

Leg and Foot Support During Non-Driving Scenario

Investigating how added support systems are valued by users and how they should be designed to increase comfort.

Master's thesis in Industrial design engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2023
www.chalmers.se

MASTER'S THESIS 2023

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Cover:

Picture illustrating a person traveling with lower leg support.

Gothenburg, Sweden 2023

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Abstract

The new generation of electric cars and future generations of autonomous cars will change behaviors while charging and driving, creating opportunities where one can relax in the car. This master thesis aimed to investigate how added support systems for lower legs and feet in Volvo cars are valued by users, and how these support systems should be designed to suit different drivers to improve sitting comfort during non-driving scenarios, such as waiting while charging or riding an autonomous car. The process has been user-centered and iterative, starting with scope definition and continuing with two user tests. The first user test focused on the design of the leg support, including size, shape and placement. The second test focused on how to maximize sitting comfort with leg and foot support, testing with and without the leg and foot support and with the user in different torso angles. Test results were analyzed quantitatively and qualitatively, showing that people sit most comfortably in a freely chosen seat back angle with both leg and foot support. Guidelines for how the leg support should be designed and the foot support should be positioned have been developed based on the user test results. The guidelines were then a basis for the final prototype that was made.

Keywords: Comfort, Non-Driving Scenarios, Relaxed position, Reclined position, Support systems, Lower leg support, Foot support

Acknowledgement

The following thesis report is the result of our master thesis covering 30 credits. The master thesis was performed at the Industrial Design Engineering program at Chalmers University of Technology. The program is part of the Design and Human Factors division at the Department of Industrial and Materials Science. This master thesis project was performed in collaboration with Volvo Cars Corporation (VCC).

We want to start by saying thank you to all employees at VCC, helping us with the project along the way, taking their time to answer our questions and volunteering as test persons during our user tests. We are very grateful for the shared knowledge and for the input we received from you. A special thank you to our supervisors at the Ergonomics Department at VCC, Nadja Lejon and Tommy Apell. Your expertise helped and guided us during the project and having you to discuss with and get inspiration from has meant a lot. We would also like to pay a special thank you to Krister Hedlund from the Ergonomics Department for taking your time to help us whenever we needed, we are incredibly grateful for that.

We want to thank Helena Strömberg, Senior Lecturer at Design and Human Factors at Chalmers University of Technology. You have been a huge support throughout the project and have supported and guided us to ensure we stayed in the right direction. It has been invaluable to discuss our thoughts and ideas with you.

Lastly, we want to thank our opposition group, Anna Gustafsson and Emelie Jansson.

Carolina Eriksson and Emilia Lundin

Gothenburg, 2023

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Glossary

VCC – Volvo Car Corporation

Torso Angle - The angle of the chest (i.e., torso) on a person seated in a car seat

(Seat) Back Angle - The angle of the car seats backrest

Infotainment system – Systems regarding information and entertainment. In newer cars the infotainment system is often a display, with functions including for example radio, multimedia and navigation.

Design position - The starting point for a seat adjustment. The design is made based on this position, and if the parts on the seat have adjustment options, the design position is used as a starting point. The design position is a reference to other settings.

TP – Test person

Reclined position - A sitting position where you lean back with the upper part of your body. In this report, a reclined position refers to a torso angle of 35 degrees or more

01

INTRODUCTION

1. INTRODUCTION

This section presents the background, aim, deliverables, project scope and process overview to introduce the project.

1.1 Background

The world's industries are switching to more sustainable alternatives, which also includes the automotive industry (Pohl, 2021). This has led to a shift from cars powered by fossil fuels to cars powered by electricity. At the same time, new technological advances are constantly being made, which leads to increasingly autonomously driven cars (Hussain & Zeadally, 2019). Autonomous cars are independent vehicles with features to navigate on the road, sense the surrounding environment and make quick decisions. Automated cars are also independent, but in contrast to autonomous cars, they might need human interaction. For example, by holding the steering wheel or by being ready to take over control. These cars can be programmed to drive in a more sustainable, fuel-efficient manner by avoiding erratic driving. According to the National Highway Traffic Safety Administration (2015), human errors are the reason for 94% of all traffic accidents. Therefore, there is an opportunity to improve traffic safety by using autonomous or automated cars (Hussain & Zeadally, 2019). While the automotive industry is changing due to technical progressions and sustainability motifs, how we ride and drive our cars is also changing as an effect (Hussain & Zeadally, 2019).

The future ahead opens for new possibilities and new demands creating new user needs. The new generation of electric cars is changing user behaviors since charging takes longer than "regular" fueling. While fueling takes a few minutes, charging often takes approximately 30 minutes, depending on charger type and car brand (InCharge, 2020). This creates a situation where the user might wait in the car during recharging, and consequently, new demands are placed on seat comfort. A similar type of waiting

behavior could be occurring in the autonomous or automated cars of the future, where driving is handled by the car itself, something that makes drivers more like passengers. While waiting in the car the user might want to, for example, socialize, relax, or work (Larsson & Östling, 2019).

The interior design of cars needs to be adapted to new, future needs. At Volvo Car Corporation (VCC), safety and comfort has always been a main priority. Volvo's seats are known to be comfortable (Volvo Cars, 2023), but with new behaviors while charging electric cars and driving more automated ones, there is a higher demand for different sitting positions. Since the pedals are not used while charging or riding an autonomous car this allows for improved comfort systems for lower legs and feet. How cars will be used during autonomous driving (AD) is uncertain and investigating lower leg and foot support further will therefore help VCC understand which comfort systems that might be needed in the future.

In order to make users truly satisfied, it is important to identify their latent needs. Ching-Chow (2013) discusses the challenging aspect of identifying these needs because they can be hard for users to express. He describes how users base their expressed needs on previous experiences and have a limited reference frame which make it hard to predict future needs in areas such as emergent technologies. According to Chow (2013), a suggested approach for finding latent needs in product development is to involve users in the design process and let them influence design decisions.

Consequently, this master thesis project explores the possibilities of added seat support systems in terms of lower leg and foot support with a user-centered approach. It investigates how the support systems can extend the adjustment possibilities of the seat and thus allow more sitting positions and better meet the potential future user needs.

1.2 Aim

The project aims to investigate how added support systems for lower legs and feet in Volvo cars are valued by users and whether they can increase comfort. It also investigates how these support systems should be designed to suit different drivers in the best way possible and improve sitting position during non-driving scenarios, such as waiting while charging or riding an autonomous car.

The research questions below will be answered during the project:

- Q1: *How should lower leg and foot support be designed to increase comfort in a seated position for the Swedish population, from the 5th percentile female to the 95th percentile male?*
- Q2: *How do users value lower leg and foot support during non-driving scenarios?*

1.3 Deliverables

The deliverables of this project are:

- A list of guidelines and recommendations which explains how support systems for lower legs and feet can be designed to improve comfort and sitting position.
- An interior concept for lower leg and foot support which improves comfort and sitting positions for non-driving scenarios.

1.4 Project Scope

The focus of the project is to investigate if there is a need or a latent need for lower leg support and foot support during non-driving scenarios. Therefore, user utility connected to lower leg and foot support is of priority. The project also examines how lower leg and foot support would be designed to fit as many users as possible. Hence, ergonomics and comfort are a priority. An interior design concept of lower leg and foot support is created and used to find out if there is a latent need for such support systems, and if

so, what they would add regarding comfort, ergonomics and user utility. Since the focus is ergonomics and comfort, the project extends beyond how cars look today focusing on how to maximize comfort for the lower legs and feet.

The project only investigates the need for and use of lower leg and foot support in the first seat row. Hence, a constraint is to not investigate these support systems in the second (or third) seat row since the seat structures and prerequisites are different between the rows of seats. Another constraint is that the project looks at the 5th to 95th percentile of the adult Swedish population. The Swedish population is used since the project and tests are executed in Sweden. Considering the chosen percentiles, 5th to 95th is common limits in developing processes (Openshaw & Taylor, 2006).

1.5 Process Overview

This project started with a definition phase that defined the project scope and helped guide the project. Defining the project scope included the initial part of the literature study. However, the literature study was used as a guiding tool during the whole project, supporting when structuring the process and analyzing results.

The two main parts of the projects were the two user tests. The first was used to get an understanding of how leg support should be designed to be as comfortable as possible while the second test focused on how seat adjustments and the leg and foot support should be adjusted for maximal comfort. Both tests were analyzed, and the results discussed and compared resulting in the final prototype and design guidelines.

In the report each part of the project is described separately but due to the projects complexity some parts have been run in parallel to use time efficiently. A process overview can be seen in Figure 1 below.

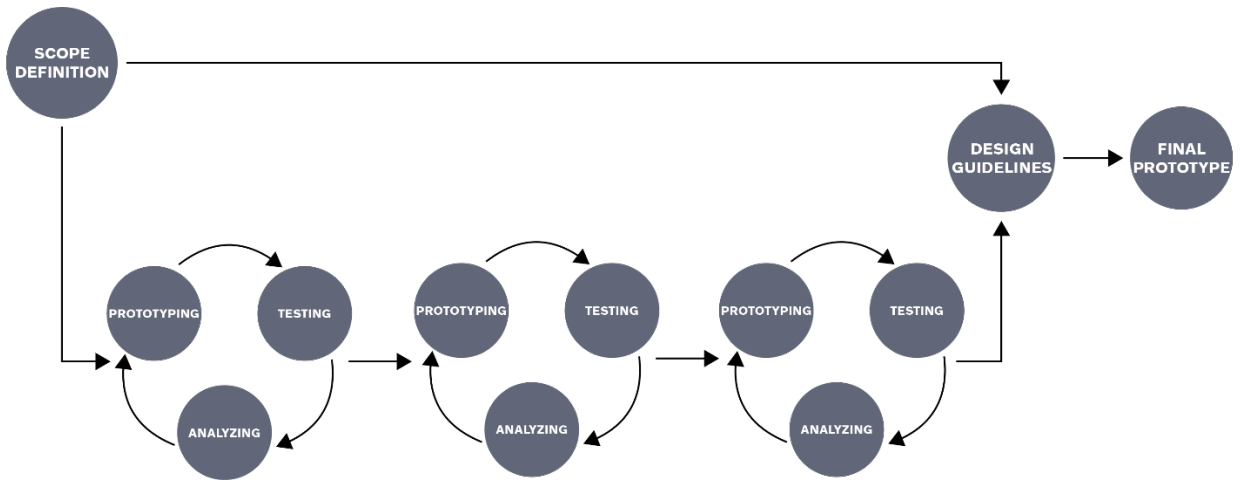


Figure 1. Process overview. Authors own figure.

02

**THEORETICAL
FRAMEWORK**

2. THEORETICAL FRAMEWORK

The following chapter presents the literature study on relevant theory used to fulfill the purpose of the master thesis. Hence, the information focuses on sitting comfort in vehicles and what factors affects it.

2.1 Comfort & Discomfort

According to Caballero-Bruno et al. (2022), a headrest, backrest, cushion and lower leg support is needed to support a natural body position when traveling in a reclined or flat position. To avoid high local loads, it is important that the surfaces are even and that the edges are smooth and do not create hanging effects with concentrated pressure on any body parts (Caballero-Bruno et al., 2022).

Mellqvist & Vicini (2022) agree and describe how small radiuses on car interior design often are connected to discomfort. They have investigated how comfort in vehicle surfaces are affected by radiuses and paddings, and found that some body parts are more sensitive for small radiuses than others. For instance, the radius against the shin needed to be bigger than the radius against the arm and the back of the head to reach a comfortable level. They also found that added padding allows smaller radiuses to reach a comfortable level. For instance, the results showed a significant difference in the allowed radius on the shin between zero millimeter padding and 15 millimeter padding, but eight millimeter padding has similar results as zero millimeter padding. Applying their findings for the lower leg support design during this project implies it is important to use radiuses on the edges and a minimum of 15 millimeter padding.

Avoiding high local loads is another important parameter in order to prevent discomfort. Zang et al. (1996), describe how discomfort is related to biomechanical factors such as joint angles, muscle contractions and pressure distribution. These factors can cause feelings of pain, soreness, and stiffness. Time is also an important aspect since discomfort increases with time on task. The sign of discomfort is an important signal to change

posture, otherwise it can lead to pain or injury (Hägg et al., 2015). During this project, it is therefore important to consider the time aspect when evaluating user tests since it can affect the result.

Comfort, on the other hand, is connected to feelings of well-being and relaxation. The appearance of a product is important when striving for comfort because aesthetics can affect how comfortable a product is perceived (Zhang et al., 1996). Hägg et al. (2015) agrees and describes discomfort as something physical while comfort is described as a more complex concept, based on a subjective experience. In the project it is important to separate these terms. Hence, when evaluating comfort and discomfort, they should be seen as different entities and not as two opposites on the same scale. Accordingly, reducing the physical factors producing discomfort does not automatically create comfort. Likewise, eliminating the feelings of comfort does not have to lead to discomfort. Although, increased discomfort will decrease comfort and a high level of comfort is related to a low level of discomfort (Zhang et al., 1996).

2.2 Ergonomics

Ergonomics is the “science of work” (International Ergonomics Association, n.d.). The goal with ergonomics is to create good conditions for humans, promoting comfort, freedom of action and recovery, and avoiding fatigue, discomfort, and injuries. Since comfort is a central part of the master thesis project, theory about ergonomics is used with the perspective of how to promote comfort and prevent discomfort.

The Human Factors and Ergonomics (HFE) discipline is looking into how humans work together with technology and how technology can be optimized for humans and their limitations and possibilities (International Ergonomics Association, n.d.). The HFE principles are to look at humans as assets and technology as something created to help and assist humans, but also to promote quality of life and respect everyone and their individual differences.

Ergonomics can be divided into three different categories: physical, cognitive, and organizational. Physical ergonomics concerning physical activity and the characteristics of anthropometry, anatomy, biomechanics, and physiology. Cognitive ergonomics concerning mental processes and how humans interact with each other, with products and technology. Organizational ergonomics concerning sociotechnical systems and how humans work and act in social contexts. Principles of physical ergonomics are most relevant for this project because they can be used in order to understand how to prevent discomfort.

How quickly people experience fatigue depends on the duration and frequency of an activity or a load (Hägg et al., 2015). A load can be both mental and physical. Physical loads are divided into static and dynamic. Static loads are both isometric and isotonic, meaning there is no change in either muscle length or force. If a performed task or activity allows for normal or neutral body positions, with the spine as close to its normal curve as possible, the chance of fatigue and pain are lowered, since a natural body position means lower static loads. Static loads with high forces during longer time periods lead to impaired blood circulation, and pain and tenderness in the muscles. Static loads with low force and shorter time periods do rarely cause problems. Therefore, it is important to consider a neutral body position in the car seat during this project.

