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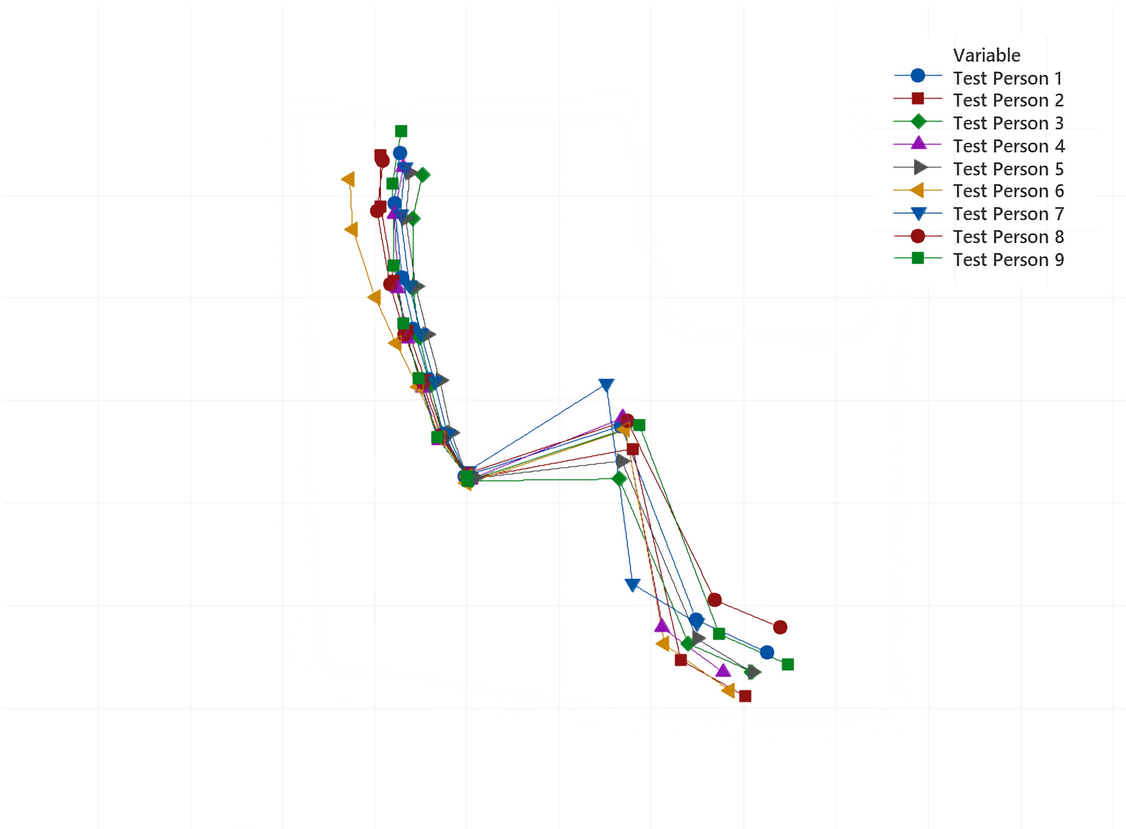

Evaluation of slouched sitting postures of rear seated car passengers

A study of parameters with a focus on influence over time

Master's thesis in Product Development

RASMUS ANDREASSON PERSSON, JONAS LARSON

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2021
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Cover: A visual representation of the different postures of the test persons in test configuration 3.

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Abstract

To evaluate passenger safety in cars, crash tests and simulations are often conducted. When doing these tests or simulations, the dummies are placed in standardised positions, called the nominal sitting postures. However, these sitting postures usually do not represent how real people sit in cars. Occupants often change their sitting posture from time to time to achieve better comfort. One possible sitting posture is called slouching, where the hips usually moves forward, the pelvis is angled and the upper body slides down. This cause the belt not to function in the way it is intended to do and could thereby lead to implications during a crash.

This study's main purpose is to identify and evaluate different parameters that contribute to slouching as well as studying how the comfort experience is affected. To achieve this, the study was split into three different stages, being pre-study, parameter evaluation and parameter evaluation over time.

The pre-study aimed to find parameters through benchmarking, literature studies and conducting smaller tests. It provided information on which parameters could be worth testing to evaluate the influence of slouching.
In the first study, the parameter evaluation, the results of the pre- study were used to decide which parameters to test further. Ten persons were selected to sit in five different seats that were modified to test different parameters. The results showed that the wool mix upholstery had the highest tendency to slouch while the lower sitting height had the worst comfort scores among the parameters tested.

Based on the results of the first study, the second study examined slouching over time. Since slouching is connected to the sitting discomfort of the passenger over time, the lowered sitting height was selected to be further studied. The test was conducted over 30 minutes with 5 test persons. The subjective methods for parameter evaluation over time were a comfort evaluation form and interviews. The objective measurements were the ASIS measurement and photo analysis.

Based on the learning's from the user studies and the pre-study, a number of concepts were developed as inspiration for future product development. These solutions aimed to both improve the comfort as well as the safety of the passengers.

Keywords: Concept Development, Motion Capture System, Passenger Safety, Product Development, Sitting Posture, Slouching, User Study, Xsens.

Acknowledgements

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We would like to thank Peter Bäckström, curator at Saab Car Museum, for allowing us to test sit, measure and photograph a number of cars from their collection. Finally, we would like to thank the test persons who gave their time to help us with our research during these unusual covid-19 times.

Rasmus Andreasson Persson & Jonas Larson, Göteborg, August 2021

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List of acronyms and abbreviations

- **ASIS** — Anterior superior iliac spine, a landmark on the pelvic bone.
- **BEV** — Battery Electric Vehicle, a car with a fully electric powertrain powered by a battery.
- **Combi** — A car with larger cargo capacity. Sometimes also referred to as a 5-door.
- **Combi-cupé** — A mix of a sedan and a combi, it has the lager cargo capacity of a combi but the aerodynamic shape of a sedan.
- **Crossover** — A smaller SUV built on a regular passenger car platform.
- **Design position** — A standardised position of an adjustable interior part that is used as a reference, applicable for seats, steering wheel, mirrors etc.
- **ICE** — Internal Combustion Engine, a car with a traditional combustion based engine, most commonly using petrol or diesel as fuel.
- **IMU** — Inertial measurement unit, the sensors used by Xsens.
- **MYXX** — Model year XX.
- **PHEV** — Plugin Hybrid Electric Vehicle, a car with a traditional combustion engine supported by a smaller electric motor and battery.
- **Sedan** — A four door saloon car.
- **SUV** — Sport Utility Vehicle, a bigger car built as a body on frame.
- **Measuring point sticker** — Sticker used on specific points for easier measuring on images.
- **Xsens Awinda** — A sensor system marketed by Xsens Technologies B.V. using up to 27 battery powered wireless sensors to capture the movement of a person.

1
Introduction

1.1 Background

When evaluating passenger safety in cars, crash tests and simulations are conducted. When doing these tests or simulations, the dummies are placed in standardised positions from a safety point of view. This position can be referred to as the nominal sitting posture.

When sitting, occupants are changing their sitting posture to achieve better comfort from time to time and when that is done, the sitting load is spread out over a larger area of the body. This means that passengers have a larger range of sitting postures than the nominal position and this will affect the effectiveness of the safety equipment in the car.

One sitting posture is slouching. Slouching can be split into two types, upper body slouching and lower body slouching. In lower body slouching, the pelvis is rotated rearwards, and slide forward. This causes the person to slide down in the seat. This causes the position of the seat belt in relation to the body to change which will cause implications during a crash (Thorbole, 2015).

To create a comfortable and safe sitting experience, knowledge is needed on how passengers sit and how it varies over time.

1.2 Aim

The objectives of this study is:

- A literature study evaluating the current state of art in comfort research and factors effecting sitting postures
- Identify and evaluate factors contributing to slouched sitting posture
- Develop concepts to reduce slouching of passengers

1.3 Scope and delimitations

In order to achieve the desired results within the given time frame, a number of delimitations had to be set. Below are the delimitations along with motivations on why they were made.

- **Studies will only include adults**, this is a limitation specified by Volvo Cars.
- **Test persons will be employees and students currently at the Volvo Cars facilities**
- **All tests will be done in stationary vehicles**, this is to limit the time in close contact with the test persons.
- **A Volvo XC90 will be used for all tests**, this is to limit the variations between each test that possibly affects the test persons sitting.
- **No destructive modifications of cars will be made**, this is to keep the cars road legal and safe for future tests.
- **Modifications need to be built without need of help from the workshops**, this is because of the extended lead times and shut downs during COVID-19.
- **Concepts will be done as theoretical and digital/analogue mock-ups**, this is because of the extensive lead times to workshops due to limited personnel during the COVID-19 pandemic.
- **The number of persons at the test site will be strictly limited**, this is to reduce the risk of infections and keeping with current regulations.

2
Theory

This chapter presents information that will be useful to the reader in later chapters of the report.

2.1 Anatomy

Here some introductory information about the human anatomy is explained.

2.1.1 Pelvis

The pelvis is an irregular, bowl shaped bone connecting the spine to the femurs. In a full grown human it is comprised of four different bones. One of its major functions is to attach ligaments and muscles to support the abdomen as well as legs and hips.

The pelvis has several differences between male and females but the landmarks are in comparable places on both. Because of this, it is possible to compare measurements in between them both. The pelvis bone structure also varies in shape and angle from person to person (Drake et al., 2015).

There are three landmarks often used to the determining the rotation of the pelvis: Anterior Superior Iliac Spine (ASIS), iliac wing, and ischial tuberosities (Marani & Koch, 2014). In this project ASIS will be used. Images of the pelvis and ASIS can be seen in figure 2.1 and 2.2.

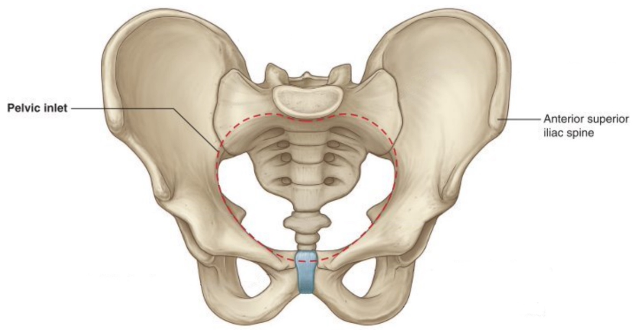

Figure 2.1: Image of the pelvis from the front. Source: (Grays Anatomy)

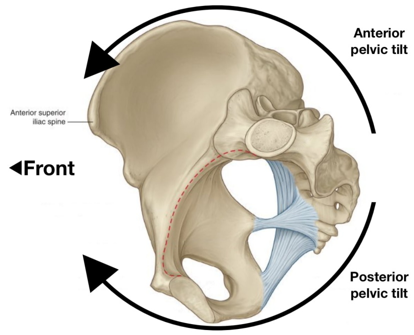

Figure 2.2: Image of the pelvis from the side. Source: (Grays Anatomy)

ASIS are two points on the pelvis that can be felt by the person themselves. This makes them useful as data points when no measurement equipment or trained personal can be used.

One way to detect slouching is to study the pelvic angle. This angle increases as the person slouches down in a posterior pelvic tilt, as can be seen in 2.2.

2.1.2 Spine

The spine consists of 24 movable vertebrae that are grouped into three different categories based on their location. These groups are from top to bottom: cervical vertebrae (C1-C7), thoracic vertebrae(T1-T12), lumbar vertebrae(L1-L5)(Berlin & Adams, 2017). For this study, the sacrum and coccyx(S1-S5), also known as the tailbone, will be relevant as well.

2.2 Crash safety

The seat belt is designed to position the lap belt underneath the ASIS points of the occupant. This allows the lap belt to restrain the occupant by the hips and reduce the risk of injury during a crash. If the pelvis slips underneath the lap belt in a crash, the risk if injury may increase. This is a phenomenon called submarining (Thorbole, 2015).

2.3 Comfort

Comfort has been defined in multiple ways by different researchers. One widely used definition states that comfort can be considered as the absence of discomfort (Hertzberg, 1958). Comfort is an important metric in product development, but since it is of subjective nature, it can be difficult to measure. With the definition that comfort is the inverse of discomfort, measurements of discomfort can be used instead.

On the other hand, discomfort can be subjectively ranked by comparing different setups having a well-defined scale that the test person can easily recognise. Another difficulty is that test persons can not compare too many different configurations. This is because it is difficult to remember subtle differences.

2.4 Slouching

In lower body slouching, the hips usually moves forward and the upper body slides down. This is caused by the pelvis rotating. The difference between nominal and slouched sitting postures can be seen in figure 2.3 and 2.4.

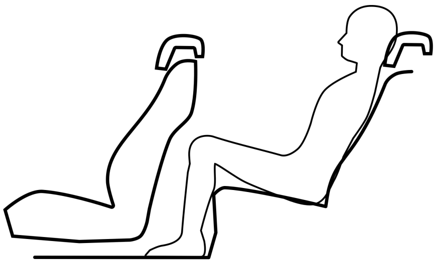

Figure 2.3: Image of a passenger sitting in a nominal posture

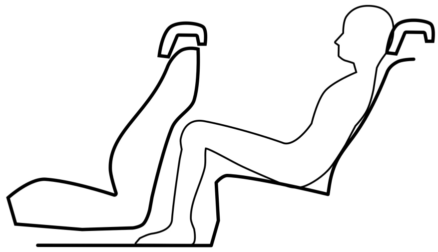

Figure 2.4: Image of a passenger sitting in a slouched posture

2.5 Method

2.5.1 Subjective methods

2.5.1.1 Comfort evaluation form

A comfort evaluation form is used to collect the opinions of the test person regarding their comfort. When constructing the form, a combination of images as well as scales or shorter questions can be used. Since comfort can be difficult to rate, it is often advised to rate discomfort instead.

2.5.1.2 Semi-structured interview

In a semi-structured interview, a set of questions are prepared in advance to ensure that certain pre-determined topics are covered during the interview. The interview is conducted in the form of a dialog between the interviewer and the interviewee. This allows for more detailed specific questions to be asked based on the interviewees answers (Galletta & Cross, 2013).

2.5.2 Objective methods

2.5.2.1 Photo analysis

Photo analysis is a method where the relative length is calculated based on a predefined scale in the image. The method used to calculate the distance can be seen in equation 2.1.

$$calculatedMove = \frac{definedDistM}{definedDistPix} * measuredPix \tag{2.1}$$

Where:

- calculatedMove is the calculated movement in millimetres
- definedDistM is the defined scale in millimetres
- definedDistPix is the defined scale in pixels

- measuredPix is the measured movement in pixels

There is a margin of error with this method. It does not take into consideration the movements of the measuring point in the cars XY-plane. For example, the knee point also moves based on how wide the person sits with their legs. This can cause the measurements to look like the person have lowered their legs and slouch less when, in fact, they are slouching more but also sit with their legs further apart.

2.5.2.2 Posture tracking system

There are currently a number of tracking systems on the market that are used for motion and posture tracking. One manufacturer is Xsens, which currently markets two product lines, MVN Awinda and MVN Link. In this project, the MVN Awinda is used for posture tracking. This system uses 17 sensor units placed on semi-defined locations on the test person, in combination with computer models, to estimate the position of the human body.

Each sensor unit does not measure its position in space. Instead, each sensor captures acceleration and rotation. This allows the system to build a model of the body's movement. This method is a good and simple way to get an approximation of the position and movement of the test person's body.

A Xsens sensor unit contains three types of sensors to achieve this:

- An accelerometer is used to monitor the linear movement.
- A gyroscope is used to monitor the rotational movement.
- A magnetometer is used to capture the magnetic fields.

These sensors are sensitive to magnetic fields which may disturb the measuring and result in a data noise. To prevent this, a magnetometer in the sensor measures the surrounding magnet fields to then, in the software, be able to compensate and create more accurate data.

In order to make it possible for the Xsens system to generate a manikin which match the test person, the height and shoe length needs to be measured.

2.5.3 Benchmarking

Benchmarking is done to learn and improve. It involves comparing competitors as well as internal data. The data tested is often objective, but some can also be subjective. The data collected is then compiled to determine best practices (Tuominen, 2016).

2.5.4 Brainstorming

Brainstorming is a method to generate creative ideas. It is done by having a group of people using their imagination to create or invent new ideas. It is of utmost importance that this environment is free from criticism in order for the group is open-minded and does not hold back its creativity (Dziak, 2020).

2.5.5 Pugh's matrix

A Pugh's matrix is used to eliminate the less significant parameters. This method is used to score concepts based on a weighted criteria score. This allows the user to evaluate the concepts in an unbiased and visual manner. At the beginning of the screening process, a set of criteria are set which are of importance to the final product. These criteria are then weighted based on their relative importance to each other. A baseline or reference concept is chosen. Based on this reference, each concept is scored based on how it compares for each criterion. The scores are 1, -1, or 0. These scores are then multiplied by the weighting of each criterion and summed to get the concept's final score (Flaschner, 1997).

3
Pre-study

3.1 Benchmark

In the car industry, benchmark is an integral part of the development process. It is used both as a comparison for your own products as well as getting an overview of where the industry is heading as a whole. In this project, both cars produced by Volvo Cars as well as cars produced by competitors were studied to get an insight into how different parameters of the rear seat affects slouching and sitting comfort. A standardised way to measure the cars rear seats were developed, see figure 3.1. This made it possible to compare the different cars and find similarities that could then be developed into configurations that were to be tested in the lab on the test persons.

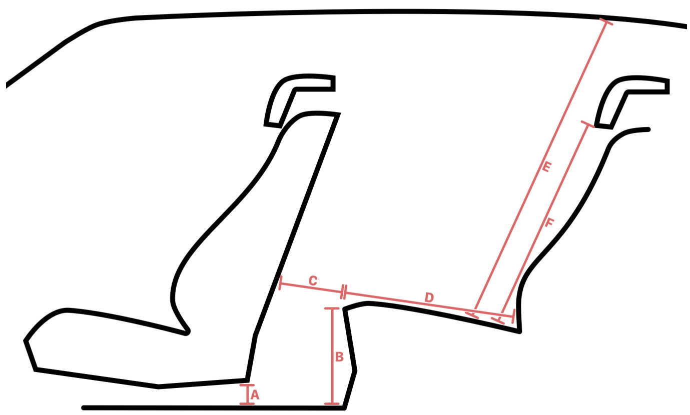

Figure 3.1: Measurements done in the market research

The models chosen for this comparison can be seen in table 3.1. Volvos current lineup was also measured, which can be found in appendix B. The cars tested were chosen based on size, body type and powertrain. All measurements can be seen in appendix C and visualised in figure 3.1.

