hallam University

Mark Phillips, Design Director, Design Futures, Sheffield Hallam University
m.r.phillips@shu.ac.uk / [redacted]

<table>
<tr>
<td>You should contact the Data Protection Officer if:

• you have a query about how your data is used by the University
• you would like to report a data security breach (e.g. if you think your personal data has been lost or disclosed inappropriately)
• you would like to complain about how the University has used your personal data

DPO@shu.ac.uk</td>
<td>You should contact the Head of Research Ethics (Professor Ann Macaskill) if:

• you have concerns with how the research was undertaken or how you were treated

a.macaskill@shu.ac.uk</td>
</tr>
<tr>
<td colspan="2">Postal address: Sheffield Hallam University, Howard Street, Sheffield, S1 1WBT, UK
Telephone: [redacted]</td>
</tr>
</table>

Thank you
I would like to thank you for taking the time to read this participant information sheet and for your interest in this research. If you choose to take part, your responses will be extremely helpful.

Appendix B – Consent Form

Sheffield Hallam University

Consent form – Participants

Evaluation of a proposed new seating system for vehicles

Please read and confirm your consent to participate in this evaluation by ticking the appropriate boxes and signing and dating this form.

1	I confirm that the purpose of the evaluation has been explained to me, that I have been given information about it in writing and read it, and that I have had the opportunity to ask questions about the evaluation and have had these answered satisfactorily.	☐
2	I understand that my participation is voluntary, and that I am free to withdraw at any time without giving any reason and without any implications for my legal rights.	☐
3	I understand that annoymised data (including anthopometric measurements) and annoymised photographs may be used in research publications and I hereby give consent.	☐
4	I understand that all personal and interview data will be kept confidential at all times.	☐
5	I agree to take part in this evaluation.	☐

Agreement

Name of participant: ……………………………………

Signature: ……………………………………

Date: ……………………………………

Contact phone: ……………………………………

Contact email: ……………………………………

Information supplied will be used by Sheffield Hallam University in accordance with The Data Protection Act 1998 and other applicable legislation.

Name of person taking consent: ……………………………………

Signature: ……………………………………

Date: ……………………………………

Consent form S-TS R1.docx Page 1 of 1