To avoid physical stress on the body, the design of the support systems should make it easy to change posture regularly, twisted and asymmetrical postures should be avoided, joints should not be fully extended over longer time periods, extremities should be kept as close to the body center as possible and high pressure on sensitive soft tissue should be avoided (Hägg et al., 2015).

2.2.1 Anthropometry

Every human is different and designing for good ergonomics requires taking people's differences into account. It is important to

consider people's gender and physical resources, which change with age (Hägg et al., 2015). Both physical and mental capacity decreases when people grow older, putting an even higher demand on the design. In this master thesis, the difference of people's anthropometrics is an important aspect to consider in order to develop support systems comfortable for all in the chosen population.

Anthropometry is the science of people's measurements. Anthropometry defines the body's different dimensions and the methods used to determine those measurements. The measurements include a person's size, form, and functional capacities (National Institute for Occupational Safety and Health, 2022). Anthropometry is used in development processes to make sure the design of a product physically fits the intended users (Antropometri.se, n.d.). Making products compatible with 5th to 95th percentile anthropometric measurements is also important in order to prevent unintended and unsafe use of products (National Institute for Occupational Safety and Health, 2022). In addition to that people are different in terms of length, width and strength, everyone also has different proportions. This means a person of average height rarely has average value for the other body parts. It is also important to consider how demographic characteristics such as age, gender and ethnic groups can affect the body dimensions and create variations between the different user groups (Antropometri.se, n.d.).

Normal distribution is used to present the statistics of anthropometric measurements. The main part of a population will then be concentrated on the mean value of a measure while fewer have lower and higher values of the measure. In a graph, this will be shown as symmetrical curve with the highest point in the middle of the x-axis. Percentiles are often used for analysis of anthropometrics where, for instance, a person of average height of a population belongs to the 50th percentile. This means a woman of the 5th percentile is shorter than 95% of the measured female population and a man of the 95th percentile is taller than 95% of the measured male population

(Antropometri.se, n.d.). In product development it is common to design for the 5th percentile female to the 95th percentile male which covers approximately 90% of the population (Openshaw & Taylor, 2006). This design restriction is often made because it is difficult to ensure that a design fits an entire population, and by setting a percentile restriction on a population there are specific metrics to deal with. Hence, this project uses the Swedish population from the 5th percentile female to the 95th percentile male.

When performing user tests in the project, it is important to include people that belong to different percentiles of the population to understand their different needs, regarding body measurements and how that affects comfort. Since this project focuses on support systems for lower legs and feet, body height, knee height and buttock-knee length are relevant measurements to consider when comparing people's anthropometrics (Figure 2).

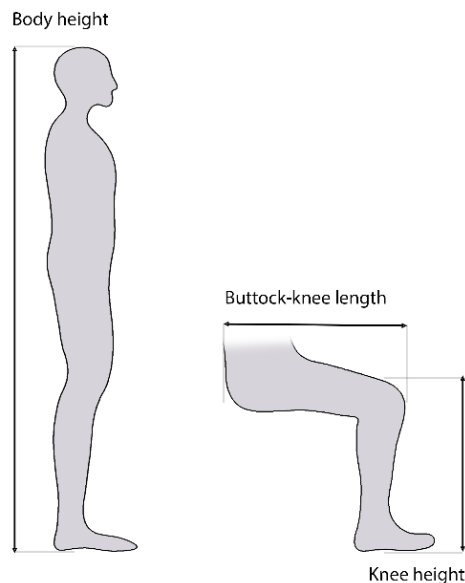


Figure 2. Body measurements. Authors own figure.

2.3 Automobile Seat Comfort

In a car, the driver is limited by a small space due to the demands of reaching controls, pedals and vision requirements which make it difficult to change posture. Harrison et al. (2000) explain how drivers are in a high-risk group of spinal disorders due to the static sitting posture and vibrations. Callaghan &

McGill (2001) explains how movement is required to nourish the intervertebral discs and other structures in the body. Static sitting disrupts nutrient delivery which will create muscle fatigue and discomfort (Gyi, 2012). According to Callaghan & McGill (2001), standing is a good rest from sitting. Although, sitting with little dynamic movement will provide some rest for structures of the back and therefore, altering between multiple sitting postures will prevent static loads on the spine. Considering this for a car seat design it should be avoided to force users to one ideal sitting position. Instead, the design should allow for a variation of sitting postures (Callaghan & McGill 2001).

Harrison et al. (2000) describes how the car seat directly affects the driver's spinal biomechanics and mention important factors to increase comfort and reduce pain in the car seat. It is important to have adjustable bottom tilt, seat height, seat back angle, lumbar support, head rest support, arm rests and linear front-back adjustment (Figure 3).

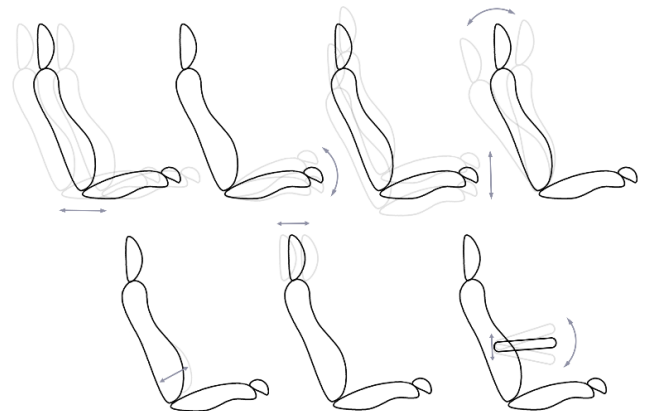


Figure 3. Seat adjustments. Authors own figure.

A dense foam in the seat bottom is also recommended since it will reduce vibrations. Other important parameters affecting the comfort and the driver's posture are shape, upholstery characteristics and covering materials (Harrison et al., 2000). Gyi (2012) agrees adjustable seats are important and explains how a large number of adjustable parameters increase the likelihood of the driver finding a range of comfortable positions. Hence, developing support systems with different parameters possible to adjust is of importance when striving for comfort.

Kolich (2008) also investigates automobile seat comfort and what factors affect it. Kolich presents four different categories of parameters important to consider: Vehicle package, Social factors, Individual factors and Seat factors. Vehicle package defines the roominess in the car as headroom, legroom, shoulder room and hip room. Vehicle package is an important parameter since the same seat can be placed in different vehicle packages and receive different comfort ratings. The category of Social factors will also affect the perceived comfort where Kolich mentions nameplate and purchase price of the vehicle as examples. Individual factors like body size, age, and posture can affect the comfort rating as well. Posture is described as the most important, but also the most complex individual factor since people's posture can differ entirely, even if they have similar anthropometrics. The last category, Seat factors, includes stiffness in the seat, geometrical shape, and breathability. The geometrical shape needs to accommodate the anthropometric variability of the user group and the breathability is important when considering environmental conditions, such as temperature in the car. As mentioned before, styling is also an important part of the Seat factors since the aesthetics can affect the perceived comfort (Kolich, 2008).

2.4 SAE Standards

The need for automobile standards emerged during the early 1900's since standardization in an industry facilitates and promotes safety and productivity, and helps fulfill laws and requirements (SAE International, 2023). Society of Automotive Engineers (SAE) is the biggest association for automobile standards and has over 1900 active ground vehicle standards helping the automobile industry to become safer and implement new solutions. For the master thesis it is important to understand relevant existing standards and common terms used within the car industry.

SAE J2732 Seat Dimensions

When measuring a car, it is always assumed that the origin point is in front of and below

the car (SAE International, 2008). The x-axis is the axis that represents the car in length, the y-axis is the one that represents the car in width, while the z-axis is the one that represents the car in height. The car's right and left sides are defined on the car's direction of travel when it drives forward. Hence the right and left sides of the car are always the same.

The seat is divided between A-surfaces and B-surfaces. A-surfaces are the surfaces closest to the occupant, while B-surfaces are the surface farthest away from the occupant (SAE International, 2008).

The H-point or hip-point is crucial when measuring car seats since it is the point where a person comes to rest in the car seat. The manikin used to measure where the H-point is has the weight of a 50th percentile American man and the leg length of a 95th percentile man (Bubb et al., 2021). The H point is a central reference point for the ground vehicle design. The vertical height from the H point to the heel point is called H30. H30 is different depending on whether it is a high or low car. Higher cars have a bigger H point measurement.

The seating reference point (SgRP) is the, by manufacturers estimated H-point, used to simulate the pivot point of the human thigh and torso.

SAE J4002

The heel point or Accelerator Heel Point (AHP) (Figure 4) is the point that represents where the heel of the shoe ends up when pressed into the floor covering (SAE International, 2022).

The Ball of Foot Reference Point (BOFRP) (Figure 4) is representing the point for the Ball of Foot (BOF), which is a point measured, with the foot in a certain angle touching the undepressed pedal at the same time as the AHP is pressed into the floor covering.

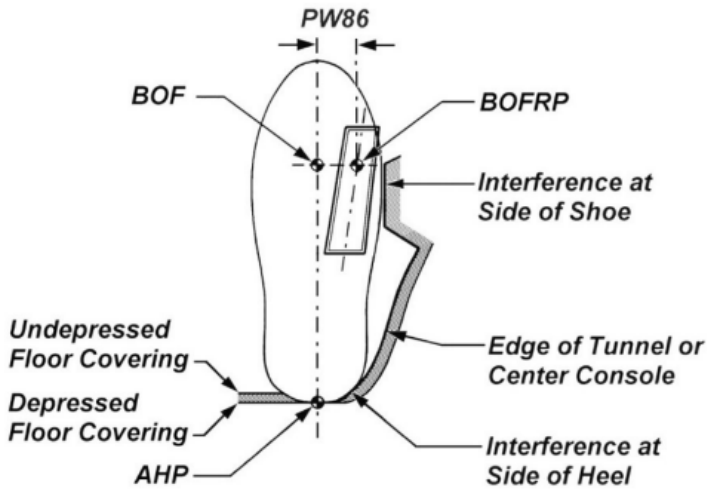


Figure 4. Reference points (SAE International, 2022).

03

**RELATED
WORK**

3. RELATED WORK

This chapter presents previous research related to this project. In order to understand future user behaviors and user needs, the research focuses on activities in non-driving scenarios.

3.1 Activities in Non-Driving Scenarios

Activities in non-driving scenarios are divided into activities during transportation today and what activities people expect to do in autonomous cars.

3.1.1 Activities During Transportation Today

In a web survey, participants answered questions about current activities they perform when driving a manual car and what activities they carry out as a passenger (Pfleger et al., 2016). During a car ride as a driver, the most common activities were listening to music (95,3%), talking with passengers (95,0%), interacting with the infotainment system (73,0%) and eating/drinking (66,7%). Calling (36,7 %) and texting (28.7 %) were also common activities. In the survey, they rated how frequently different passenger activities were performed. As a passenger, the most frequent activities were watching out of the window (85%), texting (74%), talking to passengers (72,3%) and listening to music/radio/ audio books (72%). This was followed by drinking/ eating (54%), surfing the internet (52%), reading (49,7%) and social media (47,3 %). To learn more about passenger activities, observations were conducted in subway trains where one activity was counted for each person. The most identified behavior was daydreaming/performing no activity at all (18,5%). Reading books/newspapers (16,1%) and talking to passengers (14,3%) were common activities. They also observed people looking out of the window (11,5%) and reading on the phone (9.8%). The findings from the different studies are then discussed in relation to future needs in autonomous cars. *“The automated car is more than a place for play and productivity as we identified a high demand for example for relaxing,*

daydreaming, sleeping, and looking out of the window” (Pfleger et al., 2016). Since doing nothing was the most observed activity in the subway, Pfleger et al. (2016) argues there will be a high need for a relaxing environment in automated cars. Being able to adjust the seat to a more relaxing position is mentioned as an example of how to provide this.

The insights from previous studies on activities during transportation today will in this study be considered during the planning of the user tests. The insights also support the purpose of this thesis by confirming that there is a need to be able to adjust the seat to a more relaxed sitting position.

3.1.2 Activities in Autonomous Cars

Different studies have been conducted where people are asked about their expectations related to hypothetical scenarios of riding autonomous cars. In an online survey by Octavio et al. (2019), people were asked about activities they would prefer during different travel scenarios. When traveling with others, talking was the most selected answer. Reading, listening to music and looking out of the window were also common answers. When traveling alone, they wanted to relax/sleep/rest and use the phone. Although, reading, listening to music, and looking out of the window still were common answers. A study made by Jorlöv et al. (2017), showed that a reclined seat was desired to support more relaxing activities such as sleep, reading or surfing the internet. 42% wanted a reclined seat during a short drive and 65% wanted a reclined seat for a longer drive. A third study by Larsson and Östling (2019) resulted in similar answers. For a short commuting drive, relaxing, watching movies and working was mostly selected. For family trips, relaxing and watching movies still were popular answers together with chatting, eating, and playing on the phone. According to a study made by Caballero-Bruno et al. (2022) people want to relax in a flat position during long-term rides and in a reclined position during midterm and short-term rides.

The studies show there is a potential need for relaxing activities in future non-driving scenarios. The lower leg prototypes in this study will therefore be tested in several reclined positions in order to understand how the torso angle affects the comfort when seated with lower leg and foot support.

04

METHODOLOGY

4. METHODOLOGY

A user centered and iterative approach has been used during the project where the users have affected the development and design decisions made throughout the process. The process in the project can be divided into four phases: scope definition, prototyping and testing, analysis and evaluation, and guidelines and final design (Figure 5).



Figure 5. Methodology process. Authors own figure.

The scope definition was the first phase of the project where inspiration and knowledge were gained about support systems for non-driving scenarios. This phase resulted in a list of requirements for the project and questions that aimed to be answered in user tests. In the prototyping and testing phase, prototypes of lower leg support and foot support were developed and tested in different rounds. Each test was followed by analysis and evaluation to compile the results as well as decide on what to investigate further. Iteration between these two phases has been a central part of the project where problems and requirements could be identified. When all questions were answered, the result was presented in guidelines and a final prototype design.

4.1 Scope Definition

The scope definition consists of a literature study, an inspiration study and expert interviews. These activities provided knowledge and inspiration that helped to

understand the limitations and possibilities for the project. An additional output from the scope definition was specified questions to examine in user tests. These questions were used as a guide for planning the user tests and prioritizing further activities in the project.

4.1.1 Literature Study

A literature study (Snyder, 2019) was made in order to identify user needs and gain background knowledge about ergonomics, comfort and non-driving scenarios. The sources used were books, reports, articles and other research studies. Some of the keywords used when searching for sources were anthropometrics, sitting, ergonomics, body postures, comfort, user activities, and autonomous vehicles. The sources were found by tips from the expert interviews, where the interviewees recommended both articles and research studies but also technical terms to search for. Sources was also found through keyword-searching at google scholars and Chalmers library. Lastly, information was found on the SAE Mobilus platform that has industry standards for the automobile industry. The sources were chosen based on their relevance for the project. The chosen literature sources were read, and interesting parts were noted and used as references in the report's theory and related work chapters. This information influenced decisions on methods used in the project and requirements for the support systems.