3.1.1 Studied cars

Audi A7

Table 3.1: List of cars included in the market research

Vehicle	Body type	Powertrain
Audi A7	Combi-cupé	ICE
Audi E-tron Sportback	Combi-cupé Crossover	BEV
Jaguar I-Pace	Combi-cupé Crossover	BEV
Mercedes EQC	Crossover	BEV
Porsche Taycan	Sedan	BEV
Tesla Model 3	Sedan	BEV
VW Passat	Combi	PHEV
Saab 9000	Sedan	ICE
Saab 9000 Aero	Sedan	ICE
Saab og9-5	Sedan	ICE
Saab 9-2x	Combi	ICE
Saab 9-3	Combi	ICE
Saab ng9-5	Combi	ICE

The Audi A7 is a big sedan with a sloping roof line. This makes it feel more cramped in the rear seat for longer passengers. The sitting experience is overall good with comfortable seats and good legroom. The main problem found is the lack of thigh support and limited space underneath the front seat, making it difficult to move your feet. It was also found that the roof height was acceptable but the interior feels cramped because of small windows. This car was studied when it was cold outside which might affect the upholstery but the leather felt hard and slippery.

Audi E-tron Sportback
Audi E-tron Sportback is an electric Combi-cupé crossover. It uses a flat floor mounted battery but because of its higher build, it still has good foot space for the rear seat passengers. As in the Audi A7, the sloping roof line is limiting the headroom but the bigger windows makes it feel roomier. It has comfortable seats and the leather upholstery is less slippery than in the A7. The E-tron Sportback also had acceptable legroom, and thigh support.

Jaguar I-Pace
The Jaguar I-Pace is an electric Combi-cupé crossover. It uses a flat floor mounted battery and because its a lower car, there is limited foot space underneath the front seat. This also lowers the floor- to seat-distance which usually limits the thigh support. Jaguar has solved this by giving the seat cushion a special shape where it has a greater angle at the buttocks and a smaller angle at the thighs. This makes the passenger sit lower and therefor provides more thigh support. There are split opinions on this solution, one felt that this help to provide more thigh support and locks you into position and limits the possibility of slouching. Another felt that it was uncomfortable and created an unnatural sitting posture. Other findings was that the I-Pace has good roof height even though it has a very sloped roof.

Mercedes EQC

Mercedes EQC is an electric crossover. It uses a flat floor mounted battery. It has the seat mounted quite high, which makes it possible to get more thigh support, something that is negated by the low angle of the seat cushion. A negative side effect of the high mounted seat is that the headroom is decreased. Other than that, the EQC has a okay seat with good legroom and a lot of room underneath the front seat.

Porsche Taycan
The Porsche Taycan is a low electric sedan with a low roof line. The battery is floor mounted with cavities made for the feet. This increases the available feet space compared to the Tesla Model 3 and Jaguar I-Pace but it is still limited compared to higher BEV or ICE´s in the same class. The Taycan has a comfortable seat with okay thigh support thanks to seat cushion angle, just like in the Jaguar I-Pace. The low roof height and limited legroom makes the car feel cramped.

Tesla Model 3
Tesla Model 3 is an electric sedan with a sloping roofline and floor-mounted batteries. This car was judged to have a high probability of slouching in rear seat. This was due to the uncomfortable seat, which lacks thigh support due to the small angle of the seat cushion and the small distance between the floor and the seat. These tendencies were also exaggerated by the very low roof height, which made passengers want to slide down. There was also no foot space, making it difficult to move your feet.

Volkswagen Passat
Volkswagen Passat Sportscombi is a ICE combi. This car is one of the most spacious cars benchmarked. It was also found to have very little tendency to slouch. This is mainly due to the comfortable seats and the less slippery leather. This was attributed to the way the upholstery is sewn as well as the leather used. There was also plenty of room for feet under the front seat, making it easy to move feet around. The small angle on seat cushion was compensated for by the floor- to seat-distance, which provided good support for the thighs.

Saab 9000
Saab 9000 is an ICE sedan produced between 1984 and 1998. This model had a comfortable and supportive rear seat. Its velour upholstery was very soft with a high friction coefficient and holds the passenger in place, making it difficult to slouch. It also had a lot of foot space and legroom but limited headroom. Thanks to the big windows, it still felt roomy and comfortable. The small angle on the seat cushion decreases the available thigh support but the high seat cushion placement as well as the possibility to push your feet underneath the front seat makes up for it.

Saab 9000 Aero
Saab 9000 is an ICE sedan produced between 1984 and 1998. The Aero-package adds, among other things, a sporty leather interior with improved side supports. The seat was very comfortable and supportive. The very soft leather upholster was quite slippery, something that may be caused by the age of the car. It was found

that the high angle on the seat cushion provides a lot of thigh support.

Saab og9-5
Saab 9-5 is an ICE sedan produced between 1997 and 2010. The car tested was equipped with a comfortable seat with soft velour upholstery. As in the Saab 9000, this upholstery was found to have a high friction coefficient and holds the passenger in place, making it difficult to slouch. Unfortunately, the low seat cushion angle limits thigh support. It has good foot space underneath the front seat makes it easy to push feet forward, something that increases comfort and provides a little bit more thigh support. Because of it having lots of headroom and big windows, the interior feel spacious.

Saab 9-2x
The Saab 9-2x is an ICE combi produced from 2005 to 2006. This interior was found to be a mixed experience. Overall, it had an okay seat with okay support. It also had okay headroom, good foot space but a bit tight legroom. The seat still felt cramped, something that can not be completely explained while looking at the measurements taken. A theory is that it can be affected by how close the passenger sits to the door, a measurement that was not recorded.

Saab 9-3
Saab 9-3 is an ICE combi produced between 2002 and 2011. This model had comfortable seats with a lot of support. The leather was soft but had a high friction coefficient making it harder to slouch. It was also found to have extra ordinary headroom which makes the interior feel spacious. Unfortunately, it has a very limited legroom. The floor- to seat-distance together with a angled seat cushion provides a lot of thigh support, if the passenger is able to fit.

Saab ng9-5
The last generation Saab 9-5 is an ICE was produced between 2009 and 2011. This car has okay seat with quite slippery fabric and leather upholstery. This makes it easy to slouch but because of the angle of seat cushion, it also makes it easy so slide back. The small windows and sloping roof line make it feel a bit cramped, causing the passengers to slide down. The measurements were taken in a pre-production hybrid version which might have affected interior dimensions.

Volvo V60
Volvo V60 is an PHEV combi. The rear seat of this car was a bit cramped. This was mainly due to the limited headroom, legroom and small windows. Other factors for discomfort was the small seat cushion angle together with a short floor- to seat-distance giving limited thigh support. It was also found that this car have a limited amount of foot space without the ability to push your feet forward making it hard to change sitting position.

Volvo V90
Volvo V90 is a PHEV combi. Compared to the V60, this car was found to have

better legroom. Other than that, it had limited headroom and small foot space. It did have better thigh support than in the V60 thanks to more legroom and a more angled seat. The low windows makes it feel a bit cramped if you are taller.

Volvo XC40
Volvo XC40 is a crossover available as both BEV and as an ICE, here tested as an ICE. This car was equipped with fabric upholstery with a friction coefficient that possibly is higher than the leather upholstery tested in other Volvos. This made it more difficult to slouch. The XC40 had good headroom and foot space while having limited legroom. Thanks to the greater floor- to seat-distance, it had okay thigh support.

Volvo XC60
The Volvo XC60 is a crossover and the tested configurations was a PHEV. This car was overall very comfortable with good headroom and foot space. The legroom and thigh support was found to be okay.

Volvo XC90
The Volvo XC90 is a crossover and the tested configurations was a PHEV. The XC90 has three individual seats in the rear where the seats can be moved back and forward as well as change the backrest angle. The tested configuration had the seat set to the design position. This car had okay headroom with good foot space, legroom and thigh support.

3.1.2 Benchmark results

The conclusion from these comparisons was that modern cars are generally more compact inside. There are a number of reasons for this, such as impact protection and exterior design. Another recent trend among automakers is a sloping roofline, even on the combi/station wagon models. While this comes at the expense of rear-seat headroom, it improves aerodynamics and gives a sporty look.

Electric cars, depending on battery configuration, have limited space for rear seat passengers' feet. This is also evidenced by manufacturers using the same seat frames for SUV/Crossovers as in lower cars, limiting the possibility for passengers to slide their feet forward under the front seats, which could severely limits comfort in lower cars.

The material used for seat upholstery was also found to have an impact on perceived quality, comfort and slouched posture. This is thought to be due to the different friction coefficients of the materials, which make it more difficult to slide on certain fabrics. It was also found that the rear seat and the angle of the seat cushion were interesting factors.

As electric cars currently seems to be the way the market is heading, aerodynamics and battery placement will be integral to achieve a desired range. Because of this, roof height and foot space are an especially interesting area to research.

3.2 Pre-tests

3.2.1 Aim

The first pre-test focused on evaluating different testing methods and for the researchers to get an introduction to user studies. The pre-study was also used to get a better understanding of slouching, both in how it can be recognised and finding possible ways of detecting it, as well as to get an understanding of the steps needed to be taken into consideration when working with users.

3.2.2 Method

The tests was conducted in a Volvo XC90 MY20 with leather upholstery and backrest angle set in the two most extreme settings, 23 and 33 degrees. To get an as naturalistic result as possible, the pre-tests were conducted during a drive in central Göteborg, including both city streets and highways. The car had a camera mounted capturing the test persons side view. The total test time was aimed to be roughly 60 minutes, split into 30 minutes with backrest angle at 33 degrees and 30 minutes with it at 23 degrees. The test was done with two test persons.

To start the test, the test person was picked up at a pre-defined location. Before entering the car, they were asked to clean their hands with disinfectant and put on a face mask. When the test person was sitting in the car, the video recording and a timer for 25 minutes was started. At the timer end, it was time to change the backrest angle. This was done by going to the closest parking spot and the test person was asked to exit the car and look away from the car. This was done in order for them to not see what had been changed. The first test person started with the backrest angle set at 23 degrees while the second test person started at 33 degrees.

To capture this data, measuring point stickers were placed on the test persons shoulder, thigh and knee. The camera was mounted to the door on the opposite side of the test person. As there could not be a second researcher in the car because of COVID-19 restrictions, the camera was set to record video instead of taking individual photos.

When the drive was completed, the test person was dropped of at the decided location and was helped to remove the measuring point stickers. The face mask was collected and disinfectant for their hands were offered.

Data analysis was done by studying the recorded video in collaboration with supervisors at Volvo.

3.2.3 Results

The pre-tests did not focus on getting a numerical test result as much as being a learning experience and testing different evaluation methods.

From the gathered data, it can be seen that the there is a slight tendency to slouch when the backrest is set to 33 compared to 23 degrees. Since this is such a small data set, it is not possible to draw any conclusions from the results but it will be used in later stages of the project. An image of the result can be seen in figure 3.2 and the rest can be seen in appendix E. The initial position for the test persons has been marked with an orange shade on its measurement point stickers.

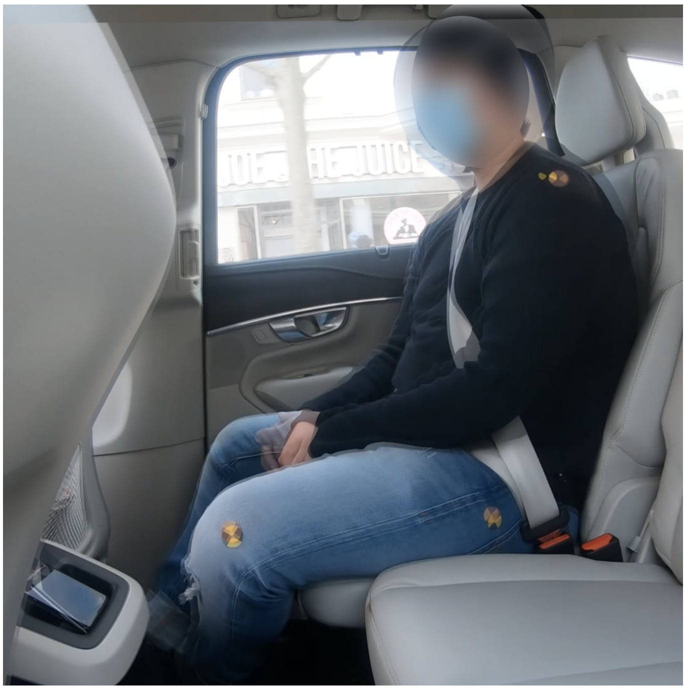

Figure 3.2: Image of passenger movement for Pre-test person 1 with upright backrest

It was found that the measurement point stickers do not adhere well to fabric.

Slouching is more subtle than first expected. This meant that a more accurate measurement method than the one used, a fish-eye video recording, was needed to get an accurate result.

When driving outdoors, the different light conditions in the cabin causes difficulties to record good quality videos.

The passengers sitting posture was dependent on the drivers driving style. It was seen that some test persons wanted to look forward and it is believed that they therefor switched sitting postures more often.

The COVID-19 recommendations made it impossible to have more than one researcher in the car together with the test person. This meant that the researcher had to focus on driving the car and could not be as active in the data collection such as image capturing or interviews. This limited the data collection possibilities since it would be difficult to make manual measurements and handle the equipment.

The length of driving studies on public roads are more difficult to control than ones conducted in a lab. This is due to the unpredictability's of driving on open roads such as varying amounts of traffic, road works and changing weather conditions.

4
Method

In this chapter, an overview of the methods used during the studies will be presented. The study was split into three different parts consisting of pre-study, Parameter evaluation and Parameter evaluation over time.

In the pre-study, the aim was to learn about the subject and how to conduct user studies. The focus of the first study was to identify and analyse parameters that contribute to initial slouched sitting postures. With the second study, the aim was to explore how one parameter affects slouching over time.

4.1 Subjective methods

Comfort is an indirect factor causing slouching. This is since people tend to slouch when trying to improve their comfort. For this reason, the experienced comfort of the test person is an interesting factor in this study.

4.1.1 Comfort evaluation form

To evaluate the perceived comfort of the test persons, a comfort form was developed and used in the first study. An updated version was used in the second study. The changes between the different forms can be seen in appendix D. In short, the second version added a question about the overall experience of the interior as well as colour coded ranking scales.

When creating the comfort form, the focus was to make it easy to understand and easy to fill out. This was done to make the data possible to compare between the test person as accurately as possible. To achieve this, it was decided to focus on discomfort instead of comfort, this is since it is easier to rate discomfort.

To rate the discomfort, a sketch of a human from the front and back was used where the test persons can mark body region where they feel any discomfort or pain based on a pre-defined scale. If the person did not feel any discomfort they did not mark anything. To later process the data, the areas on the body were split into five groups consisting of Head, Upper body, Lower body, and Feet which can be seen in figure 4.1. This was to make the processed data easier to analyse and visualise.

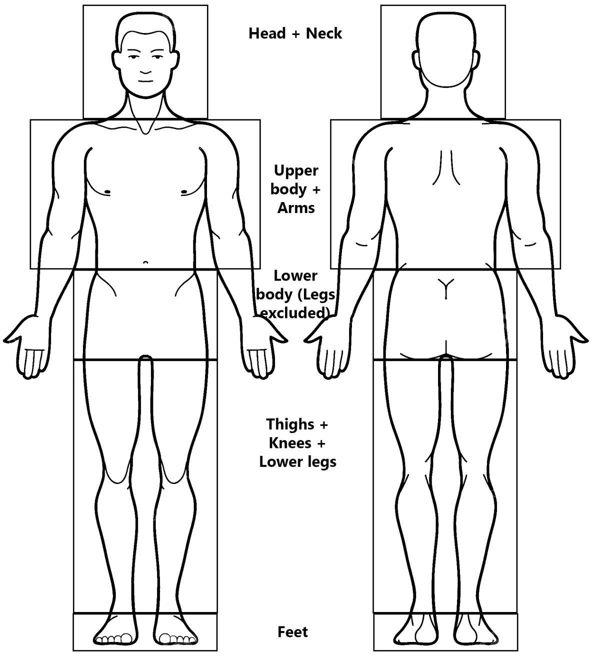

Figure 4.1: The areas sections used for the discomfort mapping

Together with the image, the form used questions to evaluate how the test person experienced the car. In the first version one question was asked, and in the second another question was added. In the first version, the question was how the test person would feel about sitting in this car for a longer trip. This was asked in order to see how the test person felt about the interior. The second version added a question about how the test person would rate the overall comfort of the car. This was asked in order to get an insight into how the test persons felt about the interior and if that could affect the possibility of slouching.

4.1.2 Interviews

The interviews were semi structured, meaning that a number of questions were prepared in advance but also making it possible to have more detailed specific questions based on the test persons answer.

The prepared questions were largely the same questions as in the form. This was done in order to get a more detailed and nuanced answers and also have them reflect on their answers. Another benefit of this was that it allowed for clarifications on any vague answers from the forms. When the test persons had made a statement, it was encouraged that they went more in detail and explained their reasoning and feelings.

The main starting questions in each interview were:

- Are you experiencing anything as uncomfortable when sitting here?
- Is there anything you don't like about sitting here with the seat belt on?
- How would you feel about sitting here for a longer journey, over one hour?

4.2 Objective methods

4.2.1 Xsens system

When using Xsens in the study, every sensor was used except for hands. This was decided in order to minimise the amount of processing needed and make the process as efficient as possible.

The segments that were relevant to look at in the Xsens system was: head, neck, T8, T12, L3, L5, pelvis, left upper leg (thigh joint), left lower leg (knee joint), left foot (ankle) and left toe. These can be seen in figure 4.2.

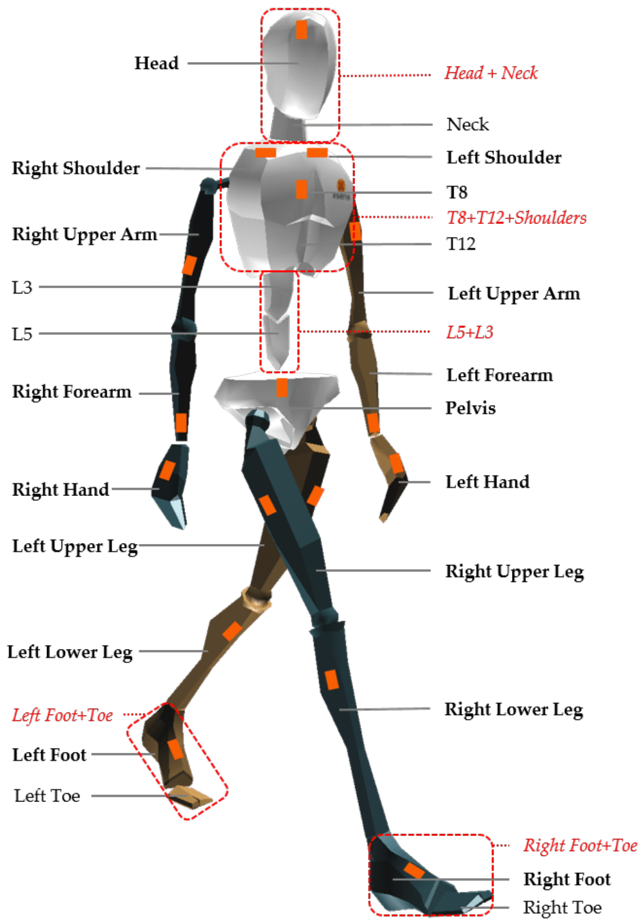

Figure 4.2: An visual representation of the different segments that is tracked by Xsens. (Source: Xsens.com)

In the first user study, 5 minutes of data capture was done in each configuration.

The data capture started when the test person was standing outside the car and stopped when each test was competed. When all the tests were done, a nominal sitting position was captured. This was done when all tests were completed in order to limit the effect it had on the test results.

For the second study, the total test time was extended to 30 minutes. In order to limit needed data processing, the data was captured in 4 different 30 second intervals with a fifth one to capture the nominal position. While the main reason behind only capturing 30 second chunks instead of the entire test were to decrease processing time, it was also useful to limit data loss at possible system crashes.

When data was captured and processed it was exported into Excel files to be analysed. When exporting the files, a frame skip of 10 was used to limit the amount of data making it more manageable. This produced a file at roughly 10 Hz which was decided to be enough for the static analysis used in this project. In Excel the measurements were averaged and checked for any measurement errors.

4.2.2 Photo analysis

To complement the Xsens sensor recordings, photo analysis was done at each measurement. This was used as a complement. The analysis was done with one camera capturing the side view of the test person and one capturing the front view. In the first study, the dimensions were taken from the width of the "measurement point sticker" and in the second study, the dimensions taken from a pre-defined scale placed inside the car on a plane close to the measurement point, equation can be seen in equation 2.1 and an image can be seen in figure 4.3.

Another method used for evaluating the slouching was to match and overlay each photo taken of the test person in the specific test. This makes it possible to clearly see the movements as the time progress during the study. The combination of these two methods offer a numerical and visual comparison of the captured data and a great complement to the Xsens data.

The measurements were done by matching each test persons images using the nominal one as the basis. The movement were then calculated in both X and Y axis.

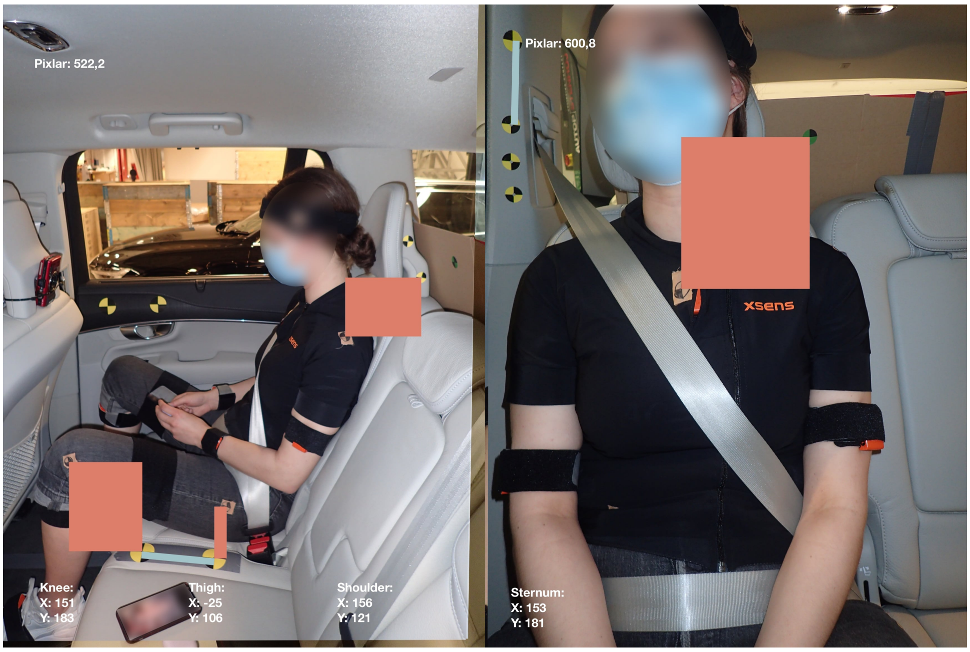

Figure 4.3: Image of the measurements done for every test person

4.2.3 ASIS measurement

In both the first and second user study, the ASIS points were measured in relation to the lap seat belt. This measurement is found by taking the vertical distance from the ASIS to the top of the lap belt. A negative value shows that the ASIS point is underneath the edge of the belt.

For the first test person in the first user study, it was believed that these measurements could be taken from the images with stickers placed on the ASIS points. This was found to be an inaccurate method since the points moved a lot in relation to the shirt. it was therefor decided that the measurements would be done by the test person them self pointing out the spot each time and the measurement was taken using a tape measure, something that can be seen in figure 4.4.

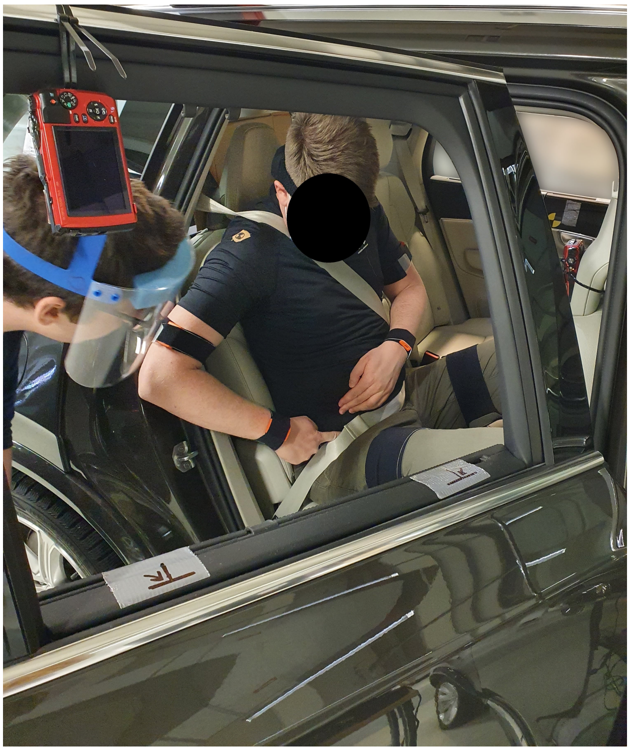

Figure 4.4: Image of a researcher measuring the ASIS point

4.3 Literature review

To get an understanding of the topic and to learn the current state of art of using motion sensing in user studies and to evaluate slouching, a literature study was conducted. It is a good tool to get a solid foundation of knowledge to build upon in the project (Denzin & Lincoln, 2018).

The literature was handed over by the supervisors as well as found through the Chalmers Library. When searching the Chalmers Library, the keywords Car seats, Lower body slouching, Pelvis, Passenger comfort, Sitting postures, Slouching, Upholstery materials, and Vehicle upholstery were used, both as standalone and in combinations.

All found information was sorted, summarised and put in an Excel document for easy access and referencing in later parts of the project. The knowledge gained was then used in the Pugh's matrix.

4.4 Method for deciding parameters

In preparation of the first user study, a number of configurations were developed as possible candidates for the studies. A configuration is a developed concept of how to test a parameter. Parameters were found through literature, benchmarking, and existing knowledge at Volvo and Chalmers. To decide on which configurations were to be excluded, a screening was done.

4.4.1 Identified criteria

Literature support
This criteria focused on if the configuration had any support in literature.

Personal experience
This criteria focused on if the researchers had any personal experience of this, either form the studies or previous experience.

Personal Hypothesis
This criteria focused on if the researchers had any hypothesis about how this configuration could lead to slouching.

Realisable
This criteria focused on if it was possible to create this configurations during the current conditions, such as limited workshop access and COVID-19 restrictions.

Future interest
This criteria focused on if there are any trends making it more likely for this configuration to be more common in the near future.

These criteria were then scored based on their importance and the ratings were set with current conditions in mind.

4.4.2 Identified Parameters

From the learnings of the market research, a number of parameters were found that were believed to either cause or be a factor in slouching. These parameters can be seen below with a shorter explanation, full Pugh's diagram can be seen in figure 4.5.

	Weighting	Reference, Backrest angle	Backrest shape	Backrest hardness	Seat cushion angle	Seat cushion shape	Seat cushion hardness	**Foot clearance**	**Thigh support**	Leg clearence	**Head room**	**Upholstery material**	Seatbelt geometry
Literature support	9	0	0	0	0	0	+	**0**	**+**	0	**0**	**+**	+
Personal experience	8	0	+R	+R	+	-	+	**+**	**+**	?	**+**	**+**	-
Personal Hypothesis	5	0	-	+	+	0	+	**+**	**+**	+	**+**	**+**	0
Realisable	8	0	-	-	-	-	-	**0**	**0**	0	**0**	**0**	-
Future interest	3	0	0	0	0	0	0	**+**	**+**	0	**+**	**+**	0
Antal +		0	1	2	2	0	3	**3**	**4**	1	**3**	**4**	1
Antal -		0	2	1	1	2	1	**0**	**0**	0	**0**	**0**	2
Summa		0	-1	1	1	-2	2	**3**	**4**	1	**3**	**4**	-1
Viktat summa		0	-5	5	5	-16	14	**16**	**25**	5	**16**	**25**	-7

Figure 4.5: The Pugh's matrix used

Backrest angle
This parameter was used for early testing in the pre-test, see chapter 3.2, and was therefor chosen to be the reference in the Pugh's matrix as this was the parameter with the most gathered knowledge. The parameter was found interesting because of the small variation between many cars. Therefor, it was of interest to study how the backrest angle affect slouching, both with smaller or bigger angles. The backrest angle also seen as a simple parameter to test thanks to the adjustable backrest of the XC90 within a specified range.

Backrest shape
The Backrest shape focused on how the shape of the backrest affect the occupants sitting. It was found during the market research, see chapter 3.1, that the shape of backrest varies a lot from manufacturer to manufacturer as well as from car to car. It was therefor interesting to see how different backrest shapes affect passengers. Unfortunately, it was found that it would be difficult to prototype without help from workshops or using different car models.

Backrest hardness
This parameter focus on how the hardness of the foam padding in the seat affect sitting and passenger posture. Through the market research, it was found that older cars generally had softer seat padding. Softer padding should spread the load over a greater area and therefor increase the comfort of the passengers and therefor, decrease the need for changing sitting postures.

Seat cushion angle
In the market research, it was found that the angle of the seat cushion varied a lot between the cars studied. A hypothesis was that a greater angle helped to give the passenger more thigh support and therefor removed some strain from legs and buttocks and with that, increased comfort. Just like for the Backrest shape, it was found that this parameter would be difficult to prototype without help from workshops or using different car models.

Seat cushion shape
The seat cushion shape focus on how the shape of the seat cushion affect the occupants sitting. It was found during the market research, see chapter 3.1, that the shape of seat cushion varies a lot from manufacturer to manufacturer as well as from car to car. Therefor was of interest to see how different cushion shapes affect different passengers. Unfortunately, it was found that it would be difficult to prototype without help from workshops or using different car models.

Seat cushion hardness
This parameter focused on how hardness of the foam padding in the seat cushion affect sitting and passenger posture. Through the market research, it was found that older cars generally had softer seat padding. Softer padding should spread the load over a greater area and therefor increase the comfort of the passengers and therefor, decrease the need for changing sitting postures.

Foot clearance
When doing the market research, it was found that the space underneath the front seat of cars varied greatly. Limited space for the feet make it more difficult for the passenger to stretch their legs, something that was found to be straining over time and caused discomfort. It was also seen that this problem is most common on BEVs, making it likely to be more common in the future.

Thigh support
Many of the cars studied had lacking thigh support. This was found to cause discomfort over time and makes it easier for the rear seat passenger to slide forward and slouch.

Leg clearance
During the market research, it was found that the distance to the front seat varied a lot between cars with similar exterior dimensions. If the passengers legs hit the front seat, it is uncomfortable and may possibly affects their posture.

Head room
The head room parameter was based on a problem found in many cars studied. It was found that the roof height affected how the passenger sit in the rear seat, even if they do not physically touch the roof. Low roof heights can make the passenger slide down in the seat, causing slouching.

Upholstery material
Some of the leathers tested in the market research was found to have a very low friction coefficient while some fabrics had a very high friction, something that effected the passengers possibility sit and move in the seat.

Seat belt geometry
Seat belt geometry focused on if the placement of the belt attachment points would affect the posture of the passenger in the rear seat sit.

4.5 Test person selection

Due to COVID-19 there was limited access to test persons. Because of this, variations between test persons was limited. For example, only three of the ten test persons in the first study were female.

When searching for test persons, there was a wish to have them normally distributed when it comes to body height and age, as well as an equal distribution of gender. As the search progressed this was found to be difficult and focus shifted to instead fill the required number of test persons needed. There was a wish to have between 12 and 20 test persons, which is recommended for a qualitative study (Wallgren, 2019). However, the number was limited to ten test persons in the first study and five in the

second due to restrictions of COVID-19. In the first study, three female and seven male were studied. In second study, two female and three male. Between the second study, the goal was to have as many reoccurring test persons from the first study as possible. This was in order to have the possibility compare the results between the tests and test persons. This was achieved for four of the five test persons.
A list of the test persons from the first and second study as well as their measurements can be seen in table 4.1.

Table 4.1: Table of test persons

Test person	Gender	Height (mm)	Test participation
Test person 1	Male	1830	1 & 2
Test person 2	Male	1840	1
Test person 3	Male	1720	1
Test person 4	Male	1790	1
Test person 5	Female	1690	1
Test person 6	Male	1840	1
Test person 7	Male	1740	1 & 2
Test person 8	Female	1830	1 & 2
Test person 9	Male	1970	1 & 2
Test person 10	Female	1870	1
Test person 14	Female	1720	2

4.6 First user study, Parameter evaluation

This study researched how different modifications affect the probability of slouching to appear. As in the pre-study, in this study a XC90 was used as the starting point. The main reason for this being that the XC90 is the biggest car in the Volvo Cars current lineup providing the most flexibility to modify it to fit the study needs.

Based on the learning's form the pre-study, the study was done in a stationary car in a lab. The advantage of this is that it improves the repeatability of the study since it is a controlled environment.

4.6.1 Chosen configurations

In order to eliminate the less significant configurations, a Pugh's matrix was used, that can be seen in figure 4.5. The five criteria selected to be used in the matrix were Literature support, Personal experience, Personal Hypothesis, Realisable, and Future interest. These criteria were then weighted based on their importance and the current test possibilities. Because of the previous experience with studying the backrest angle, it was chosen to be used as the reference for the Pugh's matrix.
With current conditions in the lab, a large focus when choosing configurations were put on the possibility to manufacture them. This criteria cancelled a number of

interesting configurations. Based on this, configurations with the highest scoring were Foot clearance, Thigh support, Headroom and Upholstery material.

Headroom was later dismissed because of manufacturing difficulties and was exchanged for backrest angle.

4.6.2 Tested configurations

In this section, the five different configurations are defined with a description of the modifications along with photographs.

4.6.2.1 Configuration 1, Standard leather interior

In this configuration, a standard unmodified XC90 with a light beige leather interior is used. The backrest angle of the rear seat is 27 degrees, the Design position for the car. This car is used as a base line to compare with the other modifications and can be seen in figure 4.6.

- Front and rear seats placed in Design position
- Test person sits on the right side

Figure 4.6: Image of the unmodified interior used as a reference

4.6.2.2 Configuration 2, Restricted foot space

In this configuration, a car with a light beige leather interior is used. The space underneath the front seat has been filled which hinders the test person to push their feet forward and stretch their legs which limits the movement possible. This modification replicates the experience passengers get from lower cars and especially BEV with their batteries underneath the front seats. This configuration can be seen in figure 4.7.

- Front and rear seats placed in Design Position
- Test person sits on the left side

Figure 4.7: Image of the restricted foot space modifications

4.6.2.3 Configuration 3, Standard wool mix interior

Same as configuration 1 but with a grey wool mix interior instead of beige leather. The wool mix upholstery is interesting material since it has a higher friction coefficient. The panoramic roof equipped in this car lowers the roof height by 23 mm. This configuration can be seen in figure 4.8.

- Front and rear seats placed in Design Position
- Test person sits on the right side

Figure 4.8: Image of the wool mix interior

4.6.2.4 Configuration 4, Lowered sitting height

In this configuration, a car with a light beige leather interior is used. Seats in design position and the floor has been raised 80 millimetres. This change replicates the sitting experience passengers have in lower cars and can be seen in figure 4.9.

- Front and rear seats placed in Design Position
- Test person sits on the right side

Figure 4.9: Image of the lowered sitting height modification

4.6.2.5 Configuration 5, Reclined backrest

This configuration used a car with a light beige leather interior. The rear seat is modified to have the backrest angle increased to 33 degrees, a change of 6 degrees. This configuration can be seen in figure 4.10.

- Only front seat placed in Design Position
- Test person sits on the left side

Figure 4.10: Image of the reclined backrest

4.6.3 Test procedure

In the first user study, five configurations were to be studied, one regular and four modified. These configurations were to be tested by a group of ten test persons. To get an as unaltered behaviour as possible, none of the test persons were informed about what they were testing or what had been changed in the different configurations. They also sat in the configurations in random sequence, this is to not pollute the study results.