4.1.2 Inspiration Study

An inspiration study was done to analyze what kind of support systems there are for lower leg and feet on the market today. The aim of the inspiration study was to understand how other car brands have chosen to design their lower leg and foot supports to increase sitting comfort in the car and if there are any common denominators for these supports. The purpose was also to pinpoint how the need for lower leg support and foot support are met by competitors today.

The inspiration study was done with two focus areas, one to investigate if other car brands have lower leg and foot support, and if

so, how they are constructed. The other focus area was to investigate in which other contexts lower leg and foot support are used and how these support systems work and function, focusing on form and design.

Car brands with lower leg and foot support

The first step was to find which car brands had lower leg and or foot support in their cars. This was done by searching for cars with lower leg and foot support on Google's search function but also by browsing different car brand websites and newspaper articles about cars with lower leg and foot support.

The second step was to investigate how the cars with support systems for lower legs and feet were designed and to look for common attributes across brands.

Other markets with lower leg and foot support

During this part of the inspiration study, research was first done on which other markets have lower leg and foot support. These areas were found by trying to think of other situations in which a person sits still for a long period of time, or where it is important to sit comfortably in order to relax. The examples found were cinema, airplane, furniture and spa treatment. When the four areas were found it was investigated how the supports were designed to increase comfort while seated.

4.1.3 Expert Interviews

During three weeks, eleven expert interviews were conducted with the aim to get a deeper understanding about the client, to understand the requirements for car seats and to gather tips on literature and standards useful for the project. The interviews were conducted as directed open interviews using guidelines from the book interview methodology by Annika Lantz (2015). The interviewees were experts in their field and employees at VCC from the Ergonomics Department, Safety Department, UX Design Research Department and the Accessories and Special Vehicles Department. The interviews lasted about an hour and were documented through written notes. The notes were then read through and

useful information such as literature tips were gathered. The expert interviews were helpful to broaden the perspective and knowledge about the company and technical terms used in the automotive industry. The interviewees also provided inspiration on what to look deeper into and tips on useful literature. The information gained during the interviews were used to find literature sources and search for industry standards.

4.2 Iteration Loop 1

The aim with the first iteration loop was to explore sizes and shapes of the lower leg support and footrest. The methods used is presented in the following section.

4.2.1 Prototyping & Testing

The prototyping and testing have been an iterative process during the project where insights from each test were taken further to the next test, improving the support systems in several steps and the first test aimed to explore different sizes of lower leg support. Thereafter lower leg support prototypes in different shapes were made. Different shapes of footrests were also developed and tested. Requirements for the support systems could be made based on findings in these tests. The insights also influenced what to test further in the next loop.

The Prototype Seat

A 2017 Volvo XC90 car seat was used for testing different prototypes of lower leg supports and footrests. The car seat was placed on a rig that simulated sitting in a high car. The edge of the rig floor had an angle that created a foot support. In the car seat it was possible to adjust the headrest, cushion extension, cushion tilt, upper back articulation, back angle, height, and a linear front/ back adjustment which is more adjustable parameters than in a standard seat (Figure 6, Figure 7, Figure 8). In addition, the mechanical structure of a lower leg support from a competitor car was attached to the prototype seat. This structure was used as a base when testing different prototypes of lower leg supports in the prototype seat. This structure also had a mechanism that made it

possible to adjust the lower leg support in different angles (Figure 8).

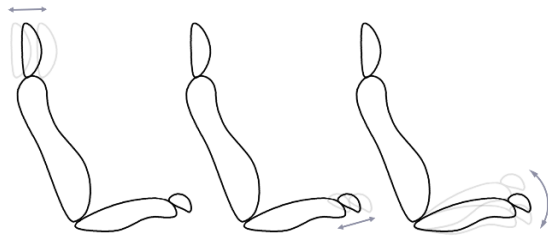


Figure 6. Headrest adjustment, cushion extension and cushion tilt. Authors own figure.

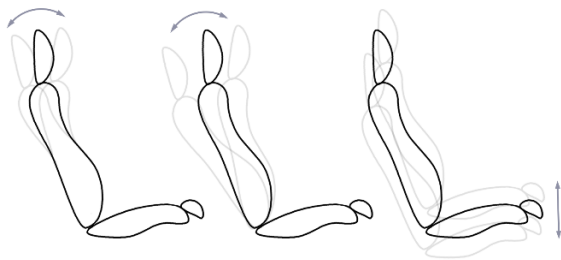


Figure 7. Upper back articulation, back angle and height adjustment. Authors own figure.

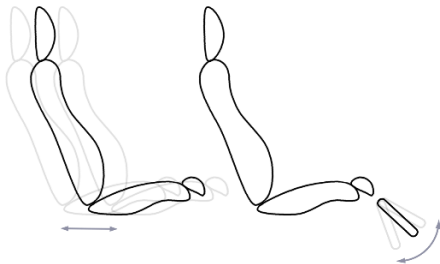


Figure 8. Linear front/back adjustment and adjustment of lower leg support. Authors own figure.

Exploring Sizes of Lower Leg Support

As a first step of exploring sizes, six square-shaped prototypes of lower leg supports were developed for testing varying sizes. They were made of kapa-board, foam padding and had a thin fabric on the surface. The prototypes had different measures in width, height and thickness as well as different hardness of the paddings from 5kPa to 7kPa (Figure 9).

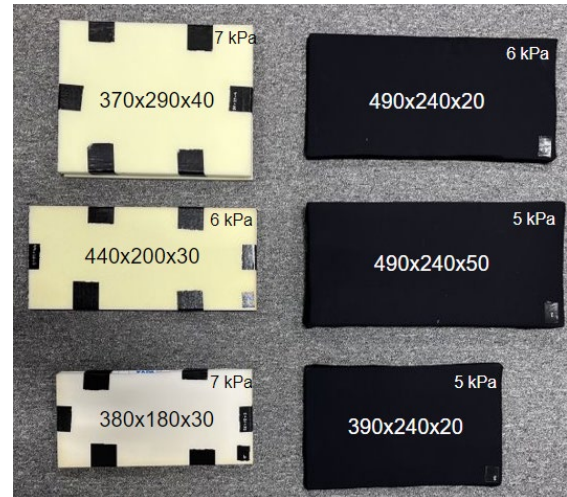


Figure 9. Six prototypes in different sizes.

The width of the used prototype seat (approximately 50cm) was used as an upper limit for the width of the lower leg support prototypes. Three people from the ergonomic department tested the prototypes together with the authors. With these prototypes, it could be investigated how the different measures and paddings affect the perceived comfort. The torso angles used during the tests were 35 and 45 degrees. An upright driving position was also tested with the leg support folded down in a vertical position. The prototypes were tested without and in combination with the footrest (Figure 10).



Figure 10. Testing in driving position, only lower leg support and both lower leg support and footrest.

Exploring Shapes of Lower Leg Support

Idea generation was made to explore different shapes of lower leg support. Sketching was done individually followed by a group discussion to communicate and develop new ideas. Several shapes were developed, and these were symmetrical and varied by their different side profiles (Figure 11).

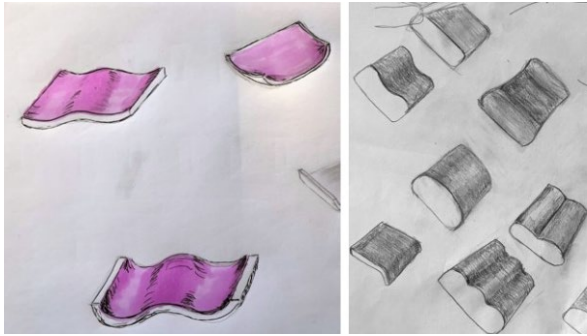


Figure 11. Leg support shapes from idea generation.

All different variations in shapes were compared and discussed in order to decide which ideas to develop further. Seven prototypes were made with inspiration from the sketches (Figure 12). They were made of kapa-board, foam padding and had a thin fabric on the surface as the previous prototypes, but all these prototypes had the same foam hardness of 5KPa. All the prototypes were tested and compared by the authors.



Figure 12. Prototypes with different shapes.

Exploring Footrest Shapes

Another session of sketching was made to explore different shapes of footrests (Figure 13). Similar to the previous idea generation, the shapes were symmetrical and varied by different side profiles. With inspiration from

the sketches, five different shapes were developed as prototypes (Figure 14). The prototypes were made in Styrofoam and then tested by the authors in the prototype seat.

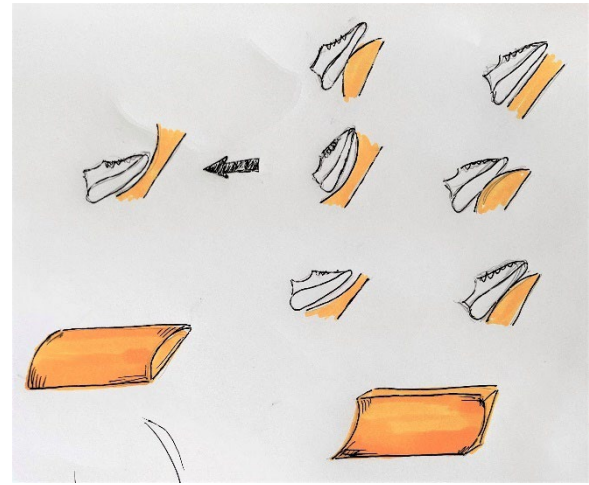


Figure 13. Footrest shapes.



Figure 14. Footrest prototypes.

4.2.2 Analysis & Evaluation

Photos and comments were collected when testing the different prototypes of lower leg supports and footrests. The photos and comments were compared and resulted in a list of insights from each test. It was then decided on what actions to take to consider the insights in further testing and development activities of the project.

4.3 Iteration Loop 2

The aim of the second iteration loop was to investigate how a lower leg support should be designed to be as comfortable as possible for different users. This was made in a user test, called the *leg support design test*.

4.3.1 Prototyping and Preparing Leg Support Design Test

From the tests in loop 1, it was clear that people preferred different sizes, placements, and shapes on the lower leg support. Testing this with people with different anthropometric measurements was therefore of interest to find their ideal lower leg support as well as what maximum and minimum sizes they find acceptable.

It was decided to create two separate tests for answering Q1 and Q2 to minimize the number of parameters in each test. The research question below were used as guidance when planning the *leg support design test* together with the more specified questions from the scope definition.

- Q1: *How should lower leg and foot support be designed to increase comfort in a seated position for the Swedish population, from the 5th percentile female to the 95th percentile male?*

To answer Q1, it was decided to let the participants test different lower leg support prototypes that had different widths, heights and shapes. The three widths chosen to test were 380mm, 440mm and 490mm. The different heights to test were 190mm, 240mm, and 290 mm. These measurements were chosen based on how wide people from the first test loop wanted to sit in the previous tests and what heights people preferred. Prototypes were created with the chosen measurements, using two centimeter thickness of foam with 5 KPa since these parameters were decided from the tests in the first loop. The prototypes still had kapa-board as a base and a thin fabric as a surface. *Shape 4* and *shape 5* from the previous test were also selected to be tested further. These were split in half in order to test them in different widths (Figure 15). To create more stability for the lower leg support, the base structure on the seat was changed from plastic to a wooden board (Figure 15).



Figure 15. *Shape 4 and shape 5 on wooden board.*

Velcro was attached to this wooden board and to the back of each prototype to facilitate changing prototypes and their positions during the test.

4.3.2 Leg Support Design Test

The *leg support design test* was held during three days, where 15 different test persons got to try out different prototypes and give their opinions and comments. The test was held in Swedish, including instructions, scenario, and interview questions. Each test took approximately 45 minutes, and the test persons were only participating during one of the time slots. The test invitation (Appendix A) was sent out via mail and the invited could sign up for one of the available time slots. The test persons were previously measured and part of a test person list at VCC, and the persons invited to the *leg support design test* were either taller than the 50th percentile male or shorter than the 50th percentile female. Eight of the test persons belonged to the taller part of the population and seven of the test persons belonged to the shorter part of the population. The test persons were equally distributed between men and women.

The purpose of the *leg support design test* was to get an answer on the following questions:

- *How should lower leg and foot support be designed to best accommodate the Swedish population from the 5th percentile female to the 90th percentile male?*

- *How should the lower leg and foot support be positioned in relation to the car seat?*
- *Is there a certain shape that best accommodates the needs?*
- *Are there lower leg angles that are perceived as more comfortable?*
- *Which parameters affect how comfortable the user experiences the lower leg support?*

The aim of the *leg support design test* was in addition to answer the questions above also to find out which prototype most people preferred and use that prototype during the *comfort systems test*.

During the *leg support design test*, a form was followed for all tests to be carried out in the same way, following the same order and going through the same questions (Appendix B). Each test started with the car seat in a defined starting position. Cameras with tripods were set up next to and in front of the car seat with the aim of being able to supplement and clarify the information gathered from verbally answered questions. When the test persons arrived, they were shown how the chair could be adjusted and which button belonged to which adjustment option. The test persons got instructions to not change the seats defined back angle since all should sit in a 45-degree torso angle during the test. They were also instructed to have the leg support completely folded out in maximum position. Then they adjusted the remaining seat adjustments into a position where they were seated as relaxed and comfortable as possible. When the test persons found a relaxed and comfortable position their car seat adjustments were measured, and they were told to only adjust the seat again if they felt they needed that to remain comfortable. The available seat adjustments were headrest and back articulation adjustments, chair height, backwards/forwards, and cushion tilt.

The test was divided into the following parts:

- Examine the preferred and accepted width of the leg support.
- Examine the preferred and accepted height of the leg support.
- Investigate whether an increased adjustment range for the leg support angle was desired.
- Investigate how a shape with middle support and side support was perceived and which width was preferred.
- Investigate how a shape with side support was perceived and which width was preferred.
- Asking questions about the different leg support prototypes and the comfort.
- Investigate if another torso angle (than 45 degrees) was more or less comfortable and if test persons has irritating or disturbing contact with the leg support when in driving position.

To examine which widths the test persons preferred and accepted, three different prototypes with different widths were tested. The three prototypes had the same height of 240mm, and the same padding hardness of 5kPa. The three prototypes were B1, B2 and B3, where B1 was 380mm, B2 was 440mm and B3 was 490mm (Figure 16).

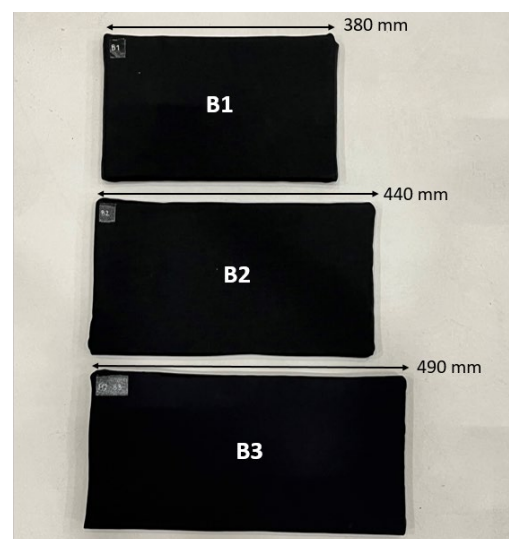


Figure 16. Prototype B1, B2 and B3.