The study was done in three cars, two with leather interior and one with wool mix upholstery. Before each study started, a number of preparations needed to be done. The main one being to clean and disinfect the interior of each car. This was to limit the risk of spreading COVID-19. This meant cleaning all possible contact areas inside the car and also the Xsens sensor system. In tandem, all the required forms, study sequence and test numbers were prepared. A final check was also done to make sure that seats and markers were all in the correct position.

When these preparations were completed, the test person was met up with at a pre-defined location. Before going to the test location, it was important to make sure that the test persons did not feel any symptoms or had been in contact with anyone who had been infected with COVID-19.

At the test location, the test person was informed about the test procedure and the safety precautions taken to make the tests as safe as possible, both between each person and between each car. The test person was given hand sanitiser and was informed about the use of face masks and visors.

The test person was informed about the test procedure and what data would be gathered. All data captured would be anonymous and could not be linked back to them. They were also informed that if they for any reason want to abort the test, to just let the test leaders know and that they do not need to give any reasons why.

When the test person has filled in and signed the consent form, they were informed about the comfort evaluation form, see appendix D.1. When done, the Xsens system was attached to the test person, see figure 4.12. Before the calibration of the system could be done, two measurements needed to be taken. These were the shoe length and their body height which gave the system input to create a realistic manikin. Measurement point stickers were put on shoulder, sternum, and knee, these images can be seen in figure 4.11. For the first three test persons, stickers were also put on their ASIS points, but it was found that the shirt moved too much making these measurement stickers unusable.

Figure 4.11: The stickers placed on the test persons used in the photo analysis

Figure 4.12: Image of a Xsens sensor placement on the test person (Source: Xsens.com)

For the possibility to calibrate the Xsens file to the cars CAD-file, two defined points on the door card were marked. Before the test person entered the car, the Xsens recording was started and the test person was asked to put their wrist on these points.

After this secondary calibration was completed, they were told to enter the rear seat and buckle up as if they were going for a ride. All markers were checked to ensure they were still in the correct positions.

A timer was set for 2 minutes. During this time, the test person was told to sit and relax. When the timer was done the photos were taken from the front and the side of the test person, location of the cameras can be seen in figure 4.8. They were given the document evaluation form and a pen to rate the discomfort of the configuration. Any questions about the evaluation form was answered. When the test person was done with the form, it was collected and Xsens data recording was stopped. To finalise the test in the configuration, the vertical distance was measured from the test persons self detected ASIS point and the top of the lap belt. After that, the test person was offered cleaning alcohol for their hands and then asked to step out of the car.

If the Xsens data seemed to have any problems, another calibrations was done. Otherwise, the test person took a short walk to the next configuration. The same procedure was done for each configuration.

To finalise the study, a nominal sitting posture was captured for each configuration. All the sensors were then removed from the test persons and hand sanitiser was offered. They were then thanked and guided back to where they were picked up.

4.7 Second user study, Parameter evaluation over time

To test the concepts influence on the passengers over time, one configuration already used in the first study was chosen to be tested over a longer time, 30 minutes. This is roughly the length of an average car ride in Europe (Fiorello, Martino, Zani, Christidis, & Navajas-Cawood, 2016). The study was done with five test persons, four of which who had already participated in the previous study. To keep the test persons entertained, they were asked to listen to a podcasts or music, they could also work from their phone if possible.

4.7.1 Choosing configuration

When choosing the configuration to be used in the second study, the results from the first user study was evaluated. After discussions it was decided to use configuration 4, lowered sitting height because of its high discomfort scores. All test persons reported similar complaints in their interviews. It was also seen that in this configuration, the test persons gave it the worst long time score.

Since passengers change their posture to improve their perceived comfort, the configuration with the most significant discomfort scores should be chosen.

Based on the findings of the first user study, Configuration 4, Lowered sitting height was chosen. The second study used the same modifications as in the first study.

4.7.2 Test procedure

Based on the learnings from the first used study, four major improvement were implemented into the second round.

More measuring point stickers
More measuring point stickers were added, both to the test persons as well as the car. This was done to improve the quality of the photo analysis.

Shorter Xsens recordings
The files recorded with Xsens were shorter and more focused. This was done in order to decrease the amount of post processing needed and to limit data loss at system crash.

Mounting of front facing camera
The mounting point for the front camera was changed and improved. This was done to avoid accidental button presses on the camera and to decrease variation between images. This also made it possible to more precisely angle the camera and capture points of interest. The camera placement can be seen in figure 4.13

Figure 4.13: Image of the front facing camera

Developed comfort form

The comfort evaluation form was reworked and improved upon. Based on user feedback the graphical design was changed to more clearly guide the test person through the form. A question about the overall comfort was also added based on feedback from supervisors. This comfort form can be seen in appendix D.

Before each study started, a number of preparations needed to be done. The main one being to clean and disinfect the interior of each car. This was to limit the risk of spreading COVID-19. This meant cleaning all possible contact areas inside the car and also the Xsens sensor system. In tandem, all the required forms, study sequence and test numbers were prepared. A final check was also done to make sure that seats and markers were all in the correct position.

When these preparations were completed, the test person was met up with at a pre-defined location. Before going to the test location, it was important to make sure that the test persons did not feel any symptoms or had been in contact with anyone who had been infected with COVID-19.

At the test location, the test person was informed about the test procedure and the safety precautions taken to make the tests as safe as possible, both between each person and between each car. The test person was given hand sanitiser and was informed about the use of face masks and visors.

The test person was informed about the test procedure and what data would be gathered. All data captured would be anonymous and could not be linked back to them. They were also informed that if they for any reason want to abort the test, to just let the researchers know and that they do not need to give any reasons why.

When the test person has filled in and signed the consent form, they were informed about the comfort evaluation form and how it has been updated since the last user study, see appendix D.2. When done, the Xsens system was attached to the test person. Measurement point stickers were put on shoulder, sternum, knee and added in this test was a sticker on the thighs, these can be seen in figure 4.11. The stickers on hip and head was added to further improve the analysis. This makes it possible to look at multiple data points to evaluate if the person has slouched or just moved certain parts of their body.

The test persons were told to enter the rear seat and buckle up as if they were going for a ride. All markers were checked to ensure they were still in the correct positions. A timer for 10 minutes was set. Xsens data recording was started. After 30 seconds the Xsens recording was stopped and photos were taken from the side and front of the test person, location of the cameras can be seen in figure 4.8. They were given the document evaluation form and a pen to rate the discomfort of the configuration. Any questions about the evaluation form was answered. When the test person was done with the form, the vertical distance was measured from the test persons self detected ASIS point and the top of the lap belt. After that, the test person was told to listen to a podcasts or music, work from their phone or just relax.

After 9 minutes and 30 seconds, the procedure was repeated, four times in total for a total of 30 minutes. When the study was done, the test persons were asked to capture a nominal sitting posture. All the sensors were then removed from the test persons and hand sanitiser was offered. If the test person had any questions about the first or second study they could now be answered in more detail. They were then thanked and guided back to where they were picked up.

4.8 Concept development

After all user studies were complected and the data had been analysed the concept development phase started. In order to improve the design of the rear seat, a number of findings were listed from the results as well as technical solutions and subjective findings from the studies.

From these findings, several brainstorming sessions were conducted, both within the group as well as with other external people. This was in order to get fresh takes on the problems and find new ways to solve them. Three of the ideas generated were then chosen to be further developed. To visualise the ideas in order to present and discuss the solutions, a number of sketches were produced.

5

Results

In this chapter the results of the two user studies will be presented. The data will be presented both as graphs, illustrations and photographs.

The data presented was collected using ASIS measurements, Photo analysis, Comfort evaluations form, and Xsens. The data will be presented grouped by source.

5.1 Parameter study Results

Here the results from the first study, the parameter study, is presented.

5.1.1 ASIS measurement

This data was captured to show the distance between the ASIS point and lap belt. However, due to poor data quality, the ASIS measurement for the first study will be excluded. This is further explained in chapter 6.3

5.1.2 Photo analysis

The data collected during the photo analysis are presented here. The measurements show the difference between the nominal sitting posture and the self-selected sitting postures in the three data points sternum, shoulder, and knee. All test persons were either in the same position or slouched down to some degree during these analyses.

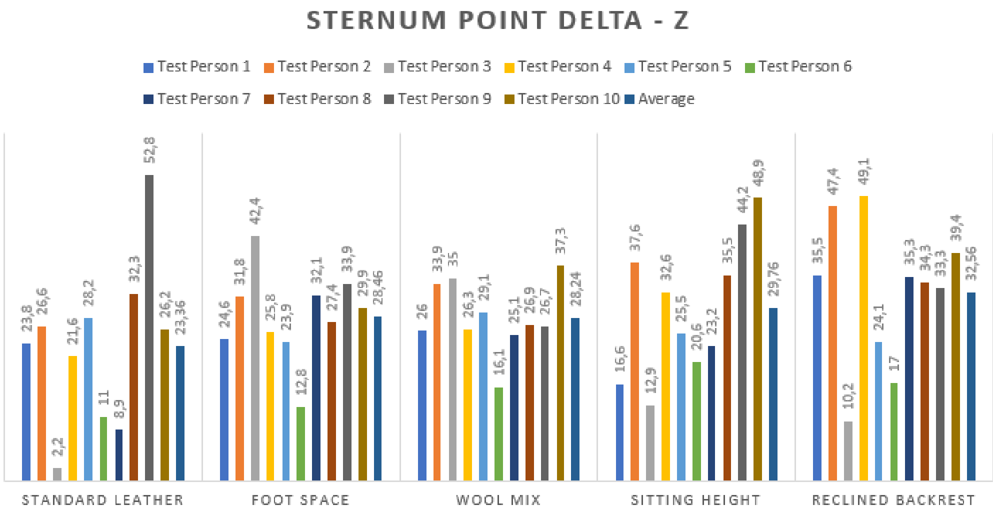

Figure 5.1: The delta values of the sternum point between nominal and self selected position shown in millimetres.

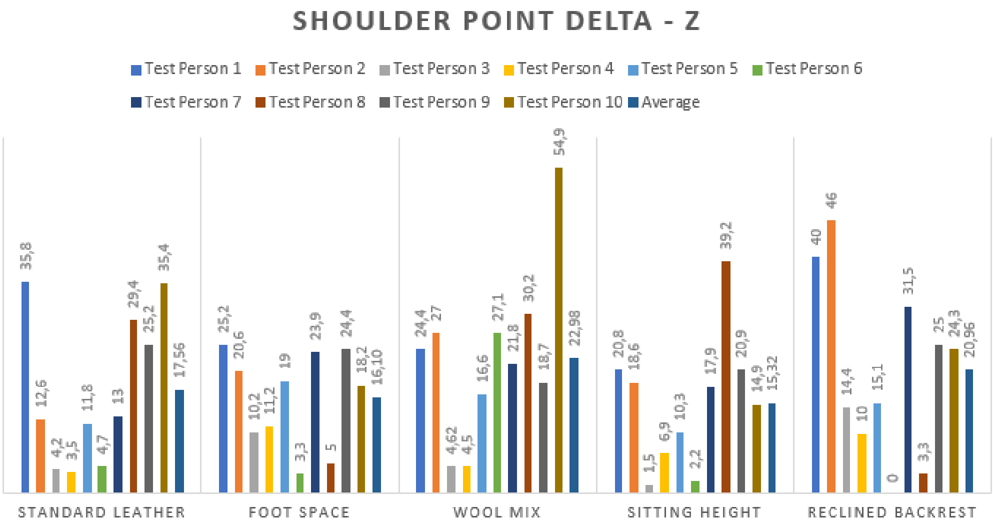

Figure 5.2: The delta values of the shoulder point between nominal and self selected position shown in millimetres.

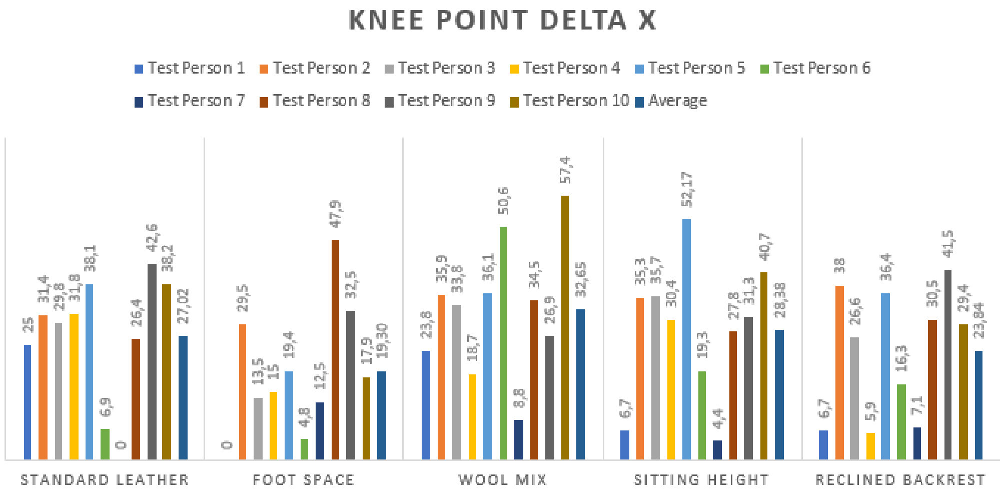

Figure 5.3: The delta values of the knee point between nominal and self selected position shown in millimetres.

5.1.2.1 Configuration 1, Standard leather interior

This configuration will be a way to compare the different parameters and their influence on slouching. According to the photo analysis the shoulder Z position differs 18 mm on average in figure 5.2 which means that the upper body has been lowered from the nominal position. This can further be confirmed in the sternum Z position where the difference is 23 mm on average in figure 5.1. The photo analysis also shows that the deviation of the knee X point is 27 mm, which means that the knees have been pushed forward, something that may be the result of slouching. This is since in the nominal position, the back is pushed back against the backrest while in the self-selected position it is more natural. This can be seen in figure 5.3.

5.1.2.2 Configuration 2, Restricted foot space

The shoulder Z point, in figure 5.2 is on average 16 mm away from the nominal position, which is about the same as configuration 1. However, the sternum delta Z point in figure 5.1 is 29 mm which is more than configuration 1 and can be the result of slouching. Looking at the knee delta X, the knee point is 19 mm which is lower than configuration 1.

5.1.2.3 Configuration 3, Standard wool mix interior

The shoulder delta Z is 23 mm and the sternum delta Z is 28 mm in figure 5.2 and 5.1. These numbers are both higher than for configuration 1 which would indicate that there is more slouching for configuration 3. The knee delta X in figure 5.3 is also higher which can indicate that the knees are pushed forward due to slouching.

5.1.2.4 Configuration 4, Lowered sitting height

The shoulder delta Z is lower than for configuration 1 in figure 5.2. The sternum delta Z in figure 5.1 is however 6 mm bigger, which still can indicate slight slouching. The knee delta X in figure 5.3 is however about the same as configuration 1.

5.1.2.5 Configuration 5, Reclined backrest

For the shoulder delta Z in figure 5.2 the value is about 21 mm and sternum delta Z in figure 5.1 the value is 33 mm. Both these values are higher than configuration 1 which could indicate more upper body slouching. The knee delta X point in figure 5.3 is about 24 mm which is less than configuration 1 and indicates less lower body slouching. However it only differs a few millimetres.

5.1.3 Comfort evaluation data

Common comments about each configuration has been categorised and summarised in appendix F for more in-depth data about the configurations.

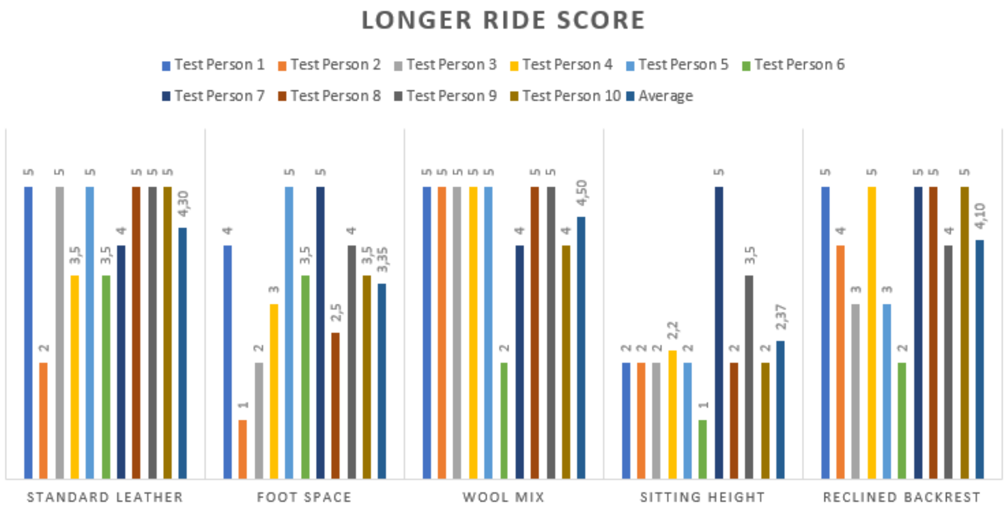

Figure 5.4: The value that has been appointed by the test persons in the comfort evaluation form. The test persons give rates the ability to ride the car for a longer time between 1 (No, it's too uncomfortable) to 5 (Yes, no problem)

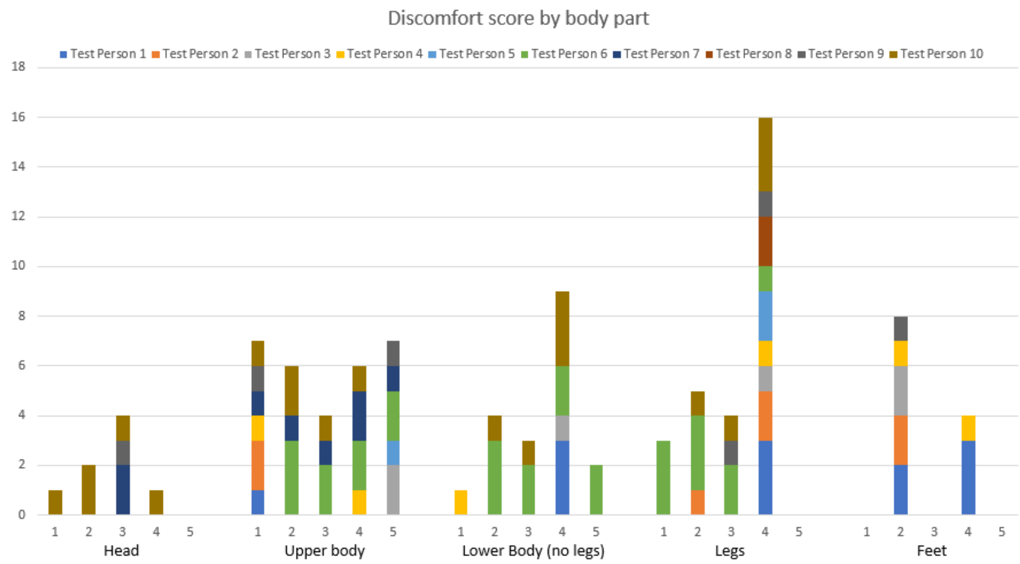

Figure 5.5: The discomfort score given for each part of the body in each configuration (1 to 5). Each test person fills in a score 1 (slight discomfort) to 5 (pain) in the comfort evaluation form

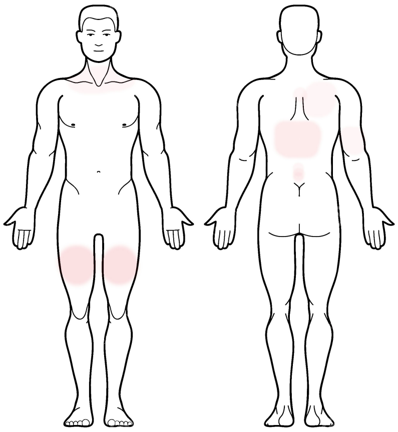

Figure 5.6: Discomfort mapping for configuration 1

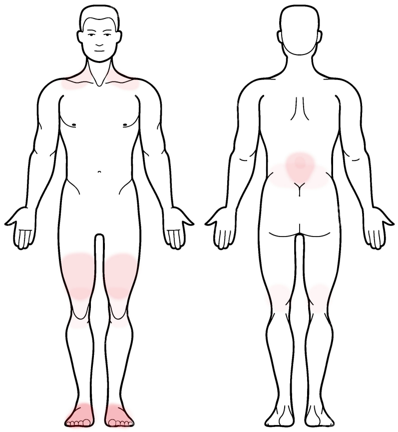

Figure 5.7: Discomfort mapping for configuration 2.