When examining preferred and accepted heights, three different prototypes with different heights were tested. The prototypes were H1, H2 and H3, where H1 was 190mm, H2 was 240mm and H3 was 290mm (Figure 17). The prototypes had the same width of 490mm and padding hardness of 5kPa. These prototypes were first positioned in line with the wooden board, and then moved higher up and lower down to find the most comfortable position.

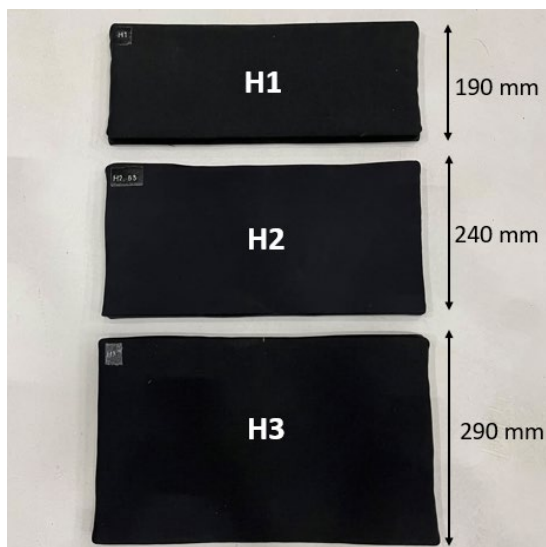


Figure 17. Prototype H1, H2 and H3.

When investigating whether an increased adjustment range for the leg support angle was desired, two differently sized wedges were used to simulate increased adjustment range (Figure 20).



Figure 18. How the wedges were used to simulate a bigger adjustment range.

The small wedge increased the adjustment range and maximum position with about 15 degrees and the big wedge increased the adjustment range and maximum position with about 30 degrees (Figure 19).

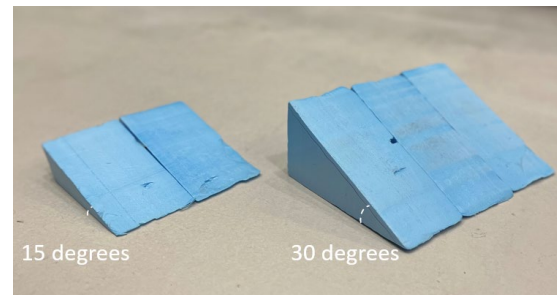


Figure 19. The wedges.

To investigate how a shape with middle support and side support was perceived and which width was preferred, test persons got to try a prototype with these features. The prototype was split in half, consisting of two parts which could be moved further apart from each other creating the sense of a wider leg support. The test persons got to try the prototype when it was put together with no space between the parts and with 40, 80, and 120 millimeters between the parts. Creating a leg support that varied from 400mm to 520mm in width (Figure 15). The prototype was 200mm high and had foam padding with the hardness of 5kPa. A similar approach was taken when investigating how a prototype with only side support was perceived and which width they preferred on that prototype. The prototype with only side support were also split into two parts, and it had the same measurements and foam padding hardness as the leg support with middle and side support. The leg support with side supports were also tested with the parts zero, four, eight and twelve centimeters apart from each other.

When all prototypes were tested, there were questions about which prototype the test person liked the most and why. They also got to grade how comfortable their preferred leg support prototype was on a scale from poor to excellent comfort. They marked their grade on a 100mm line, and the marking was then converted to a value between 0-100. Their favorite prototype was also tested in a more upright position where the torso angle was

changed from 45 to 35 degrees. They were asked if they perceived 35 degrees as a more or less comfortable resting position than the 45-degree torso angle. The last step of the test was to investigate if the leg support felt irritating or disturbing when test persons was in driving position and the leg support were folded in. This was done by letting the test persons adjust the chair to something they thought corresponded to their usual driving position, and thereafter they were asked to imagine that they had a steering wheel and pedals. When they were in that imagined driving position they were asked if they in some ways were disturbed or irritated by the leg support.

4.3.3 Analysis of Leg Support Design Test

The data from the *leg support design test* was structured and categorized based on what prototype the test persons tested. This was made to compare the test persons perceived comfort when using the different prototypes. Charts were created to present what leg support dimensions the short and tall test persons preferred and what dimensions they found acceptable. This made it possible to identify patterns of how long and tall test groups answered. Charts of the test persons seat adjustments were also created to analyze if any general adjustments were made when using lower leg support. In addition, potential patterns were also investigated when the results from the charts was compared with the photos and comments from the test.

4.4 Iteration Loop 3

In the third iteration loop, the leg support and foot support were evaluated in a context with other comfort systems. This was made in a user test called the *comfort systems test*.

4.4.1 Preparing Comfort Systems Test

The research question below were used as guidance when planning the leg support design test together with the more specified questions from the scope definition.

- Q2: *How do users value lower leg and foot support during non-driving scenarios?*

In previous tests it was clear that using the lower leg support and foot support together was perceived as more comfortable than using the support systems separately. This was something that was interesting to investigate further in user tests.

To find an answer to Q2, the lower leg support and foot support needed to be tested and compared with other comfort systems, such as back articulation, cushion tilt, and headrest. It was also interesting to ask about people's attitudes towards lower leg support and footrests. It was therefore decided that the test persons should rank these against the other comfort systems both before and after trying them.

It was important to test a position using both the lower leg support and footrest together, as well as testing the support systems separately. It was also important to test without the support systems in order to know how the comfort was affected by each support system. Testing the support systems in a torso angle freely chosen by the test persons was interesting in order to see what torso angles people choose when using the lower leg support and footrest. Comparing the difference in comfort between torso angles of 45 and 35 degrees are also interesting, to see how the seats back angle affect perceived comfort of the lower legs and feet. A sequence of twelve different seat positions was made where the test persons tested and compared all the different torso angles and the support systems for the legs and feet (Table 1).

Table 1. Test sequence.

	Torso angle	Support systems
1	Free°	Both
2		None
3		Leg support
4		Footrest
5	45°	Both
6		None
7		Leg support
8		Footrest
9	35°	Both
10		None
11		Leg support
12		Footrest

The torso angles of 35 and 45 degrees were chosen based on the usual torso angle for a driving position (Paker, 2022). The usual torso driving angle is approximately 25 degrees, and since the focus were on a relaxed position, the torso angles tested were 10 and 20 degrees more reclined than the usual driving position (Figure 20, Figure 21, Figure 22).



Figure 20. Person with a 25-degree torso angle.



Figure 21. Person with a 35-degree torso angle.



Figure 22. Person with a 45-degree torso angle.

4.4.2 Comfort Systems Test

During the *comfort systems test*, 19 people participated in one test session that took approximately 30 minutes. The *comfort systems test* was held during three weekdays where the invited test persons had the possibility to choose one 30-minute time slot that fitted to their schedule. The *comfort systems test* was held in Swedish, including instructions, scenario, and questions. The people invited to the *comfort systems test* were previously measured and a part of a VCC test list. During the *comfort systems test* a normal distribution of the height of the Swedish population was sought, and people were invited to the test based on three height groups each for men and women. Length group one, shorter people, consisted of men and women from the 5th percentile up to the 33rd percentile for body height and leg length for each gender. Length group two, medium length people, consisted of men and women from the 33rd to the 67th percentile for each

gender. Length group three, taller people, consisted of men and women over the 67th percentile to the 95th percentile for height for each gender. The test invitation (Appendix C) was sent via email to people from the list with people that were previously measured by the ergonomics team at VCC.

The purpose of test two was to be able to answer the following questions and prove or disprove the following hypotheses:

Questions:

- *Is there a latent need for lower leg and/or foot support?*
- *How do users value the different comfort systems of a car seat?*
- *Are there any general seat adjustments the user makes to increase the comfort when using lower leg and foot support?*
- *How is the perceived comfort affected by the torso angle when using lower leg and foot support?*

Hypotheses:

- *A lower leg support and a foot support will increase comfort in a relaxed position during non-driving scenarios.*
- *It is more comfortable to use lower leg and foot support together than using them separate.*
- *The leg and foot comfort will be perceived as most comfortable with the torso angle in 45 degrees.*
- *To maximize comfort while using the lower leg and foot support, users will change the back articulation from design position to a more angled position.*

The *comfort systems test* was divided into the following parts:

- Introducing the scenario.
- Grading car seat comfort systems before trying them.
- Trying leg and foot supports in a freely chosen torso angle.

- Trying leg and foot supports in a 45-degree torso angle.
- Trying leg and foot supports in a 35-degree torso angle.
- Grading car seat comfort systems after trying them.

During the test, four different versions of a form was followed. All versions contained the same parts and questions, but they came in different orders. The aim with the different versions was to avoid answers based on the test order and to be able to recognize if a certain test order affected the answers in a certain way. The four different versions are pictured in Figure 23.

Version 1	free	leg + feet only leg only feet without	Version 2	free	without only feet only leg leg + feet
	45 degrees	leg + feet only leg only feet without		35 degrees	without only feet only leg leg + feet
	35 degrees	leg + feet only leg only feet without		45 degrees	without only feet only leg leg + feet
Version 3	free	leg + feet only leg only feet without	Version 4	free	without only feet only leg leg + feet
	35 degrees	leg + feet only leg only feet without		45 degrees	without only feet only leg leg + feet
	45 degrees	leg + feet only leg only feet without		35 degrees	without only feet only leg leg + feet

Figure 23. Test versions comfort systems test. Authors own figure.

Regardless of test version all tests started and ended in the same way. It started with introducing the scenario and grading car seat comfort systems before trying them and ended with grading the comfort systems again after trying them out. During the test all seat adjustments were measured, and the test was documented by writing down answers in the form and by taking pictures. One camera with a tripod was placed centered on the left side of the seat.

The scenario introduced to the test persons before the test started was:

“You are going to take a rest in a car seat in a self-driving car. You are going for an hour-long drive and your plan is to sleep or at least try to take it easy and relax.”

When the test persons had gotten introduced to the scenario, they were asked to grade five comfort systems based on how important they thought the comfort systems were for them to be able to sit comfortably in a resting position. The test persons were handed a paper with an illustration of the different comfort systems and how they worked in order to get a better understanding of what they were grading, in case they were not familiar with all the comfort systems available in the test chair. The comfort system graded as most important was scored with a 1, while the second most important was scored with a 2, all the way down to the least important comfort system which was scored with a 5. The graded comfort systems were headrest, back articulation, cushion extension, footrest and lower leg support (Figure 24 and Figure 25).

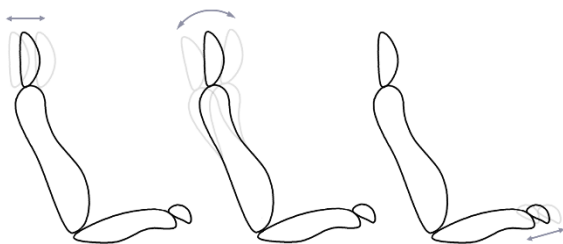


Figure 24. Headrest adjustment, upper back articulation and cushion extension. Authors own figure.

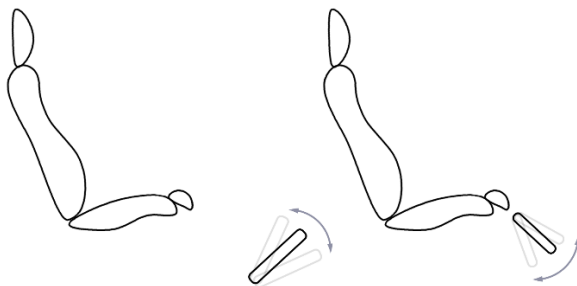


Figure 25. Footrest and lower leg support. Authors own figure.

When the comfort systems were graded the scenario was repeated when the test persons were seated in the car seat. They were then instructed to adjust the chair into a comfortable resting position. Depending on which test version the test persons completed, they either started with both leg support and footrest or without both leg support and footrest.

All tests started with testing the support systems in the freely chosen torso angle, but if it continued with the 45-degree or the 35-degree torso angle as the second depended on test version. All three torso angles were tested with both leg support and footrest, only leg support, only footrest and without both leg support and footrest. Whether test persons started with or without leg support and footrest depended on the test version. Each time the foot and/or leg support were taken away or added the test persons were told that they could adjust the seat if they thought that would make them sit more comfortably, this also applied to when the torso angle was changed. The parameters that they could adjust was backwards/forwards, up/down, headrest adjustment, back articulation adjustment and for the freely chosen torso angle also the backrest (torso angle). Parameters the test persons were not allowed to adjust was cushion tilt and cushion extension. When test persons were trying the different seat positions the comfort was graded on a scale from one to ten (Figure 26) and comments on why it felt good or bad were written down. The comfort that was graded for each test sequence was the overall comfort and the leg and foot comfort.

1	2	3	4	5	6	7	8	9	10
Very Bad		Bad		OK		Good		Very Good	

Figure 26. Comfort scale. Authors own figure.

The test ended with grading the five comfort systems (Figure 24 and Figure 25) again after trying them during the test. Similar to the grading that was done in the beginning of the test, the test persons got to place the comfort systems in a ranking. This ranking was based on which comfort system that was most important

for test persons to sit comfortable in a relaxed position, down to which comfort system that was least important for them to sit comfortable in a relaxed position.

4.4.3 Analysis of Comfort Systems Test

Charts were created to analyze the data gathered in the *comfort systems test*. The charts presented the average comfort ratings of the total group as well as of the different height groups. This was made to analyze if the result differed between the different groups. Charts were also made based on data from the seat adjustments to analyze what adjustments the test persons made when using different support systems. All charts were compared with comments and photos to see if patterns could be found in the test persons ratings and seat adjustments.

4.5 Guidelines and Final Design

The test results from the three iteration loops were summarized and categorized based on if the findings were applicable for the lower leg support or the footrest. The findings were also categorized based on if they concerned design or adjustments of the support systems. When the findings were structured, guidelines were developed based on what requirements and requests there were for the comfort to be as high as possible. The recommended measurements for the support systems were chosen based on what measurements most people in different height groups accepted.

The adjustable parameters for the support systems and the adjustment ranges in the guidelines are suggested based on what adjustments people needed during the user tests to find a comfortable position. The test persons preferred prototype during the *leg support design test* was used for creating guidelines for the shape of the lower leg support.