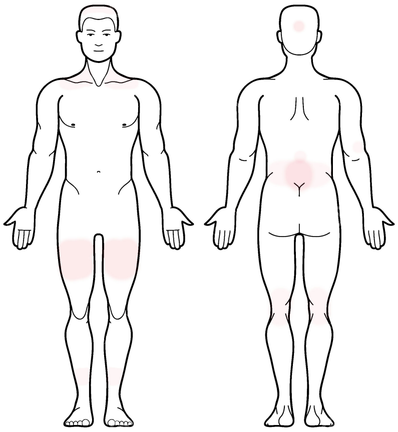

Figure 5.8: Discomfort mapping for configuration 3

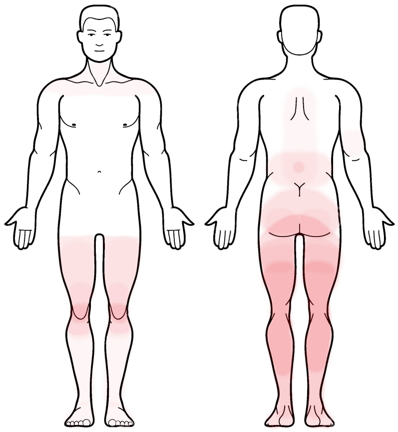

Figure 5.9: Discomfort mapping for configuration 4.

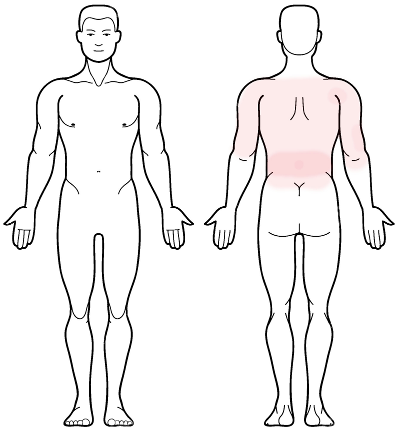

Figure 5.10: Discomfort mapping for configuration 5

5.1.3.1 Configuration 1, Standard leather interior

Looking at the comfort evaluation, most people find configuration 1 easy to sit in for a longer time with an average score of 4,3. There is a slight discomfort mainly for the upper body as shown in figure 5.5 and figure 5.6, but it's still considered quite low in comparison to the other configurations.

5.1.3.2 Configuration 2, Restricted foot space

Looking at the comfort score, less people would like to ride this car for a longer ride as seen in figure 5.4, which is mostly due to the lack of foot space for taller people. Configuration 2 also has the highest discomfort score for the feet as seen in figure 5.5 and in the discomfort mapping in figure 5.7. This discomfort can make people change their initial sitting position and that might lead to more slouching.

5.1.3.3 Configuration 3, Standard wool mix interior

From what it looks like in figure 5.4, most people would have no issue to ride this car for a longer period of time, with the highest score out of all configurations. There is however a slight discomfort for the head compared to other configurations as seen in figure 5.5 and 5.8. This was due to the unplanned sunroof which lowered the roof in the edge with about 22 mm and resulted in the tallest test person to feel the roof next to his head.

5.1.3.4 Configuration 4, Lowered sitting height

Looking at the longer ride score in figure 5.4, it has the lowest score out of all configurations. It also shows in figure 5.5 that is caused most discomfort in lower body and legs. Most people complained about the lack of thigh support as seen in the interviews in appendix F. This can also be seen in the discomfort mapping in figure 5.9.

5.1.3.5 Configuration 5, Reclined backrest

When it comes to the comfort the configuration got a 4,1 in longer ride score in figure 5.4, which is one of the higher score and very close to configuration 1. Although some people had minor issues with the upper body comfort as seen in figure 5.5 and 5.10, the overall score is very good.

5.1.4 Xsens data

The Xsens data is presented as diagrams of segment position and pelvis orientation. Test person 10 has been excluded from all graphs due to poor quality.

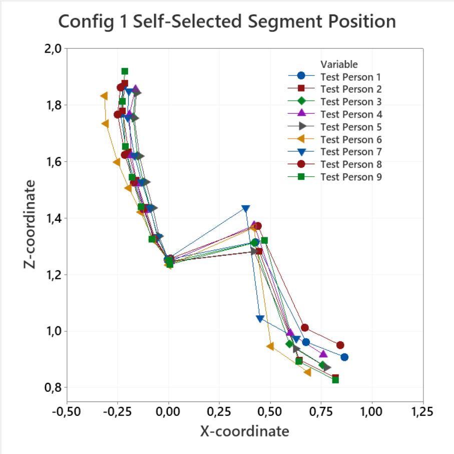

Figure 5.11: The position of each segment of every test person in the self-selected position for configuration 1.

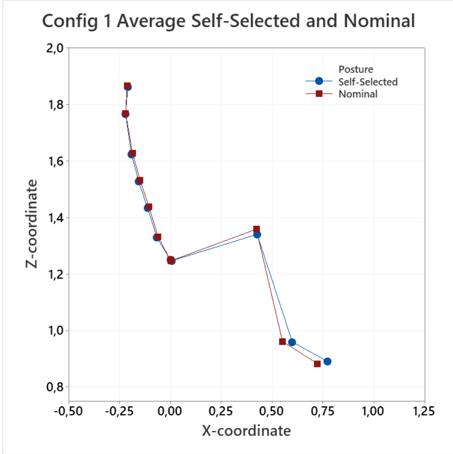

Figure 5.12: The average values of self-selected and nominal position for configuration 1.

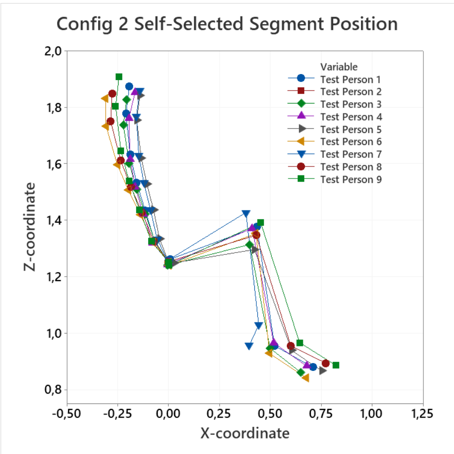

Figure 5.13: The position of each segment of every test person in the self-selected position for configuration 2. Test Person 2 has been excluded due to poor quality.

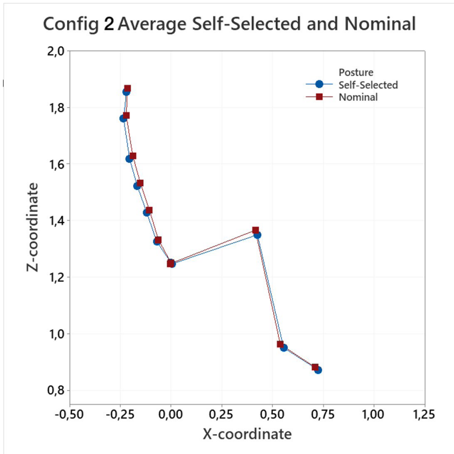

Figure 5.14: The average values of self-selected and nominal position for configuration 2. Test Person 2 has been excluded due to poor quality

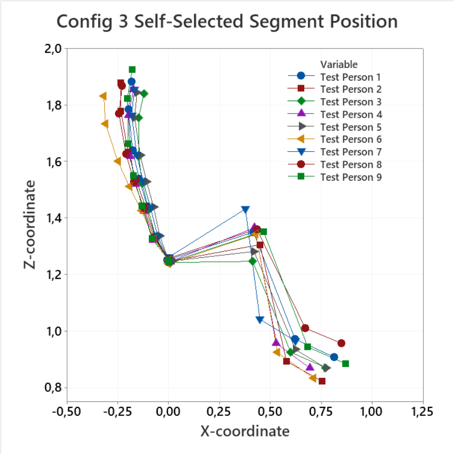

Figure 5.15: The position of each segment of every test person in the self-selected position for configuration 3.

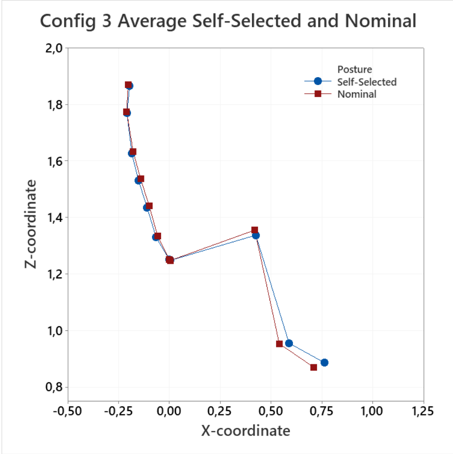

Figure 5.16: The average values of self-selected and nominal position for configuration 3

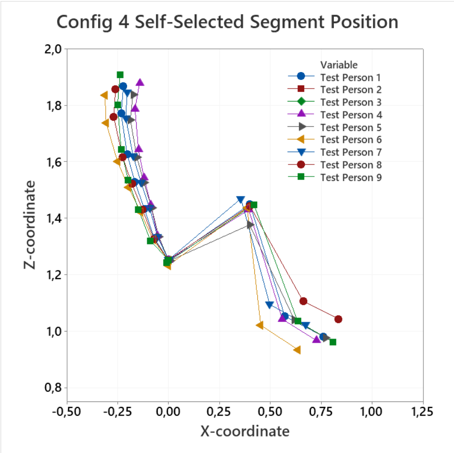

Figure 5.17: The position of each segment of every test person in the self-selected position for configuration 4. Test Person 2 and 3 has been excluded due to poor quality.

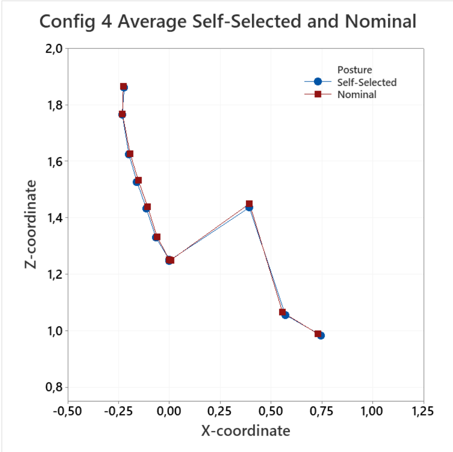

Figure 5.18: The average values of self-selected and nominal position for configuration 4. Test Person 2 and 3has been excluded due to poor quality

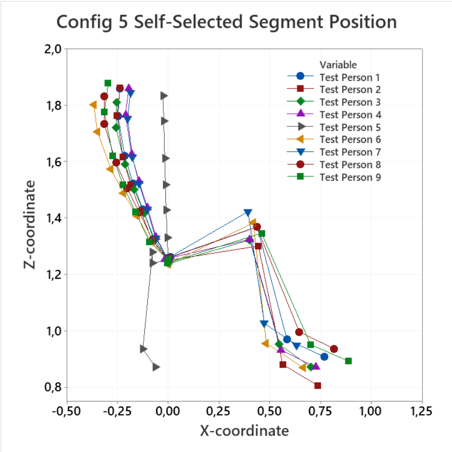

Figure 5.19: The position of each segment of every test person in the self-selected position for configuration 5.

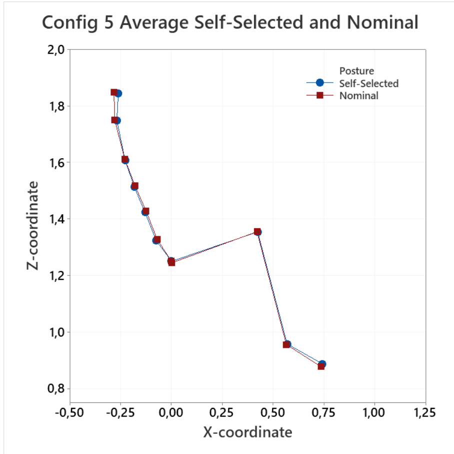

Figure 5.20: The average values of self-selected and nominal position for configuration 5. Test person 5 has been excluded due to poor quality.

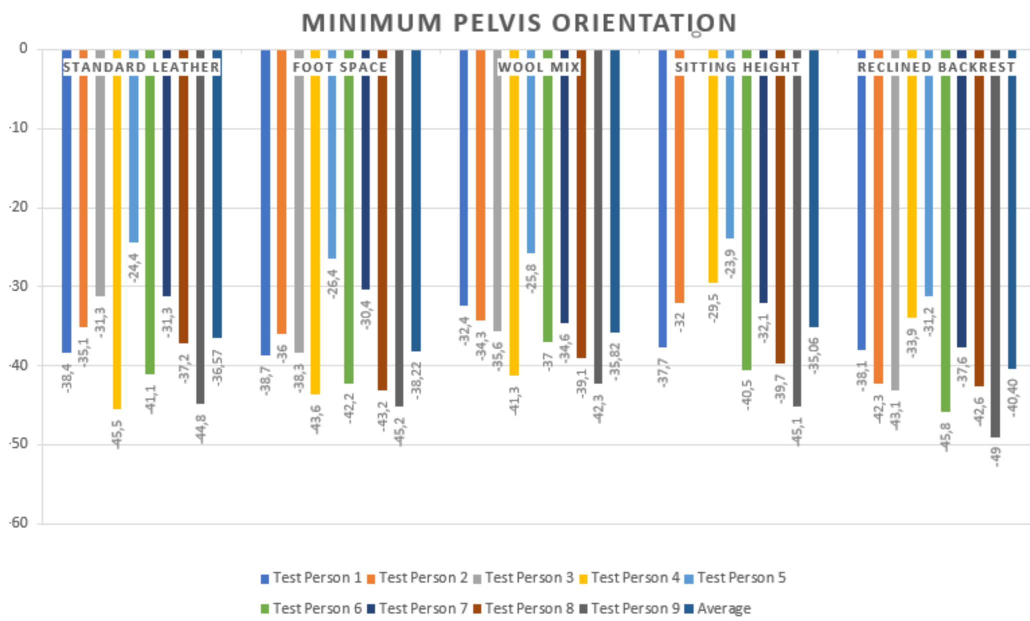

Figure 5.21: The most extreme angle of the pelvis that was observed is shown in this graph.

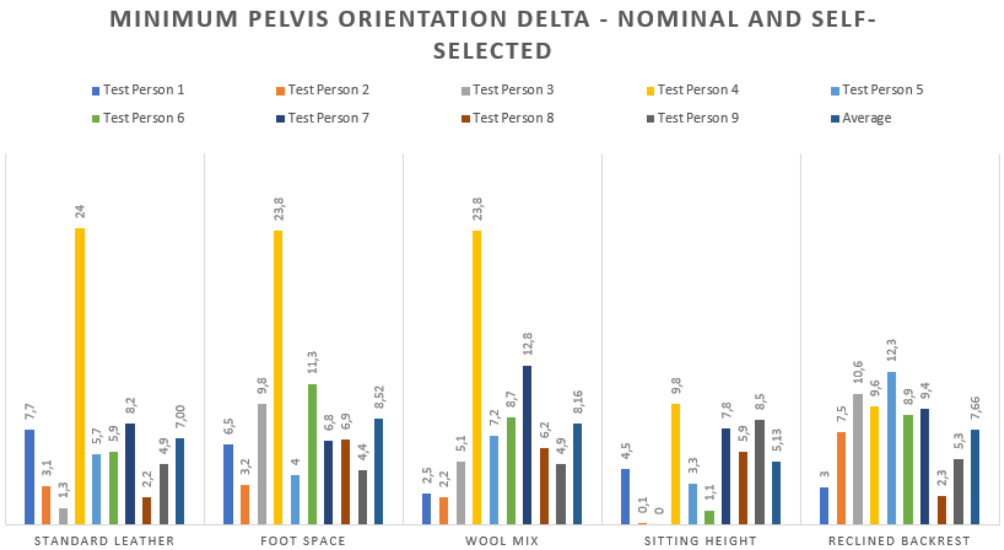

Figure 5.22: The minimum pelvis orientation delta value between the self selected and nominal position, shown in degrees.

5.1.4.1 Configuration 1, Standard leather interior

When looking at the Xsens data, all participants posture can be seen in figure 5.11. In figure 5.12 the average sitting posture for self-selected and nominal position can be seen, but it's important to remember that the pelvis point is a common point for both graphs. For the lower body, the knees are a bit more angled as most people seem to place their foots further forward in self selected position. The Xsens data also tells about the pelvis orientation as seen in figure 5.21 and comparison to nominal position in figure 5.22. This shows that the average difference is up to 7,00 degrees, which also can indicate slouching.

5.1.4.2 Configuration 2, Restricted foot space

In figure 5.13 the Xsens sitting posture can be seen for each individual but test person 7 will be excluded due to poor quality from the average score. In figure 5.14 there is a more clear difference where the upper body is more lowered and leaned back compared to the nominal position and this can be the result of more slouching. It's clearer to see in configuration 2 compared to configuration 1. Further the pelvis is about 1,6 degrees more angled compared to configuration 1, as seen in figure 5.21.

5.1.4.3 Configuration 3, Standard wool mix interior

In figure 5.16, there is a slight difference in the back area which is slightly lowered and leaned back. This can confirm that there is slouching compared to the nominal position. Individual posture can be seen in 5.15 In figure 5.21 the pelvis orientation is about 0,8 degrees less than configuration 1, however the delta between self selected and nominal is about 1,1 degree more between the configurations as seen in figure 5.22.

5.1.4.4 Configuration 4, Lowered sitting height

Figure 5.17 shows that each individual has the knee point further up. In figure 5.18 there do not seem to be a lot of slouching in the self selected position compared to the nominal. This could somewhat also be confirmed by the photo analysis. In the pelvis orientation in figure 5.21 it has about 1,6 degree less which is less than configuration 1. In figure 5.22 the delta orientation to nominal is even lower.

5.1.4.5 Configuration 5, Reclined backrest

Test person 5 was excluded from the average value due to poor data quality which can be see in the individual posture in 5.19. Looking at the average posture in figure 5.20, there is slight difference in the upper body, but it is about the same difference as in configuration 1 when comparing self-selected and nominal position. The lower body is also very alike between self selected and nominal for configuration 5 according to this data. The pelvis angle in figure 5.21 is the highest out of all configurations. In figure 5.22 it has a score of 7,7 degrees which is 0,7 degrees more than configuration 1.

5.2 Parameter study over time, Results

5.2.1 ASIS measurement

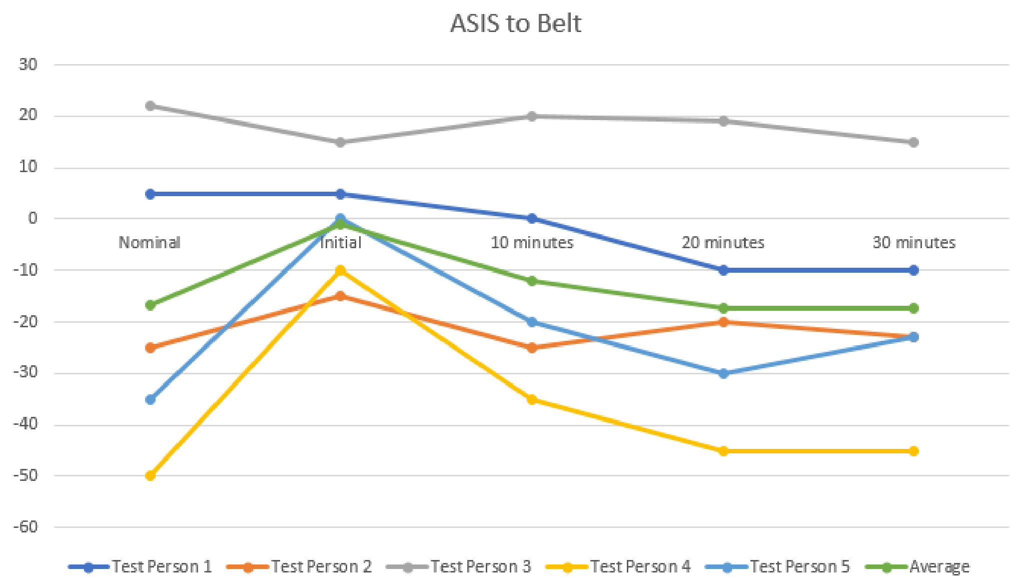

Figure 5.23: The distance from the ASIS point on the test person measured vertically to the top of the lap seat belt. A negative value shows that the ASIS is underneath the belt.

Looking at the ASIS measurement in figure 5.23, it is clear that the distance between the belt and ASIS point reduces as time passes, at least for the first 20 minutes, while looking at the average. The nominal value is about the same as the 30 minute value on average.

5.2.2 Photo analysis

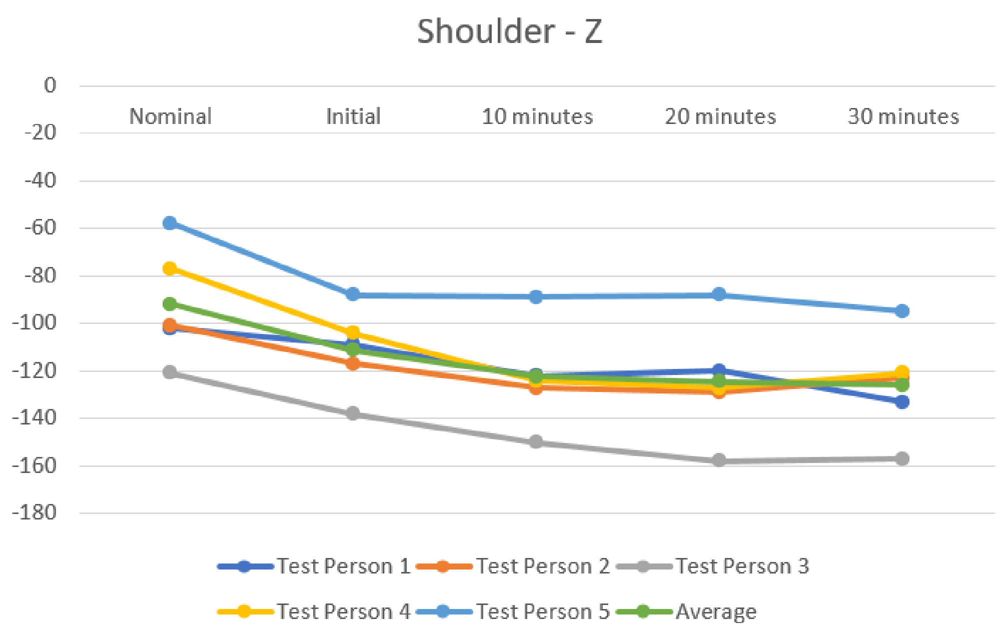

Figure 5.24: The shoulder Z position shown in millimetres.

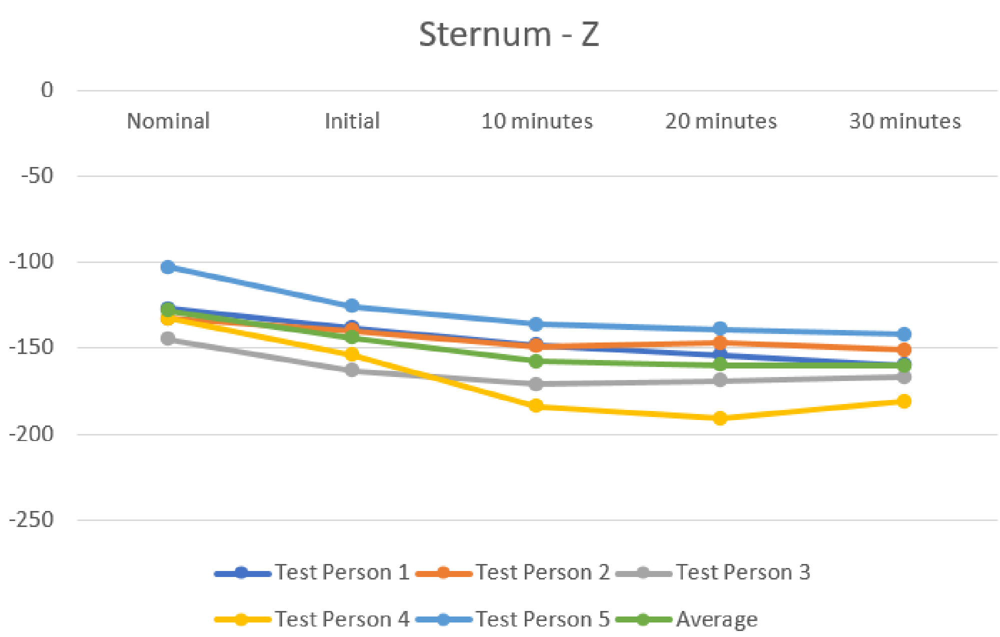

Figure 5.25: The sternum Z position shown in millimetres.

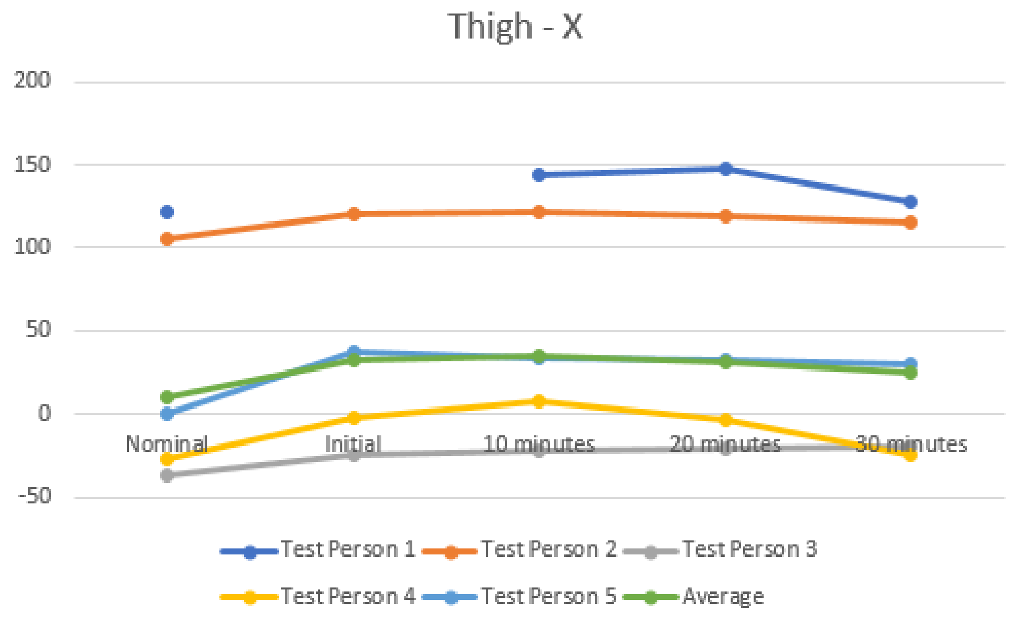

Figure 5.26: The thigh X position shown in millimetres.

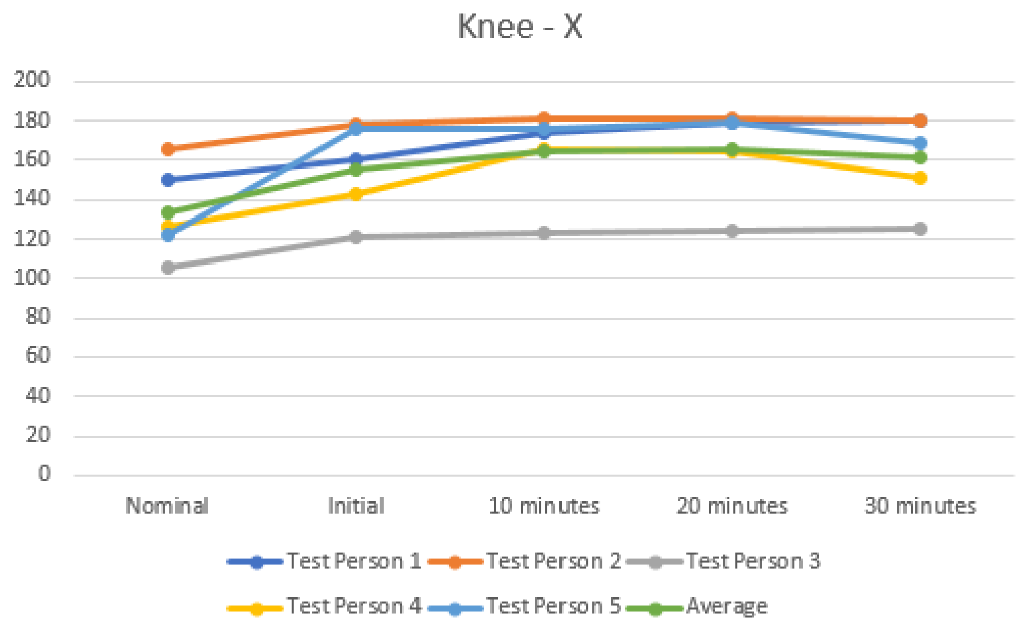

Figure 5.27: The knee X position shown in millimetres.

In the photo analysis the shoulder Z position decreases from the nominal position and over time, up to 20 minutes on average in figure 5.24. This means that the shoulder is moving further down. The sternum position in figure 5.25 follows the same trend and further confirms this for the upper body.

There is data missing from figure 5.26 for test person 1, but the general trend is that the X position of the thigh is moved forward from the nominal position and somewhat stays on the same position except after reaching 30 minutes where they move somewhat back again. The knee X position in figure 5.27 mostly confirms this, but has a slightly bigger increase between initial and 10 minute position.

5.2.3 Comfort evaluation data

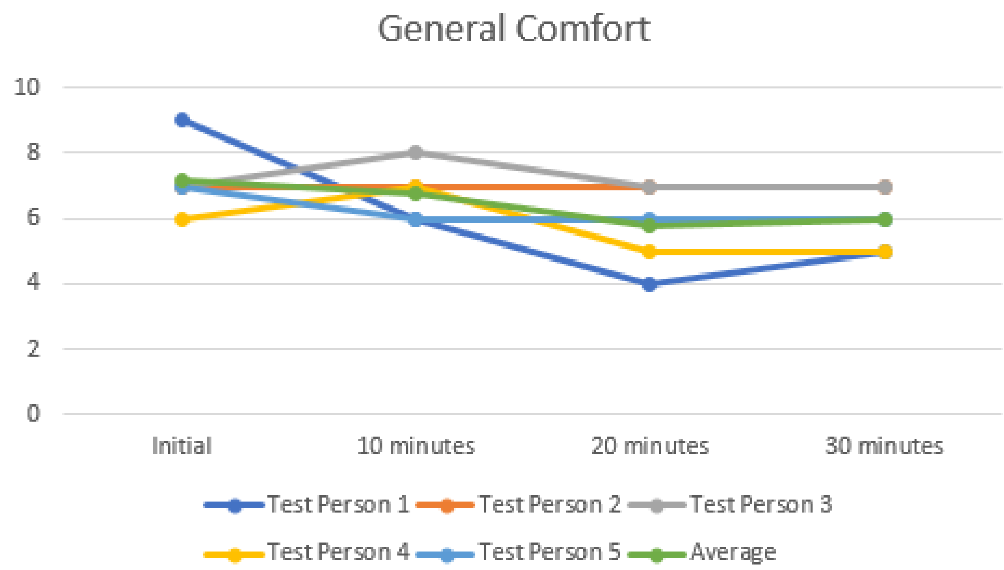

Figure 5.28: The general comfort score given in the comfort evaluation form by each person for every given time/position.

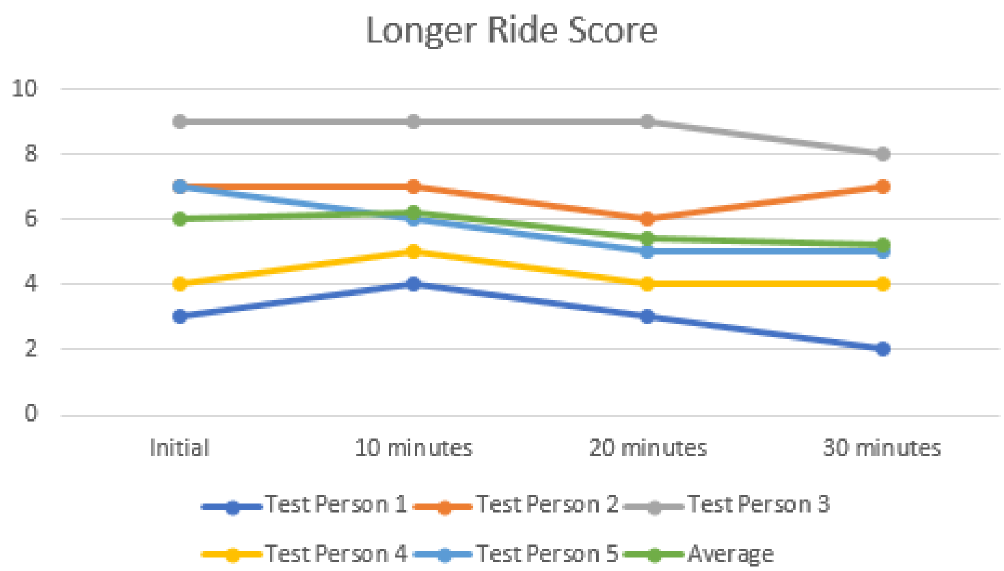

Figure 5.29: The value that has been appointed by the test persons in the comfort evaluation form.

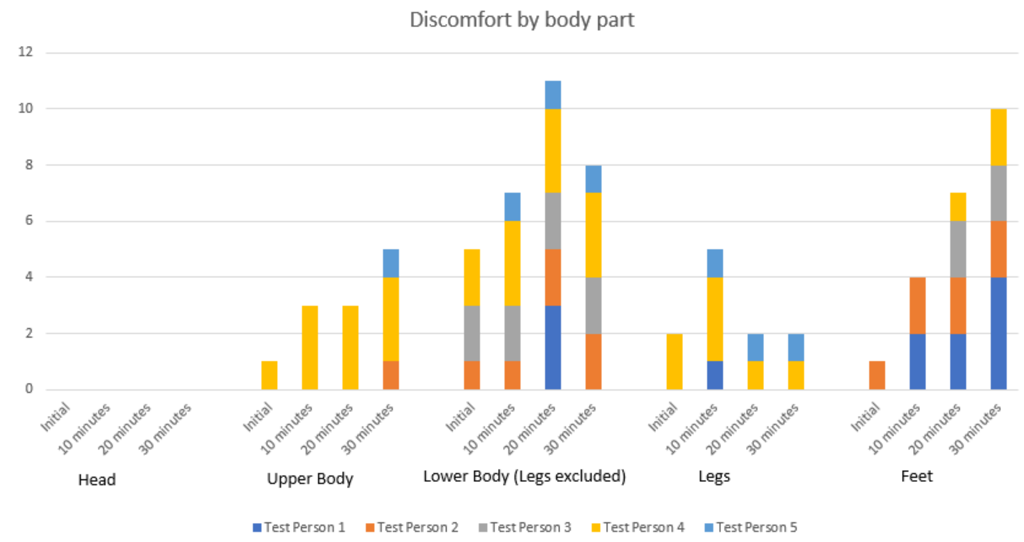

Figure 5.30: The discomfort score given for each part of the body in the comfort evaluation form at each time.