The final design of the lower leg support was developed accordingly to the guidelines. The dimensions of the final design were taken from the measurement span developed for height and width. The exact height for the

final design was then selected from the measurements accepted and preferred by most test subjects, both regarding the flat test prototypes (B1, B2, B3, H1, H2 and H3), but also *shape 5*, the prototype with side support. The side support was developed by analyzing comments users made when trying *shape 5* from the *leg support design test*. The comments were from how the leg support felt both when in use in a relaxed position, but also how it was experienced when folded down, and the test subjects imagined that they were sitting in a driving position. A prototype was then made with the chosen dimensions and attached to the prototype seat to present the final design of the lower leg support.

05

**RESULT &
ANALYSIS**

5. RESULT & ANALYSIS

The following chapter presents results and analysis from the project. The results and the analysis presented are from the scope definition, development, user tests and the final design.

5.1 Scope Definition

In this section the result from the scope definition is presented. This includes results and analysis of the inspiration study. A table summarizing important findings from the scope definition is also presented and it is followed by a list of questions for user tests.

5.1.1 Inspiration Study

The car models found to have lower leg and/or foot support in their cars today were:

- Hyundai Ionic 5
- Rolls Royce Phantom
- Mercedes Maybach
- Kia Sedona
- Toyota Sienna
- BMW i7
- Seekr 009
- Bentley Mulsanne
- Volvo XC90 lounge
- Land Rover Range Rover SVAutobiography LWB
- Audi A8 L
- Bentley Bentayga
- Nio ES8

From the car brand inspiration study (Figure 27), it was found that several car brands have lower leg and foot support in the second seat row, while only one car was found to have lower leg support in the driver's and passenger's seat and one in the passenger's seat. The lower leg supports are often wide and long and some were adjustable in length to support the whole calf. The foot support was often a solution where it could either pop up from the floor or be a smaller part that folds out from the back of the passenger seat. The lower leg support and the foot support were often two separate solutions that were placed in a way that made it look hard or uncomfortable to use them at the same time.



Figure 27. Lower leg and foot support in passenger's seat. Authors own picture.

From the inspiration study with focus on other markets it was found that for spa treatment chairs, there can be a built-in foot support and adjustable leg supports, while in cinemas and airplanes the lower leg supports were often big and wide to give support to the entire leg and the feet.

Table 2 below presents attributes defining design parameters seen in the inspiration study for leg support and foot support.

Table 2. Design attributes.

LEG SUPPORT	FOOT SUPPORT
Big	Small
Soft	Hard
Adjustable	Adjustable
Flat	Flat
Smooth (transitions)	Stable

Except the attributes of being flat and adjustable, the attributes for the lower leg support and foot support differ from each other and sometimes they are opposites. When developing the support systems, it is therefore important to separate them and consider how the requirements and demands on these support systems differ.

5.1.2 Summary Scope Definition

The findings from the scope definition were summarized and it resulted in a list of requirements for support systems and a list of important factors that affects comfort in vehicles (Table 3).

Table 3. Summary scope definition.

REQUIREMENT	FACTORS AFFECTING COMFORT
Provide smooth edges	Time
Use minimum of 15 mm padding for the lower leg support.	Aesthetics
Provide a flat surface	Vehicle package (roominess)
Allow for natural body postures	Social factors (nameplate, purchase price)
Fit people with different anthropometrics	Individual factors (body size, age, posture)
Allow for a variation of different sitting postures	Seat factors (stiffness, shape, breathability)

User test questions

Some questions were also developed as a result of the scope definition phase. These were used as guidelines for how activities should be prioritized during the project. The questions were also used as a basis for the user tests. The questions are presented below.

- *How should the lower leg and foot support be positioned in relation to the car seat?*
- *Is there a certain shape that best accommodates the needs?*
- *Are there lower leg angles that are perceived as more comfortable?*

- *Which parameters affect how comfortable the user experiences the lower leg support?*
- *Is there a latent need for lower leg and/or foot support?*
- *How do users value the different comfort systems of a car seat?*
- *Are there any general seat adjustments the user makes to increase the comfort when using lower leg and foot support?*
- *How is the perceived comfort affected by the torso angle when using lower leg and foot support?*

5.2 Iteration Loop 1

The results from the first iteration loop include findings from tests of different lower leg support prototypes and footrest prototypes that varied in dimension and shape. A summary of the most important insights from this phase is also presented.

5.2.1 Prototyping and Testing

In the following section insights from the prototyping and testing activities are presented.

Exploring Sizes of Lower Leg Support

When testing the prototypes, the hardness of the padding made a big difference to the experience of comfort of the lower leg support. Foams with the hardness of 5kPa, 6kPa and 7kPa were tested. The foams with hardness over 5kPa were perceived as too hard and created discomfort. Using two centimeter thickness of foam was enough since thicker padding felt uncomfortable during driving position. This was because the upper radius on the leg support created pressure on the calf. Another interesting insight was how the preferred size and position of the leg support varied among the test persons. For instance, one preferred 490mm for a comfortable width while another just needed 370 mm. The combination of using both lower leg and foot support was perceived as more comfortable than using just one of them since it gives

maximum support and reduces pressure on the lower legs.

Exploring Shapes of Lower Leg Support

When testing the different shapes, *shape 1*, *shape 2* and *shape 3* created uneven pressure on the lower legs (Figure 28).

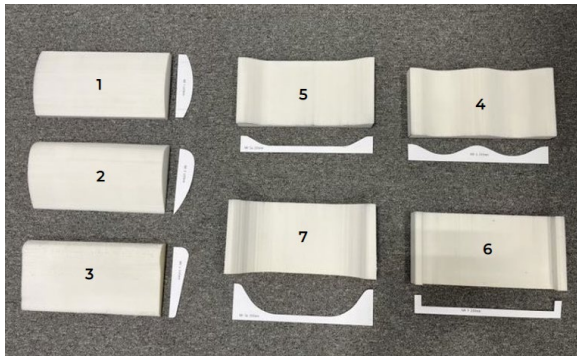


Figure 28. Lower leg support prototypes in different shapes.

However, *shape 3* were very comfortable for one test person but was sensitive to adjustment in height position since it fast become uncomfortable when moving it up or down. *Shape 5*, *6* and *7* were made to create support on the side of the legs. *Shape 4* and *shape 5* felt very comfortable and created an embracing, supporting feeling according to test persons. *Shape 7* had bigger sides with more radius that created a feeling of being stuck. The sides of *shape 6* were not in contact with the legs and did not create any support. In conclusion, *shape 4* and *shape 5* were significantly more comfortable than the other prototypes.

Exploring Footrest Shapes

When testing the different footrest prototypes, the wedge-shaped footrest created similar support as the rig, just in a different angle. This was the most comfortable prototype because the rounded shapes and the rectangular one did not support the whole foot (Figure 29).

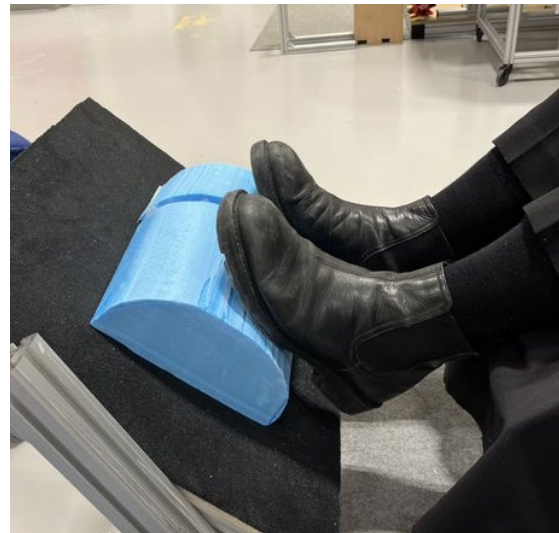


Figure 29. Rounded footrest.

Since none of the prototypes were more comfortable than using the flat foot support on the rig, none of the shapes were investigated further. Instead, it was decided to change the construction on the rig to make it possible to change the angle of the foot support.

5.2.2 Summary iteration loop 1

The most important insights from the first iteration loop are summarized in Table 4 below. The table presents actions on how the insights should be considered further in the project.

Table 4. Summary Iteration Loop 1.

	INSIGHT	ACTION
LEG SUPPORT	Foam hardness of 5 kPa most comorable	Requirement for future prototypes
LEG SUPPORT	Using 2 cm thickness of foam was enough	Requirement for future prototypes
LEG SUPPORT	Preffered dimensions varied among test persons	Test different measures with users
LEG SUPPORT	Shape 1, 2, 3 created uneven pressure	Avoid shapes with a curved side profile
LEG SUPPORT	Side support creates an embracing feeling (as long as it is not too big)	Test shape 4 and 5 further with users
FOOT SUPPORT	The flat footrest was most comfortable	Use a flat foorest and test footrest angles with users

5.3 Iteration Loop 2

The results from the second iteration loop consists of findings from the *leg support design test*, a summary of the most important findings and answers to the test questions.

5.3.1 Leg Support Design Test

This section presents the results from the *leg support design test*, investigating seat adjustments, leg support dimensions and shapes, leg support placement as well as the leg support adjustment angle.

Seat Adjustments

The charts below (Figure 30, Figure 31, Figure 32, Figure 33) show how the test persons wanted to adjust the back articulation, headrest, sitting height and cushion tilt when sitting with a lower leg support.

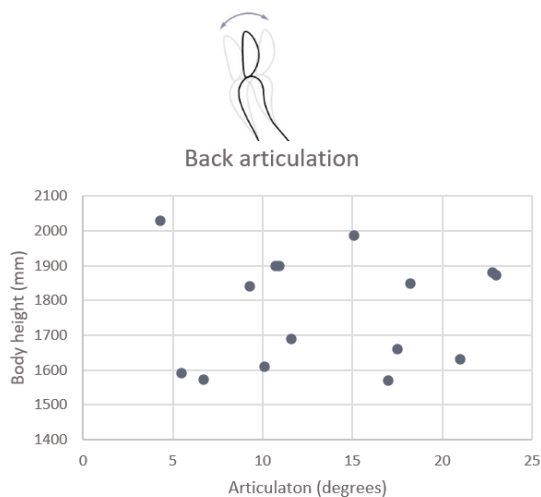


Figure 30. Back Articulation Adjustment.

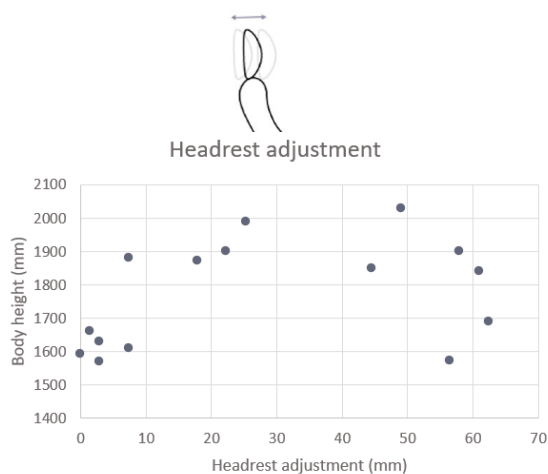


Figure 31. Headrest Adjustment.

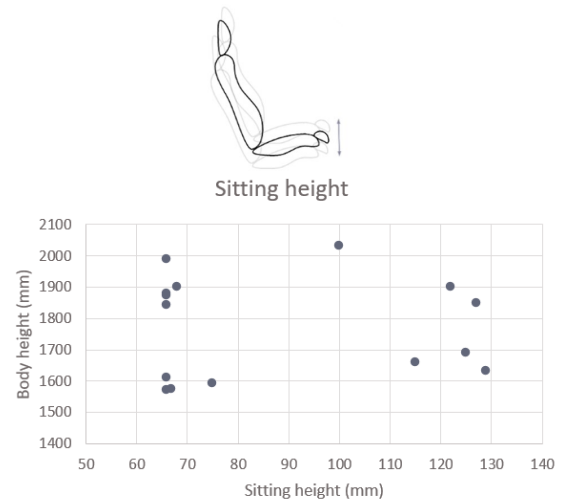
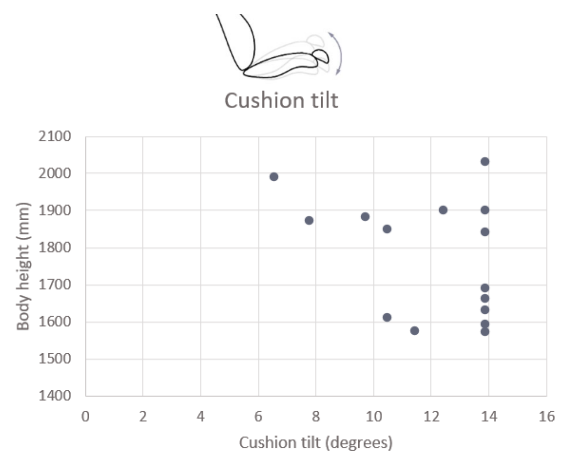


Figure 32. Sitting Height Adjustment.



the height, the chair also tilts where maximum tilt is in the bottom position. The lower leg support comes higher up in the bottom position and therefore it can be assumed that the nine people sitting in the bottom position wanted to have the lower leg support higher up than the ones sitting higher up. The cushion tilt is also an adjustment that affects how high the lower leg support is placed. The chart shows all test persons placed. The chart shows all test persons wanted to tilt the seat over six degrees where eight persons had it in maximum (13,9 degrees). Since many wanted to use the cushion tilt and sit in the bottom position, it is clear that people want to sit tilted when using lower leg support.

It is clear that people want to sit with the cushion tilted when using lower leg support.

Since the test persons buttock-knee measurements were different, so were the optimal length of the seat. Persons whose buttock-knee measurement fitted or nearly fitted the length of the design position of the seat benefitted more from the leg support and could sit more comfortably with it, with even support on the calf. The reason for this is that the angle of their knee correlated with the angle of the leg support (Figure 34). For people with shorter buttock-knee measurement the calf was pushed out from the seat cushion, resulting in a higher pressure from the upper part of the leg support on their calf (Figure 35). For people with longer buttock-knee measurements the experience was the other way around. They got more pressure from the lower part of the leg support (Figure 36). Shorter and taller people are therefore in need of cushion adjustment and a possibility to move the leg support in x-direction in order to sit more comfortably.

Shorter and taller people need an adjustment possibility in the x-direction to get the pressure evenly distributed over the calf.



Figure 34. Buttock-knee measurement.



Figure 35. Buttock-knee measurement (short).



Figure 36. Buttock-knee measurement (tall).

Examining preferred and accepted width of the leg support

All widths were accepted by most test persons, but B2 (Figure 16) were preferred by most, a third (five out of 15) of the test persons (Figure 37). B1 was preferred by three of the test persons and B3 by four of the test persons. Three persons had a hard time choosing between the prototypes, one liked B2 and B3 equally and two persons liked all three prototypes equally. Even though B2 is the prototype preferred by most people, the difference between how many preferred the other prototypes is small. Comments show that several of the persons choosing B3 as their preferred prototype thought that B2 were wide enough but that B3 was even more comfortable since it gave them a bigger freedom to change position. Other comments from examining the widths show that half of the test persons do not think they feel any difference between B2 and B3 or that the difference is so small that it does not matter. A majority of short test persons like B2, while the preference of tall people is more scattered with one more tall person preferring B3 over B1.

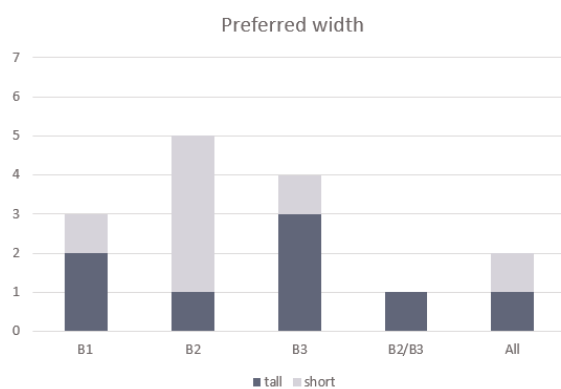


Figure 37. Preferred width of the leg support.

The most accepted width was B2, accepted by all test persons as a width they thought would work, even if it wasn't necessarily their favorite. Worth noticing is that B1 was accepted by 12 out of 15 test persons and B3 was accepted by 13 of the test persons. All prototypes are thus accepted by a large part of the test persons. Figure 37 presents which prototypes the test persons perceived as

acceptable in width, showing that B1, to a larger extent was accepted by shorter people, while B3 to a larger extent was accepted by taller people.

The most accepted width is B2, but all prototypes are accepted by a large part of the test persons.

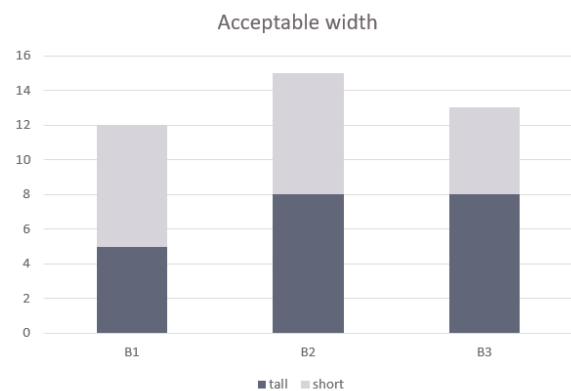


Figure 38. Acceptable width of the leg support.

Examining preferred and accepted height and placement of the leg support

When prototypes of different heights were tested, the height preferred by most test persons were H3 (Figure 17), preferred by six of the test persons (Figure 39). The majority of test persons preferring H3 were tall people. The second most preferred prototype was H2, preferred by four of the test persons. One person preferred H1 and four people thought two or all of the prototypes were equally good.

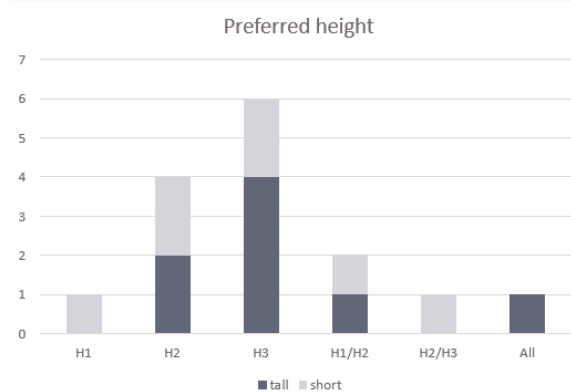


Figure 39. Preferred height of the leg support.

The most accepted height was H2, accepted by 14 out of 15 test persons (Figure 40).

Similar to when the persons evaluated the widths, the test persons were supposed to not only evaluate which height they preferred but also which ones they accepted, resulting in that more than one height could be accepted by one test person. H1 was, to a higher extent, accepted by shorter people while H3 were accepted to a higher extent by taller people. The short people who found H3 acceptable needed to have it 2-6 cm up from the centerline. Otherwise, the lower edge came too far down on the heel, and it became uncomfortable. Comments from this part of the test indicates that it is appreciated with a bigger prototype but H2 is sufficient. One test person says:

“It feels better with a larger surface area.” – TP 15

The height preferred by most test persons were H3 and the most accepted height was H2.

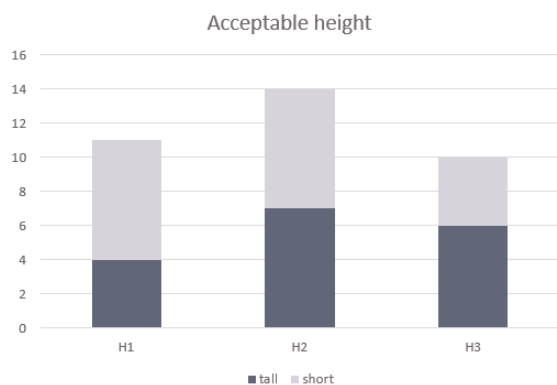


Figure 40. Acceptable height of the leg support.

During the test it was seen that changing the placement in height up or down was an important parameter in order to increase the comfort of the lower leg support.

Changing the placement of the lower leg support up or down was an important parameter in order to increase comfort.

Figure 41, Figure 42 and Figure 43 show the preferred placement of H1, H2 and H3.

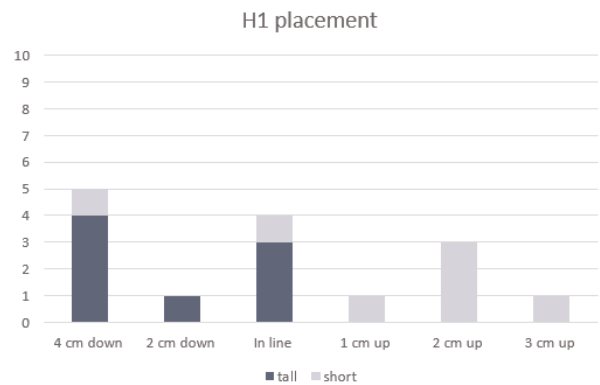


Figure 41. Preferred placement of the H1 prototype.

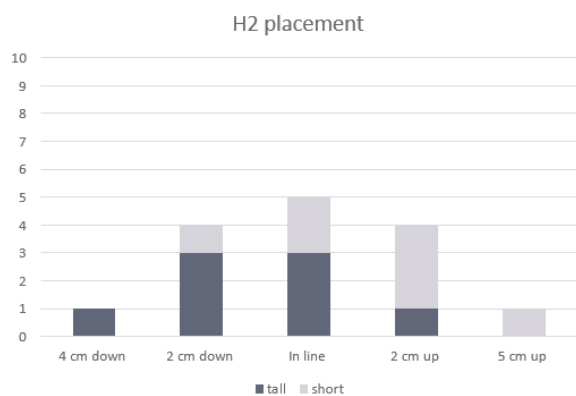


Figure 42. Preferred placement of the H2 prototype.

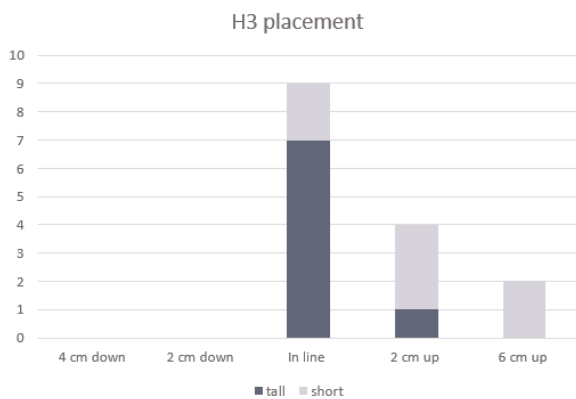


Figure 43. Preferred placement of the H3 prototype.

Generally, the shorter test group wanted to move all the prototypes up while the tall test persons wanted to move them down. The results show the correlation between the height of a prototype and necessary adjustments, in regards of comfort. For instance, H1, the shortest prototype, was placed from three centimeters up to four centimeters down, while H3, which is the longest prototype, was moved six centimeters up. In some examples from the comments, people explain why they wanted to move the prototype. The main reasons to move the

prototype further down was to give more support to the lower part of the leg, and to compensate for an uneven pressure on the calf.

The following comments show two examples:

“It presses down on the calf, but it got better when you moved the prototype further down.”

– TP 1

“There is better support for the lower leg when it is moved four centimeter down.”

– TP 8

Reasons to move the prototype up was because the upper or lower edge of the prototype came to far down on the leg and created discomfort:

“I feel the upper edge but it got better two centimeter up.”- TP 10

“It is great six centimeter up as I have mobility and a lot of support. When placed further down, I cannot relax because it irritates the heel.” – TP 12

The results show that people wanted to move the lower leg support towards the middle of the calf. Having the ability to adjust it some centimeters up or down provided more even pressure on the leg and increase comfort.

Generally, the shorter test group wanted to move all the prototypes up while the tall test persons wanted to move them down.

Investigate whether an increased adjustment range for the leg support angle was desired

The number of people wanting or preferring the leg support with either the small (15 degrees) or big (30 degrees) wedge is six out of 15 test persons (Figure 43). Four test persons preferred the lower leg support without the wedges and a third (5 out of 15) of test persons did not have a clear opinion on whether they thought it was more comfortable or not. The persons not knowing whether they liked it or not are represented with a question mark in the chart (Figure 44). Two thirds of the ones preferring the leg

support with one of the wedges was shorter test persons which leads to that one third of the ones who preferred to be seated with one of the wedges was taller test persons. All of the ones who preferred to use the leg support without a wedge was tall.

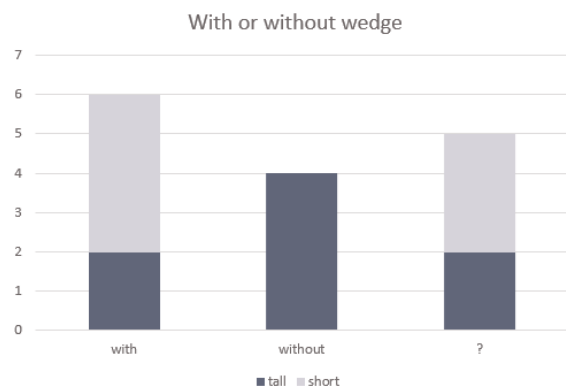


Figure 44. Test persons preferring with or without wedge.

Eleven of the test persons find the big wedge acceptable while twelve find the small wedge acceptable (Figure 44). All people in the shorter category (7 test persons) finds both the wedges acceptable while fewer in the taller category finds the wedges acceptable. Four out of eight tall test persons accept the big wedge and five accept the small wedge.

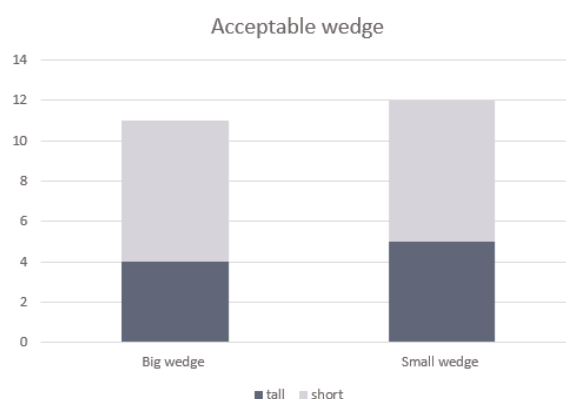


Figure 45. Wedge acceptance.

A conclusion is that an increased adjustment is more important for those who are shorter than the 50th percentile female than for those taller than the 50th percentile male. During the test shorter people were more likely to want the increased adjustment range and to accept it. The reason why tall people during

the test did not like the wedges were because it often gave them a lot of pressure on the calf where the leg support ended. Their femurs were often so long that it was difficult to get the pressure evenly distributed over the calf. When further adjusting the height of the wedges, this problem became even more difficult (Figure 36). Tall people would therefore need an adjustment possibility in the x-axis to be able to fully benefit from the added adjustment range.

An increased adjustment angle is more important for those who are shorter than the 50th percentile female than for those taller than the 50th percentile male.

Investigating a shape with middle support and side support

Figure 46 shows that most people (seven out of 15) prefer *shape 4*, the prototype with side and middle support, when the two parts of the prototype were fully together. One third (five test persons) preferred the prototype when it was 4 centimeters apart, 2 preferred it 8 centimeters apart and one preferred it 12 centimeters apart. Since the support on this shape placed the test persons legs in a very specific position, many felt that they needed to have their legs apart, when the two parts of the prototype were moved further away from each other. This was a feeling that most test persons felt uncomfortable with and therefore preferred the two parts closer together.

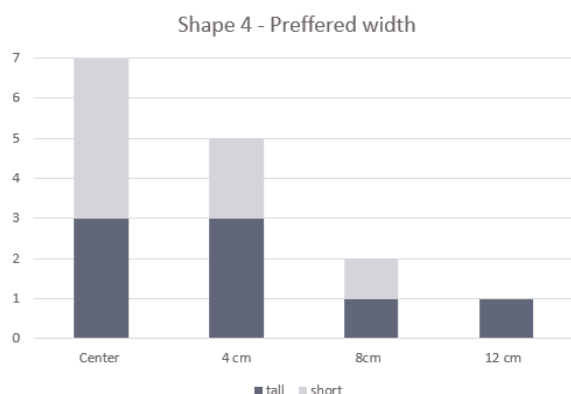


Figure 46. Preferred width of the leg support prototype with side and middle support.

Investigating a shape with side support

Six out of 15 of the test persons liked *shape 5*

the best when the two prototype parts were moved 4cm apart (Figure 47). A third (five test persons) preferred the prototype fully together, one preferred it 12 centimeters apart and 3 persons preferred it two centimeters apart. The reason behind why 3 people tried two centimeters were because they had a hard time choosing if they preferred the two prototype parts centered or four centimeters apart. They then got to try 2 centimeters and preferred that width.

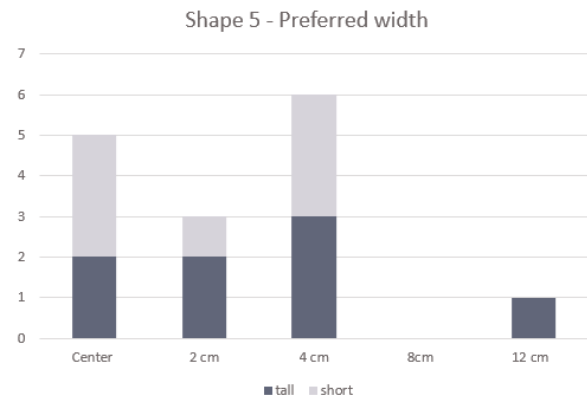


Figure 47. Preferred width of the leg support prototype with side support.

An interesting finding when trying the shapes is that people generally prefer to sit closer together with the legs when seated with side support than when the leg support prototype is flat. A side support thus creates the opportunity to make a less wide leg support.

A side support creates the opportunity to make a less wide leg support.