Looking at the average graph in figure 5.28, there is a trend where the initial is the most comfortable position and then goes down slightly from a score of 7 to 6 until 20 minutes, where it stays for the rest of the test period. There is a slight difference in figure 5.29 where the longer ride score gets lower at 30 minutes, but it mostly follows the same trend. Just as in the first study, most people found discomfort in the lower body for this configuration as seen in figure 5.30. This was especially true after about 20 minutes and would then go down again when reaching 30 minutes. Most people also had discomfort in the feet after 30 minutes.

5.2.4 Xsens data

Due to poor quality, the xsens data for test 2 will not be included. These problems are explained more in detail in chapter 6.4.

6
Discussion

In this chapter, a discussion about the results, methods and the study as a whole will be held.

6.1 Discussion of the results

Here the results from the first and second study, as can be seen in chapter 5, will be discussed.

6.1.1 Parameter evaluation

Main objectives of this study was to identify and evaluate factors that contributes to slouched sitting posture.

6.1.1.1 Configuration 1, Standard leather interior

The first configuration is a regular XC90, standard leather interior with the seats in design position. It is a reference for the other configurations and compares initial sitting position to nominal. With the data provided from the result in photo analysis and Xsens data, it's clear that there is a difference in the self-selected position compared to the nominal, which is to be expected when it comes to slouching for all configurations. Most people also find this configuration comfortable.

6.1.1.2 Configuration 2, Restricted foot space

For configuration 2 it was theorised that the lack of foot space, such as in smaller electric vehicles, makes it more difficult to push the body back against the backrest because of the awkward knee angle, which is mentioned in appendix F. The knee point is also on average lower than for configuration 1, which is most likely also due to tall people are forced into a more upright position with their legs with the lack of foot space. Shorter people, e.g. test person 5 did not notice the restricted foot space as seen in figure 5.5. The researchers can confirm from the result that less foot space could be a parameter for slightly more slouching. This can confirm the theory from the pre-study that less foot space makes it more difficult to push the body back against the back rest.

6.1.1.3 Configuration 3, Standard wool mix interior

Slouching seems to be confirmed for fabric seats in all data except pelvis orientation. the pelvis orientation is lower than for configuration 1, however the delta between nominal and self-selected i higher. This means that there could be a slight error in the Xsens system or that it's easier to slouch in configuration 3 without rotating the pelvis. Another theory is that the Xsens sensors friction against the backrest is different for between the for the fabric in this configuration and cause errors. The researchers, however, still believe that slouching is easier in configuration 3 while looking at the overall data. One theory for this might be that it is more difficult change to a more up-right position due to higher friction in the fabric seat. This however should prevent slouching in the first place, as theorised by the researchers.

6.1.1.4 Configuration 4, Lowered sitting height

Configuration 4 is somewhat different from the other configurations since it's the one that changed the sitting posture the most in the lower body with the lower seats to mimic a V60 or S60. The conclusion of the data for configuration 4 is that although it seems to be the most uncomfortable, most people do not initially slouch as much in this seat compared to configuration 1. This is a surprising result since the theory was that with higher knees, it would be easier for the back so slide down and rotate the pelvis. By looking at the taller test people, it could be seen that most of them would hit their knees in the front seat and were not able to slouch down without putting even more pressure on the knees. An example of this could be seen in 6.1 and was also mentioned in the interview highlights in appendix F. This would make it harder to sit different than the nominal position, since that would be the optimal one to not put pressure on the knees, However, since discomfort most likely will lead to different sitting positions over time, this configuration is the most interesting one to look at for longer rides.

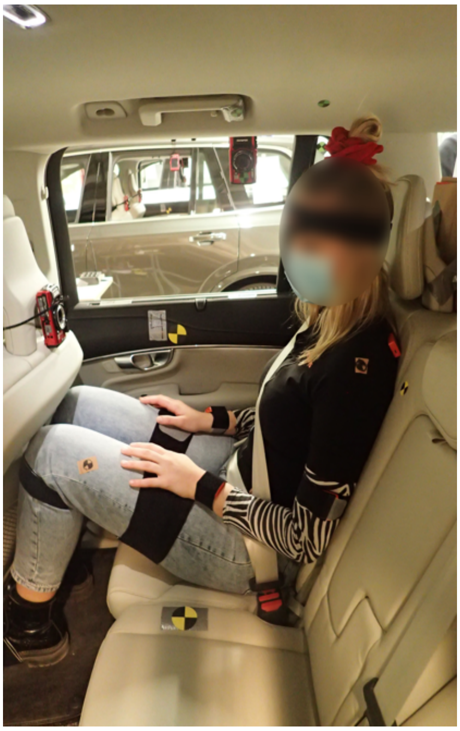

Figure 6.1: An example of how taller people would hit their knees in the from seat. This example is of test person 8 for configuration 4.

6.1.1.5 Configuration 5, Reclined backrest

In conclusion of this parameter evaluation, it is possible that a more angled backrest is a parameter that results in slightly more slouching. It is important to remember that the backrest is angled at 33 degrees for configuration 5 instead of 27 degrees as in the other configurations and this needs to be accounted for when looking at the pelvis angle. However, the delta value is still higher than for configuration 1. This configuration is also one of the most comfortable ones. One theory is that people might not need to slouch as much since their initial sitting position is already comfortable.

6.1.2 Parameter evaluation over time

The quality of the Xsens data was too low to use for the second test. However since the second study used the same reference system for the photo analysis the it became much more reliable to compare. This was one of the biggest changes from the first test, where the reference was always the nominal position for the same configuration. This means that the first test always gave a delta from the nominal position, while the second study gave a position in space. Read more in chapter 6.4

Looking at all the data, it is clear that time is a parameter that affect both slouching and discomfort. Looking at the ASIS measurement it is surprising that the nominal would have a about the same value as 30 minute position, but it is likely because of errors during the testing which is further discussed in chapter 6.3. There is at least some indication that slouching increases over time while looking at the photo analysis. The slouching was mostly seen in the upper body. There can also be seen some slouching in the lower body, however the drastic change of leg position makes it difficult to track how much the legs move forward after 30 minutes. This can be seen most clearly for test person 11 after 30 minutes in figure 6.2 where drastic change in the leg position gives a lower X position because of the legs leaning to the side. The change of sitting position also affected the comfort which can be clearly seen again in figure 5.30 for lower body between 20 and 30 minutes for test person 1.

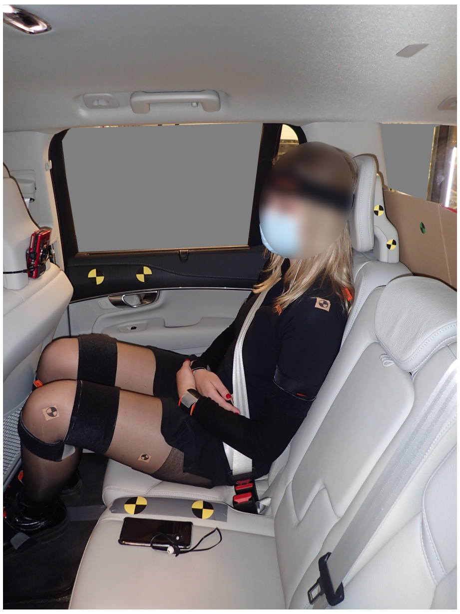

Figure 6.2: Test person 11 after 30 minutes. The legs are leaned to the side which causes the knee X value to be lower.

6.2 Limits because of COVID-19

The COVID-19 pandemic limited this project in a number of areas. To reduce the risk of spreading the infection, all the user studies were done in lab with as few persons at the test site as possible at once.

The number of test persons were also limited and the contact between the researchers and test persons were minimised as much as possible. This made it more difficult to take accurate body measurements of each test person. These measurements were used both to calibrate the Xsens system as well as test result.

The vehicles used were also extensively cleaned between each test at all possible contact points or places the test persons might have touched. This was time consuming and further limited the number of test that could be done.

Data of test persons length were measured using lidar and supplemented with measuring tape and should therefore be reliable for the Xsens calibration.

6.3 Measured objective data

During the main two studies, three methods were used to capture objective data from the test persons. These were measuring tape, photographs and Xsens. The combination of methods were used to calibrate the system as well as backup in case of any unforeseen problems with any of the measuring methods.

Test persons posture was captured with Xsens and photographed from the front and side. These images were then used to calculate the difference between the nominal position and the self selected ones. While this was only done for two images in each configuration in the first study, it was extended to five images in the second one. This was done for the nominal, 0 minutes, 10 minutes, 20 and 30 minute photographs. They were a useful complement to Xsens and while it did not have the number of data points generated by the Xsens system, they still provided cromulent data in order to see trends over time and generated more visual data.

The first study didn't have the same reference system for the different configurations. Therefor, only the delta value between nominal and self selected could be calculated for each configuration. However, during the second study the test persons sat in the same car for the whole test and could therefor use the same reference system. This resulted in being able to get the X, Y and Z position of the points. In the first study the points used was shoulder, sternum and knee. During the second study, thigh was added to more easily identify slouching.

Because of errors in the captured Xsens data, it was decided to exclude some of the data from the results. In the first study, it was done for Test person 10 because of with strange pelvic angles that did not make sense with the pictures taken. For the second study, it was decided to not use any of the captured Xsens data. This was because of uncertainties of data accuracy when it was found that the data was changed while processing making them no longer matching the captured images.

The biggest issue with this way of measuring the ASIS point was that the test person would themselves identify the ASIS points after instructions from the test leader. For the first study, the ASIS data was of too low quality to use since there was no clear connection and the most probable cause was pointing at the wrong spot. During the first study negative values was also not included and was set as 0. However, for the second study, the test persons had a walk-through of how to find the ASIS point on their bodies so they would be more accurate during the test. There still seemed to be some error with the measurement for the nominal position. The most probable cause for this is that the nominal position was measured last out of all the sitting positions and the belt was not taken off between the sitting positions. The belt could therefor be stuck to the persons clothes and not have an accurate position when switching between the 30 minute position and nominal. There is also still the chance that the test person had difficulties to find the ASIS point such as in the first study.

6.4 Xsens for measuring slouching

From this study it was found that Xsens Mtw Awinda (version 2018) is not suitable for a longer period of static testing. From what can be seen in previous projects researching similar themes, this Xsens system can be very accurate and repeatable (Hansson & Lysén, 2019). This has not been the case in this study using the 2018 software version. There are several possible causes of these problems, one being because of the noisy environment in the lab where a lot of magnetic fields can be found. Other possible causes could be electronic devices using the same 2,4 GHz band used by the sensors to communicate with the base station.

The Xsens system uses file processing to improve data quality and remove possible noise. When processing recorded data, the system need the test person to take a short walk before and after the main data collection in order to calibrate the algorithm. This was not possible to do since the test persons were not allowed to walk between each measurement since this would disturb the objective of the test. Another possibility would have been to record the entire test in one file and walk before and after the 30 minute test was done but Panagiota Papadopolou at Chalmers, who has a lot of previous experience with Xsens, had recommended us to keep files short in order to limit the loss at possible system crashes. This is also something we experienced a number of times during the studies.
During each user study, a considerable amount of time was put on getting a good calibration of the test person before the study started. It was seen during the study that certain people were more likely to get a successful calibration. The researchers think this depends on two main factors, how they walked during the calibration and the anthropometry of the person. For example, a person with a longer torso in comparison to their stature seemed to have a more difficult getting a good calibration. The Xsens software has the ability to add more information about the test person (e.g. lengths of different limbs) in order to get a more accurate model but this was not done in order to keep close contact with the test persons to a minimum.

It was also found that certain sensors locations on the body were sensitive to the small positional changes happening when the clothes move in relation to the body. These movements could cause big changes to the posture of the Xsens manikin. It was discovered in early testing of the system that the pelvis sensor location was important for the overall posture and it was therefor taped to all test persons for everyone that were comfortable with it. It was later found that the sensors for the lower legs also play an important role. If a test person has baggy pants, there is a chance that the sensors move up when the test person is sitting down. This can cause the legs of the Xsens manikin to be at different heights and also affect the knee angle. These sensor movements could also cause problems that embiggen even further during processing of the files which can be seen in figure 6.3

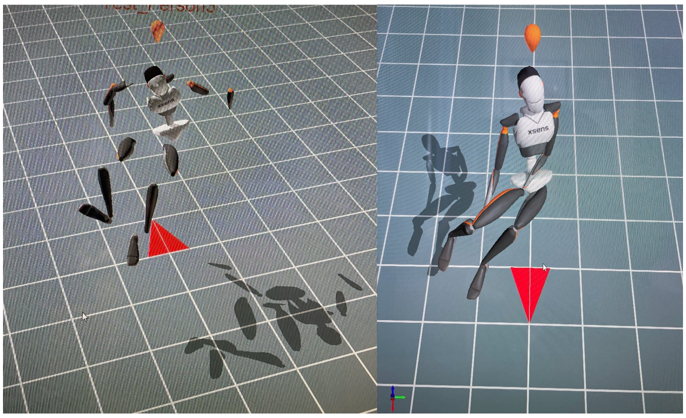

Figure 6.3: Two recurring bugs in Xsens

In the future, it would be interesting to investigate other similar solutions such as Xsens MVN Link, a full body suit. The MVN Link offers to a large extent the same functionality as Awinda used in this project. The main differences are that the sensors are mounted to a full-body suit and are wired. This could solve the possible problem of interference on the wireless frequency band. It would also help keep each sensor in its desired location and minimise sensor to body movements.

6.5 Developing possible solutions

One the main objectives of this study was to develop concepts to reduce passengers from slouching. Based on the learning's from the tests and the project as a whole a number of concepts were developed as inspiration for future product development. These solutions aimed to both improve the comfort as well as the safety of the passenger.

6.5.1 Extendable thigh support

A concept with an extendable thigh support was developed. Based on similar, existing solutions found on the front seats of many cars this support extends forward but also moves up in order to support the passengers legs and offer more support. This was what was seen during the second study, where test person 1 had issues finding thigh support after a longer time and would put the legs to the side until they were supported. Lack of thigh support was also one of the biggest reasons for discomfort during the first study.

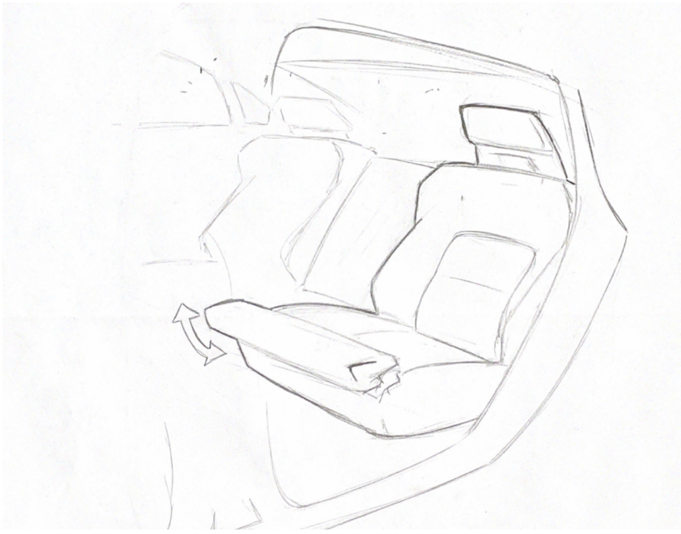

Figure 6.4: Illustration of an extendable thigh support

6.5.2 Pressure sensors

One finding during the pre-study that the researchers found was that slouching is less likely if the passenger is aware of the slouching itself. It was therefor very important that the test persons had no idea what was tested. There is therefor a theory that is there was some kind of warning or feedback system om the sitting position, people would be aware and more often do something about it. In theory, this could be a flashing symbol just like the seat belt symbols that are already used today in Volvo cars. The sensor system to detect bad sitting posture could either be pressure sensors in the seat to map out the pressure points and calculate if the person is slouching or use cameras and AI to decide (or both). Cars today can already today sense if there is someone in the seat. With further development it could also sense how someone is sitting in the seat.

6.5.3 Battery placement

In configuration 3, it was clear that lack of foot space did slightly increase slouching. This issue is mostly for smaller electrical vehicles such as Tesla Model 3, which configuration 3 was modified after. However, to reduce slouching it's important to note that it might be a bad idea to trade foot space for battery space. Some of the solutions that can be seen today, like in Polestar 2, the battery can be placed mostly in the tunnel, which gives more space under the front seats.

6.6 Future work

To further move forward and identify parameters that cause slouching, it would be interesting to see how all 5 configurations would look over time. This could further explore how discomfort affects the sitting posture and if that leads to slouching. For now there is a connection that can be seen between discomfort and time. However, there is no reference as only configuration 4 was tested for the second study. It would be interesting if slouching over time if the discomfort is not as drastic.

Another thing for the future would be to test even more parameters and make fitting configurations. Some were identified during this project which would be interesting to explore but did not make it into the tests due to lack of time these can be seen in figure 4.5. For example, one that the researchers found very interesting during the pre-study was lowered roof but it was difficult to design a configuration for it and was therefor replaced by backrest angle. Another that that would be interesting to look closer at is backrest hardness. However, there are even more parameters outside this project that could be further explored.

There definitely are some flaws to the methods that were used to measure slouching. The Xsens failed during the second study and to solve this, the Xsens system would have to be started while the test person was outside of the car and then walk in and run the system for the whole test period, which would potentially cause crashes and result in no data. It is therefor a good idea to try a different method to measure slouching. One idea, like mentioned in the possible solutions would be to have pressure sensors in custom-made seats. This would be able to give a heatmap of where the pressure points are and tell when a person begins to slide down into a slouching position. Another idea is to get a more advanced Xsens system, with a whole suite. The project also had some issues with the available license and had to download a beta version to be able to export to excel. There are however later versions available with functions especially designed for vehicles and processing.