Preferred prototype and comfort

The prototype preferred by most test persons (seven out of 15) was *shape 5*, while *shape 4* came close behind preferred by six persons (Figure 48). B2 and H2 were preferred by one test person each. As a conclusion 87% of the test persons (13 out of 15) preferred a prototype with side and/or middle support. Two out of 15 preferred a flat prototype. Comments from test persons who preferred *shape 5* over *shape 4* described that *shape 5* gave them more freedom to move around and vary leg position, which they thought they would want to do if seated for a longer period of time.

87% of the test persons preferred a prototype with side and/or middle support where shape 5 was preferred by most test persons.

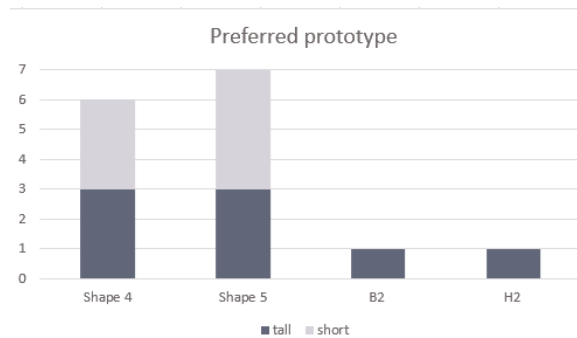


Figure 48. Preferred leg support prototype during the leg support design test.

When people got to grade how comfortable they thought their preferred leg support were, the average value was 80,4 out of 100. The answers varied between 19 and 99 (Figure 49), where 19 were the closest to “poor” while 99 was the closest to “excellent”.

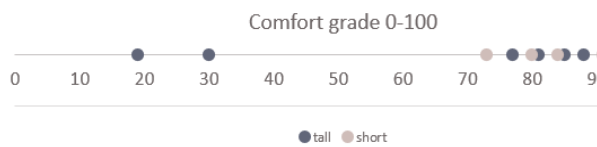


Figure 49. Comfort grading scale.

Comments from the test persons on how the comfort could be further improved included that some wanted to be able to adjust the leg support to a position with a bigger angle, like the wedge. Other comments were about the possibility to move the leg support in z-axis and x-axis so that the leg could lie with even pressure over the entire surface of the leg support. Some comments mentioned the lack of support between calf and thigh, and someone thought the foam was too hard.

Investigating if a 35-degree torso angle affects the perceived comfort

When people were seated in the 35-degree torso angle most test persons perceived it as less comfortable, but some thought the comfort were equal to the 45-degree torso angle. One test person says, “it still feels good”, while one comments “there is not a

big difference”. The test persons who feel that 45 degrees is nicer than 35 mention, for example, that a 35-degree torso angle feels less restful, that there is more uneven pressure on the lower leg and that the leg support is less useful. The conclusion from the leg support design test is that when seated with the leg support a 35-degree torso angle is perceived as less comfortable than a 45-degree torso angle.

Seated with the leg support a 35-degree torso angle is perceived as less comfortable than in a 45-degree torso angle.

Investigating contact with leg support in driving position

Figure 50 shows that eight of test persons did not think the leg support were a problem (“no”) when seated in a driving position, while a third (5 out of 15) thought the leg support would be a problem (“yes”) while driving and two people thought it might disturb them (“maybe”) while driving. A lot of the ones answering that the unfolded leg support would be a problem while driving was short and a majority (all but one) of the ones answering that the leg support did not disturb them while driving were tall. Out of the two people answering that the unfolded leg support might disturb them while driving, one was tall, and one was short. The conclusion is that as the leg support looks today, shorter people will be disturbed by the leg support while driving while taller people will not. The reason is that shorter people feel the edges of the leg support on their calf when it is folded down, while taller people end up further ahead from the leg support and are therefore not bothered by it.

Shorter people think they will be disturbed by the leg support while driving while taller people will not.

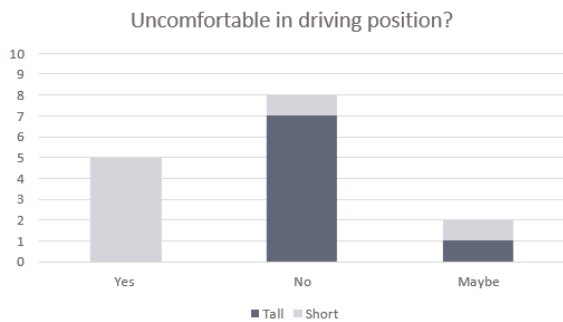


Figure 50. Lower leg comfort during driving position.

5.3.2 Summary Leg Support Design Test

The most important insights from the leg support design test are summarized below.

- It is clear that people want to sit with the cushion tilted when using lower leg support.
- Shorter and taller people need an adjustment possibility in the x-direction to get the pressure evenly distributed over the calf.
- The most preferred width was B2 (440 mm), but all widths were accepted by a large part of the test persons.
- The height preferred by most test persons was H3 (290 mm) and the most accepted height was H2 (240 mm).
- Changing the placement of the lower leg support up or down was an important parameter in order to increase comfort.
- Generally, the shorter test group wanted to move all the prototypes up while the tall test persons wanted to move them down.
- An increased adjustment angle is more important for those who are shorter than the 50th percentile female than for those taller than the 50th percentile male.
- A side support creates the opportunity to make a less wide leg support.
- 87% of the test persons preferred a prototype with side and/or middle

support where *shape 5* was preferred by most test persons.

- Seated with the leg support a 35-degree torso angle is perceived as less comfortable than in a 45-degree torso angle.
- Shorter people think they will be disturbed by the leg support while driving while taller people will not.

5.3.3 Answering Test Questions

This section includes answers to the user tests questions.

Leg Support Design Test:

- **How should the lower leg support be positioned in relation to the car seat?**
How the leg support should be positioned depends on the user's body dimensions. A tall person needs one positioning while a shorter person needs another positioning. In addition to being able to adjust the angle, adjustment possibilities are also needed in both the x-direction and z-direction in order for each individual to be able to maximize their comfort.
- **Is there a certain shape that best accommodates the needs?**
According to the test result the most commonly liked prototype is flat in the middle and has support on the sides (*shape 5*).
- **Are the adjustment possibilities available on the leg support sufficient or should the angle in which the leg support can be adjusted be increased?**
The angle adjustment range should be increased since the test result shows that especially shorter peoples comfort benefit from an increased angle adjustment on the leg support.

- **Which parameters affect how comfortable the user experiences the lower leg support?**

According to the test, parameters that affect the comfort are:

- Torso angle
- Number of adjustment possibilities of the seat
- The dimensions of the leg support
- The shape of the leg support
- Possibility of adjustment in z-direction and x-direction
- The leg supports adjustment angle
- The padding of the lower leg support



Freely chosen seat back angle - leg + foot support

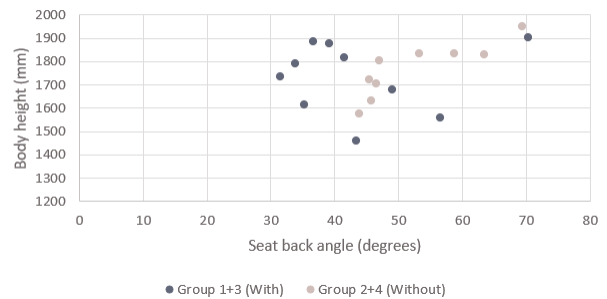


Figure 51. Testing support systems in a freely chosen seat back angle using leg support and footrest.

5.4 Iteration Loop 3

This section includes findings from the *comfort systems test* and a summary of the test result. It also includes answers to test questions and hypotheses.

5.4.1 Comfort Systems Test

In the following section, the result from the *comfort systems test* is presented. The result includes the test persons seat adjustments, their grading of the comfort systems and their rating of the perceived comfort when using different support systems.

Seat adjustments

All test persons could freely adjust the back angle of the seat in the first part of the test. Group 1 and 3 started with lower leg support and footrest while group 2 and 4 started without. Figure 51, Figure 52, Figure 53, and Figure 54 shows what seat back angle they chose to sit in when using the support systems.

Freely chosen seat back angle - only footrest

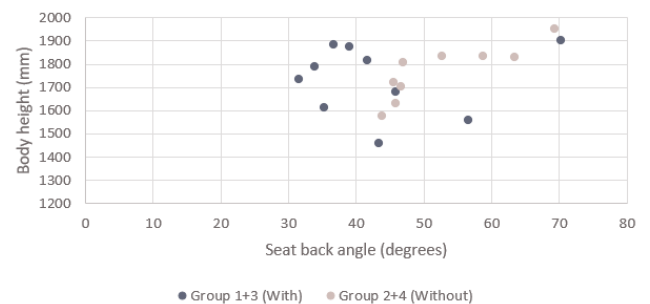


Figure 52. Testing support systems in a freely chosen seat back angle using only footrest.

Freely chosen seat back angle - only lower leg support

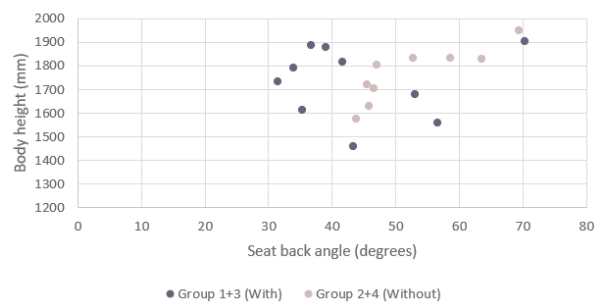


Figure 53. Testing support systems in a freely chosen seat back angle using only lower leg support.

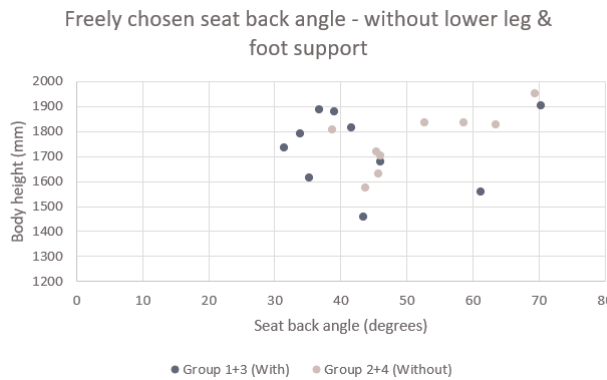


Figure 54. Testing support systems in a freely chosen seat back angle without using lower leg support or footrest.

The four charts are very similar which means most test persons chose to change their back angle a little or not at all when switching between the support systems. The chosen back angles on the seat go from 31,5 to 70,3 degrees but were most concentrated between 35 and 49 degrees. When the seat back angle is 38,9 degrees, the test persons torso angle is 45 degrees and when the seat back angle is 29,9 degrees, the torso angle is 35 degrees. Looking at the torso angle when sitting with both lower leg support and footrest, 15 out of 19 test persons chose to sit in a torso angle over 45 degrees and four test persons chose a torso angle under 45 degrees. One insight is that almost all who chose a seat back angle over 50 degrees were over 180 centimeters tall.

The chosen back angles on the seat go from 31,5 to 70,3 degrees where the majority chose to sit in a torso angle over 45 degrees.

When considering the different test groups marked with colors in the chart, an interesting difference can be seen between their chosen back angles. A majority of test group one and three (blue) have chosen seat back angles under 45 degrees while test group two and four (beige) have chosen angles over 45 degrees. This means the ones who started the test with lower leg support and footrest wanted to sit more upright, and the ones who started the test without the support systems

wanted to sit more reclined. See examples of different torso angles in Figure 55 and Figure 56 below.



Figure 55. Freely chosen torso angle (test person seated with leg and foot support (1)).



Figure 56. Freely chosen torso angle (test person seated with leg and foot support (2)).

Since the test persons did not adjust the back angle on the car seat when changing between the support systems, it could mean that the perceived comfort when using lower leg support and footrest is not connected to the torso angle. However, the difference between the test groups indicates that there still could be a connection between the chosen torso angle and use of leg and foot support. One reason why the groups without the support systems wanted to sit more reclined could be that they needed to adjust their torso angle

more to achieve a relaxed feeling. The other groups could sit more upright and still experience it as a relaxed position because of the support for lower legs and feet.

The difference between the test groups indicates that there still could be a connection between the chosen torso angle and use of leg and foot support.

Lower leg support

Figure 57 shows how people adjusted the lower leg support when sitting in different torso angles.

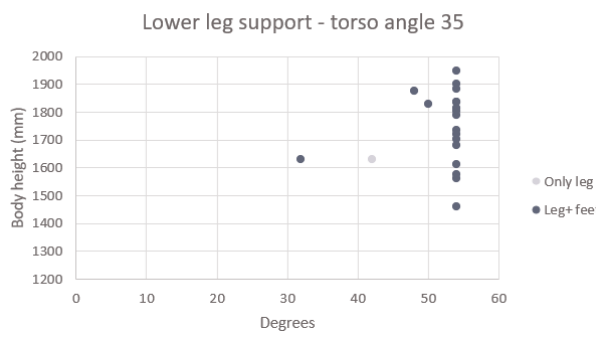
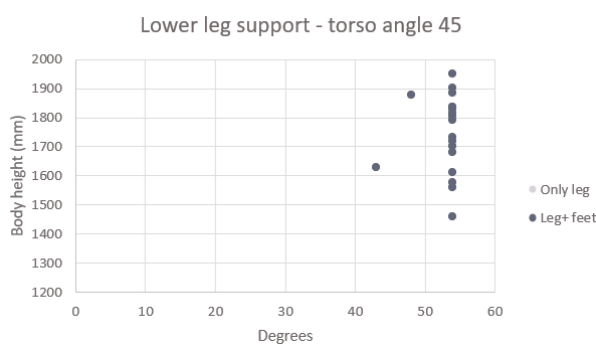
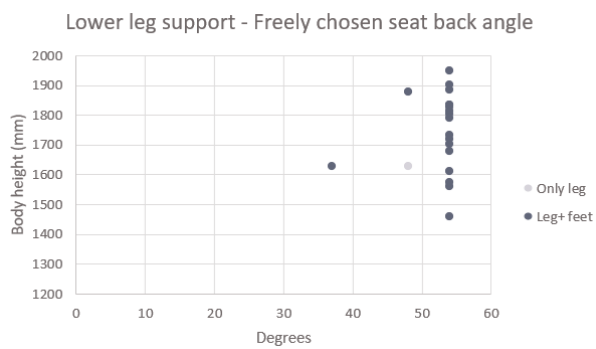


Figure 57. Lower leg adjustment sitting with different torso angles.