The first test that used Xsens resulted in a lot of files. for each person there was 5 configurations with 2 sitting positions (nominal and self-selected) with a total of 10 people. That means that there were 100 Xsens files generated and exported to excel files. This study mainly looked at the pelvis orientation and position of different segments. However, there are still more information to be gathered from the excel files, such as orientation for each segment, segment velocity and acceleration, segment angular velocity and acceleration, joint angles, ergonomic joint angles and centre of mass. Some of these can still be useful to the study, but there was not enough time to go through it all and the project was therefor limited.

7 Conclusion

This study had the aim to evaluate how parameters affect the possibility of slouched sitting postures to occur. It also studied how slouching is affected over time. There has been multiple methods for how slouching has been measured and they have had different strengths and weaknesses depending on which test they were used at. The Photo analysis seems to have been the most reliable one for both tests. Xsens worked well for the first test where the test people moved a lot which help the post processing, but did not work at all for the second test where people sat still for the whole recording duration. ASIS measurement only worked for the second test when the test persons had a walk-through of how to find the ASIS point, but there are probably still some flaws in the method regarding nominal sitting position.

During the parameter evaluation it show that restricted foot space does contribute to slouching. Although this is mostly an issue for smaller electric vehicles, it is an interesting finding and can be important to consider for the future of designing cars.

This study also shows that seat upholstery has an impact of how much people slouch and should also be considered when designing cars in the future.

When looking at lower cars such as V60 and S60, which was tested through lower sitting height, there are not many signs of initial slouching, however this parameter is what caused the most discomfort.

Looking at the lower sitting height over time there is a connection between discomfort and changing sitting position, which further can lead to slouching according to the second study. Slouching over time can most likely be minimised by giving feedback or warning to the passenger regarding poor sitting posture.

Reclined backrest also seems to have a slight impact on how much people slouch. The recommended backrest angle from this study is 27 degrees over 33 degrees while having the XC90 standard sitting height. However, further testing would be necessary to optimise the angle for minimised slouching and this is something that can be used for future cars.

Although this study has shown that certain parameters contribute to slouching, there are several parameters that was considered but never tested. To further research the phenomena of slouching, better ways of measuring may be considered as well as more parameters to explore.

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A
Appendix

A.1 Rear seat of the Audi A7

Figure A.1: Photos of the rear seats of an Audi A7 MY20

A.2 Rear seat of the Audi e-Tron Sportback

Figure A.2: Photos of the rear seats of an Audi e-Tron Sportback MY20

A.3 Rear seat of the Jaguar I-Pace

Figure A.3: Photos of the rear seats of a Jaguar I-Pace MY20

A.4 Rear seat of the Mercedes EQC

Figure A.4: Photos of the rear seats of a Mercedes EQC MY20

A.5 Rear seat of the Porsche Taycan

Figure A.5: Photos of the rear seats of a Porsche Taycan MY20

A.6 Rear seat of the Saab 9-2x

Figure A.6: Photos of the rear seats of a Saab 9-2x MY05

A.7 Rear seat of the Saab 9-3 SportCombi

Figure A.7: Photos of the rear seats of a Saab 9-3 SportCombi MY10

A.8 Rear seat of the Saab 9000 CD

Figure A.8: Photos of the rear seats of a Saab 9000 CD MY89

A.9 Rear seat of the Saab 9000 Aero

Figure A.9: Photos of the rear seats of a Saab 9000 Aero MY96

A.10 Rear seat of the Saab ng9-5

Figure A.10: Photos of the rear seats of a Saab ng9-5 MY10

A.11 Rear seat of the Saab og9-5

Figure A.11: Photos of the rear seats of a Saab og9-5 MY97

A.12 Rear seat of the Tesla Model 3

Figure A.12: Photos of the rear seats of a Tesla Model 3 MY20

A.13 Rear seat of the Volkswagen Passat Variant

Figure A.13: Photos of the rear seats of a Volkswagen Passat Variant MY19

B
Appendix

B.1 Rear seat of the Volvo V60

Figure B.1: Photos of the rear seats of an Volvo S60 MY20

B.2 Rear seat of the Volvo V90

Figure B.2: Photos of the rear seats of an Volvo V90 MY20

B.3 Rear seat of the Volvo XC40

Figure B.3: Photos of the rear seats of an Volvo XC40 MY19

B.4 Rear seat of the Volvo XC60

Figure B.4: Photos of the rear seats of an Volvo XC60 MY20

B.5 Rear seat of the Volvo XC90

Figure B.5: Photos of the rear seats of an Volvo XC90 MY19

C

Appendix

C.1 Table of measured cars

Model	Body type	BEV	A	B	C	D	E	F	Backrest angle	Seat cushion angle	Comment
Audi A7	Combi-cupé	No	100 tapered	350	220	460	949	690	23	17	
Audi E-tron Sportback	Combi-cupé Crossover	Yes	120 tapered	390	210	450	930	670	21	15-21	Spacious and comfortable
Jaguar I-Pace	Combi-cupé Crossover	Yes	80	350	190	470	960	680	27	17-27	Comfortable angled seat cushion provides more support for thighs
Mercedes EQC	SUV	Yes	120	400	220	440	910	660	25	16	
Porsche Taycan	Sedan	Yes	90	340	150	460	900	690	30	18-26	Limited leg room, knees hit backrest and limited space for feet under front seats
Tesla Model 3	Sedan	Yes	25	290	280	460	958	670	20	20	Cramped, uncomfortable seat cushion and no space for feet under front seats
VW Passat	Combi	No	120	340	240	500	1007	660	27	19	
V60	Combi	PHEV	50	320	190	450	960	710	27	19	Bad thigh support, foot space and knee room. Okay headroom
V90	Combi	PHEV	70	340	215	460	950	710	30	10-26	Limited foot space, good knee room and better thigh support than V60 OK head room
XC40	Crossover	No	150	340	180	450	970	670	21	9	Limited knee room, good foot space and head room, OK thigh support
XC60	Crossover	No	160	385	185	455	988	700	25	16	More legroom than XC40, good space for feet and alright headroom
XC90	SUV	No	180	360	250	450	920	610	17	1-17	Panoramic sun roof lowers the roof height
Saab 9000	Sedan	No	100	360	200	520	880	590	25	12	Comfortable and roomy except for headroom. Good thigh support
Saab 9000 Aero	Sedan	No	100	370	200	530	885	600	25	10-30	Same as 9000 but even more support. Worse head room than 9000
Saab og9-5	Sedan	No	100	330	250	500	920	600	27	13	Fabric upholstery with high friction, may limit possibility to slouch
Saab 9-2x	Combi	No	120	340	250	400	930	610	25	13	Knee hits backrest
Saab 9-3	Combi	No	110	340	100	450	987	660	26	24	Knee hits backrest, comfortable seat and good thighsupport
Saab ng9-5	Combi	No	90	340	240	450	900	700	30	10-24	Alright seat, its possible to slouch but because of the angle you easily slip back

D
Appendix

D.1 Comfort form 1

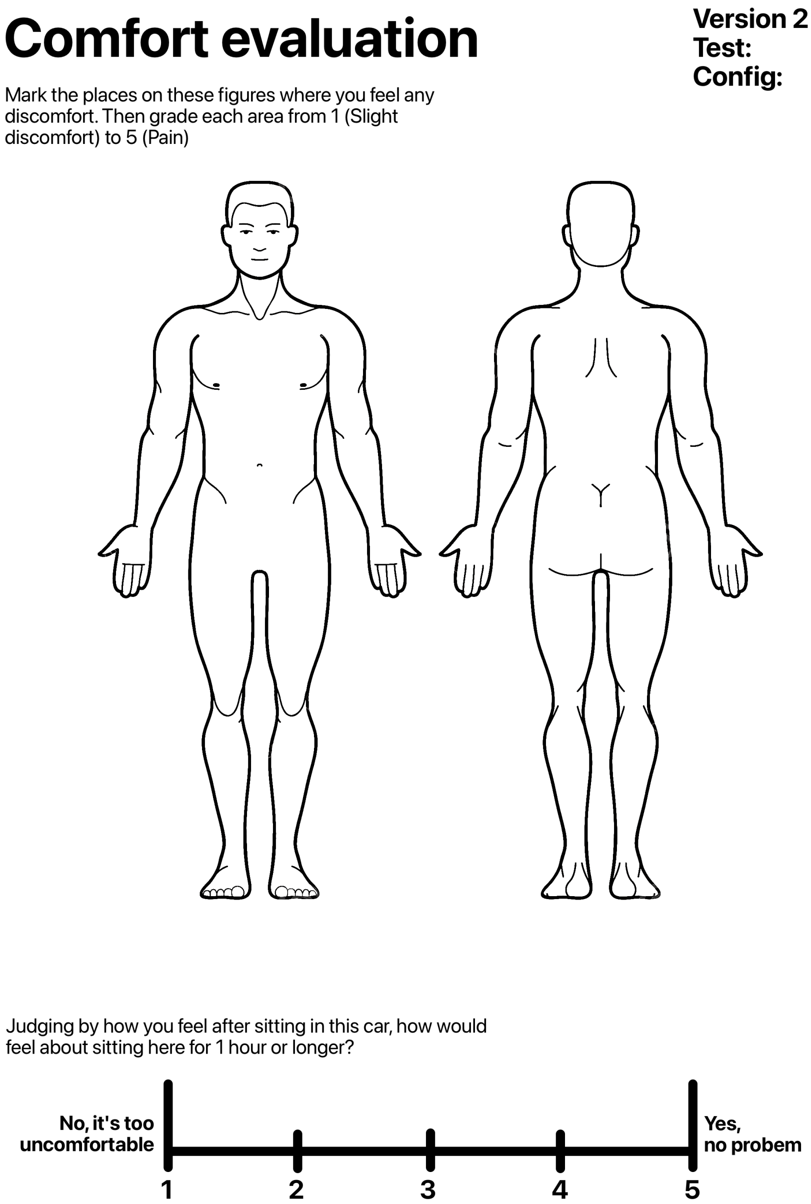
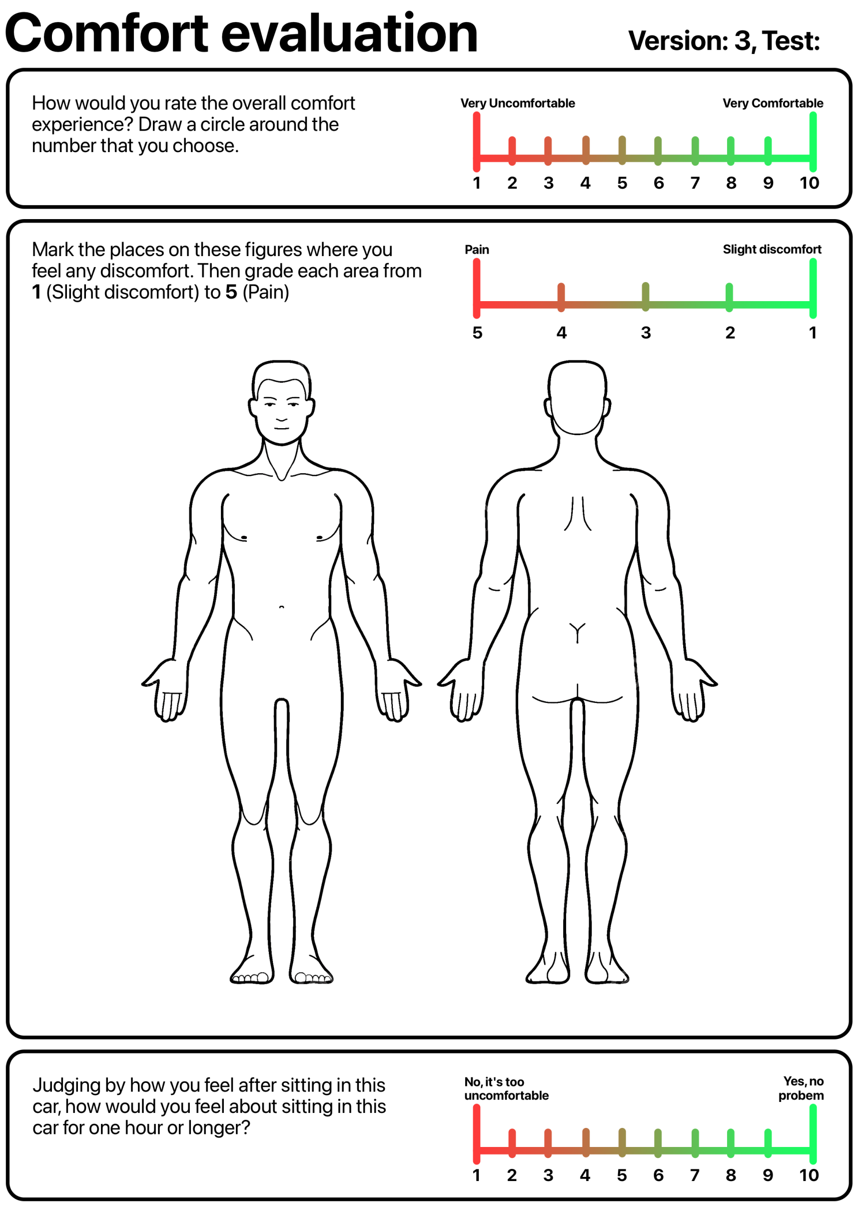


Figure D.1: The form used in the first user study

D.2 Comfort form 2



Comfort evaluation

Version: 3, Test:

How would you rate the overall comfort experience? Draw a circle around the number that you choose.

Very Uncomfortable — Very Comfortable

1 2 3 4 5 6 7 8 9 10

Mark the places on these figures where you feel any discomfort. Then grade each area from **1** (Slight discomfort) to **5** (Pain)

Pain — Slight discomfort

5 4 3 2 1

Judging by how you feel after sitting in this car, how would you feel about sitting in this car for one hour or longer?

No, it's too uncomfortable — Yes, no probem

1 2 3 4 5 6 7 8 9 10

Figure D.2: The form used in the second user study

E

Appendix

E.1 Results from pre-test

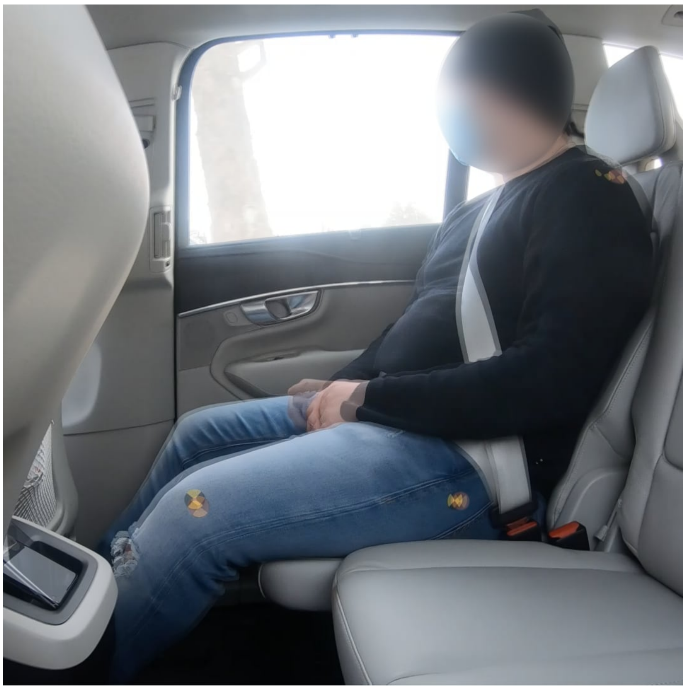


Figure E.1: Image of passenger movement for pre-test person 1 with angled backrest

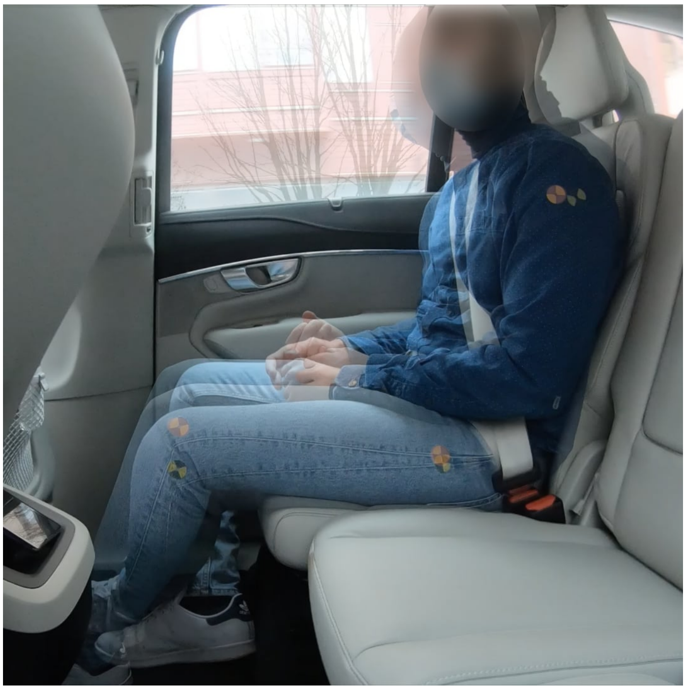


Figure E.2: Image of passenger movement for pre-test person 2 with upright backrest

Figure E.3: Image of passenger movement for pre-test person 2 with angled backrest

F
Appendix

F.1 Interview Highlights

	Configuration 1	Configuration 2	Configuration 3	Configuration 4	Configuration 5
Head					• Head is leaned a bit too much backwards.
Upper body					• Arm can be up against the rear middle seat.
Lower body (legs excluded)					
Legs				• No thigh support. • Knees are close to the body. • A lot of gap between thighs and seat. • Limited room for the knees. • Legs are too angled. • Floor is too high.	
Feet		• Can't move feet forward. • Feet wants to go under the seat. • Lacks the ability to stretch the legs. • Forces legs into an angle.		• No enough foot space.	
Other	• Generelly comfortable. • Seat is a little bit too stiff.		• Very comfortable. • Glass roof makes the car feel more spacious.	• Can't handle a longer trip.	• Generally comfortable. • Will likely start submarining/slouchin g after a while. • Somewhat wierd angle.

Figure F.1: A summary that categorised common comments about each configuration. Each comment has been mentioned by at least 2 people.

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