Almost all test persons adjusted the lower leg support to have it at the maximum top position at 54 degrees throughout the whole comfort systems test. Looking at the comments, 14 of the test persons expressed they wanted to adjust it even higher. Both colors of the dots cannot be seen in the charts because most test persons did not change the angle of the lower leg support when switching between using only the lower leg support and using the lower leg support and the footrest together. Two test persons did not have the lower leg support at maximum during the test and one changed it down from maximum just when sitting in a 35-degree torso angle. There is no clear connection between body height and chosen angle for the lower leg support since one of test persons that chose to not have the leg support at maximum were short and two were tall. The shorter participant expressed an uneven, uncomfortable pressure on the calves from the lower leg support, which could be a reason to have it lower down.

Most of the test persons wanted to adjust the leg support higher than maximum.

Footrest

During the whole test the test persons could adjust the footrest, and which angles they chose can be seen in Figure 58.

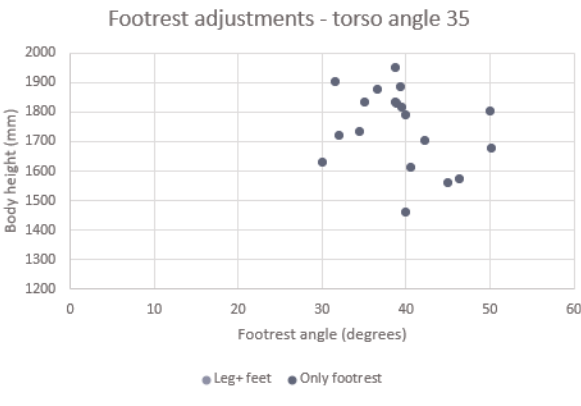
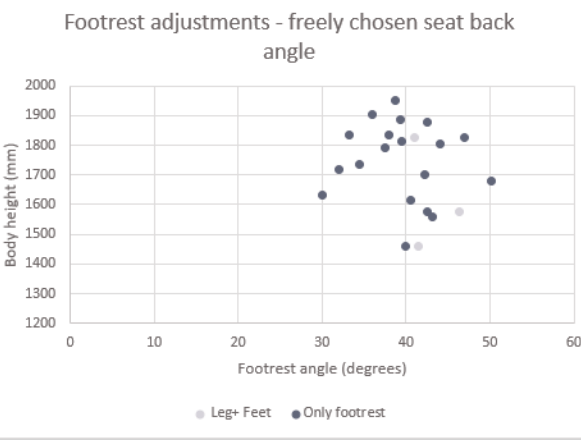
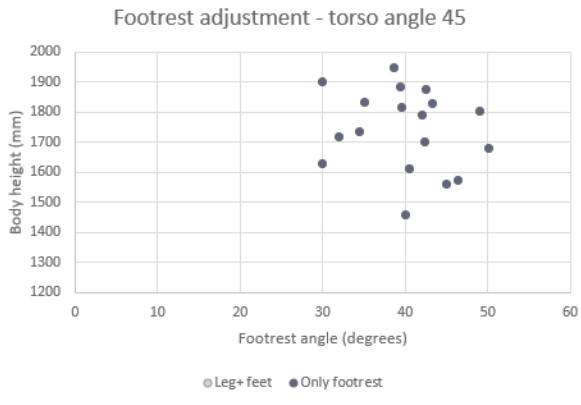
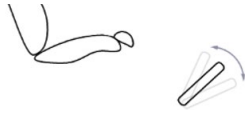


Figure 58. Footrest angle when sitting in different torso angles.

The result clearly shows how all the test persons wanted to have the footrest in an angle between 30 to 50 degrees from the floor (Figure 58). When studying the plot, it seems like a majority of the shorter test persons have chosen angles between 40-50 degrees and taller test persons have chosen angles between 30-40 degrees. For instance, in a 35-degree torso angle, six out of 7 test persons up to 170 cm chose an angle between

40 to 50 degrees while eleven out of twelve over 170 cm chose an angle between 30 to 40 degrees.

The test persons wanted to have the footrest in 30-50 degrees from the floor, and body height might affect the preferred angle.

When switching between using only the footrest and using the footrest and lower leg support together, most of the test persons did not want to change the angle of the footrest, and those who did changed the angle just a little.

Figure 59 below shows the footrest angles when comparing sitting in a 35-degree torso angle, a 45-degree torso angle and a freely chosen torso angle.

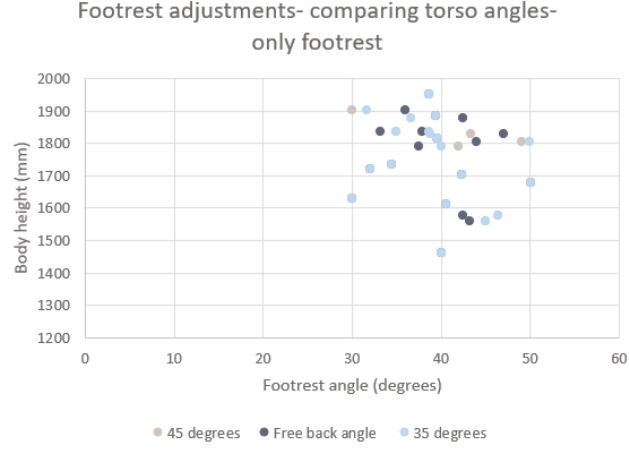


Figure 59. Comparing footrest angles when seated with different torso angles.

The chart shows some people wanted to change the angle of the footrest when changing between the different torso angles during the test. Four people changed the footrest when changing all the torso angles, three people had the footrest different for the free torso angle and the 45 degree torso angle, and one changed the footrest between sitting in 45 and 35 degrees. This means eight people wanted to adjust the angle of the footrest when changing torso angle and eleven did not change the footrest angle at all. The people who wanted to change angle

did not change it much. The differences are from 1-6 degrees. Changing the torso angle up or down does not affect in which direction they wanted to change the angle of the footrest. No clear pattern can therefore be seen between the chosen torso angle and footrest angle.

Most people did not change the footrest angle during the test.

Another parameter possible to adjust during the test was to move the whole seat forward or backward. This means they could adjust how close to the footrest they wanted to sit. Figure 60 shows the distance between the footrest and seat.

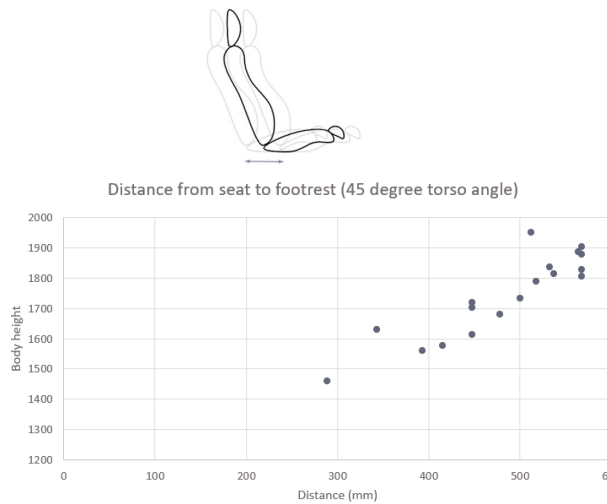


Figure 60. Relation between body height and distance between the footrest and seat.

The chart shows a connection between body height and chosen distance to the footrest. The reason could be that shorter people often have shorter legs than taller people and therefore need to sit closer to the footrest in order to reach it. Besides their height, the test persons had individual preferences of how close they wanted to sit to the footrest during the test. Some wanted to be close to the footrest and be supported on the entire foot (Figure 61) while others wanted it to touch their toes (Figure 62) or heels (Figure 63). This also creates different angles of the legs and the knees.

Body height and individual preferences affect how close people want to sit to the footrest.



Figure 61. Support from footrest (entire foot).



Figure 62. Support from footrest (toe).



Figure 63. Support from footrest (heel).

Using the lower leg support can affect how close people want to sit to the footrest. Figure 64 below shows the difference in forward/backward adjustment when

comparing using the footrest with and without the lower leg support.

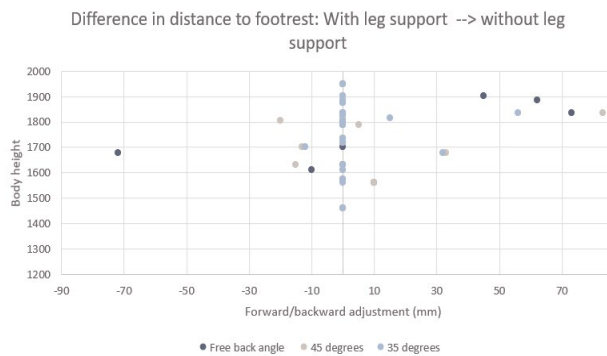


Figure 64. Distance to footrest (leg support + footrest and only footrest).

Most people had the same distance to the footrest when sitting with and without the lower leg support which is represented by the dots in the middle (zero). Six people changed their distance in the freely chosen seat back angle, seven people when sitting in a 45-degree torso angle and four people in a 35-degree torso angle. Since there are dots both on the right and left side of the middle, it means that some people wanted to sit more forward, and some people wanted to sit more backward when using the footrest without the lower leg support. Most people that changed their distance wanted to go slightly backward from 10 to 20 millimeter or forward from 10 to 83 millimeter. Some people experienced that they need more support from the footrest when taking away the lower leg support. This could be a reason why people want to sit closer to the footrest when using it without the lower leg support.

Some people wanted to change their distance to the footrest when using it together with a lower leg support.

The chart below (Figure 65) compares the test persons forward/backward adjustments when sitting in different torso angles. The y-axis on the chart shows the back angles of the seat instead of the body heights. The dots show the forward/backward difference between sitting in a 45-degree torso angle compared to

a 35-degree torso and a freely chosen back angle. Thus, a grey dot in the middle (0) means the participant had the same forward/backward position in 35 degrees as in 45 degrees.

The result from the chart shows that people generally wanted to sit closer to the footrest in a 45-degree torso angle than in a 35-degree torso angle since most grey dots are on the negative side of the centerline. Focusing on the blue dots, three of them are on the negative side, 4 are on the centerline and the rest are on the positive side. This means most people wanted to sit closer to the footrest in the freely chosen torso angle than in a 45-degree torso angle. Since a majority of the freely chosen torso angles are over 45 degrees, there might be a connection between chosen torso angle and distance to the footrest where people generally want to sit closer to the footrest when sitting more reclined. However, the chart shows that people wanted to sit much closer to the footrest in the freely chosen torso angle even if they chose an angle close to or under 45 degrees.

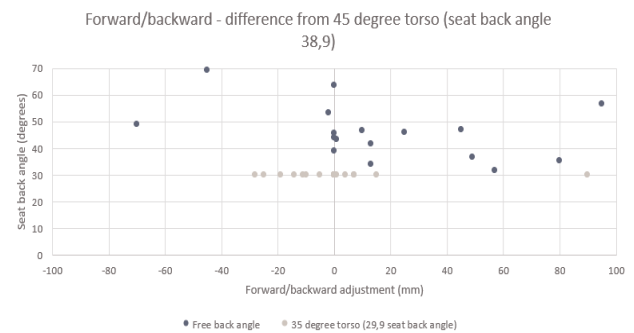


Figure 65. Forward/backward adjustment in relation to torso angle.

People generally want to sit closer to the footrest when sitting more reclined.

Back articulation

Most people did not change the back articulation when switching between the support systems. The torso angles seemed to have greater impact on the back articulation adjustment. Figure 66, Figure 67 and Figure

68 show how much the test persons used the articulation in different torso angles. In 35 degrees, many chose to articulate the back between 0-5 degrees compared to the other torso angles where the test persons wanted to use the articulation more. For instance, when comparing how many who wanted to articulate more than five degrees, it was eight people in a 35-degree torso angle, ten people in a 45-degree torso angle and twelve people when sitting in the freely chosen torso angle. Since the majority chose a torso angle over 45 degrees when choosing freely, it can be assumed that people want to articulate more when sitting reclined than sitting upright.

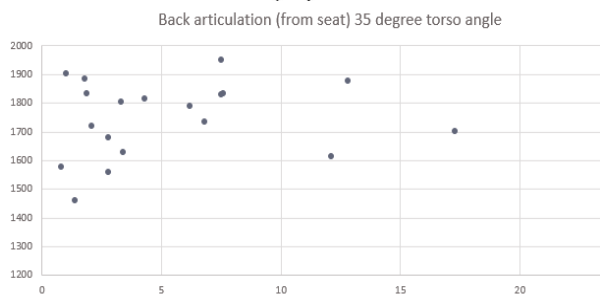


Figure 66. Back articulation use seated in a 35-degree torso angle.

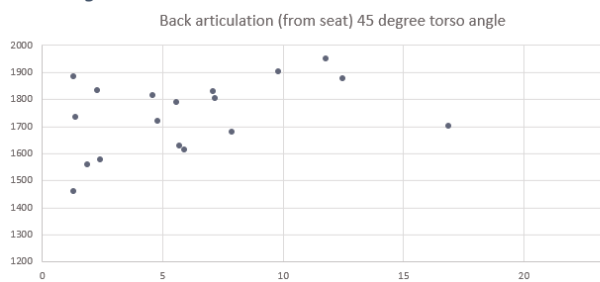


Figure 67. Back articulation use seated in a 45-degree torso angle.

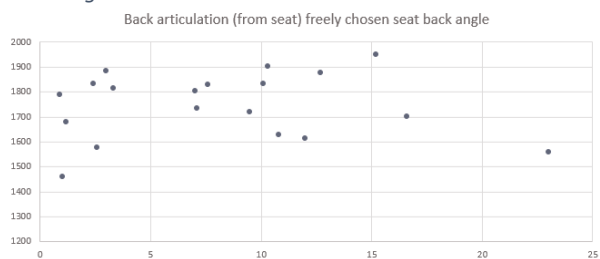


Figure 68. Back articulation use seated in a freely chosen torso angle.

People wanted to use back articulation more when sitting reclined than when sitting upright.

A reason for wanting to articulate more in a reclined position could be because people want to be able to look forward instead of looking up. According to Pflöging et al. (2016), 85% of people answering a survey said they chose to look outside the window when riding a car as a passenger and 11,5% of people were observed to be looking outside the window when going on a train. This could therefore be a common activity also during other non-driving scenarios. To be able to look outside and still relax in a reclined position, users need more support for the upper back and shoulders, and hence the need for back articulation.

Headrest

Some test persons wanted to adjust the headrest when changing torso angle which can be seen in the charts below (Figure 69, Figure 70 and Figure 71). Three people did not reach to the headrest and therefore their adjustments are not included in the charts.

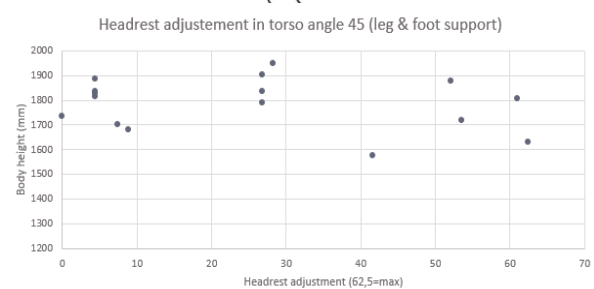


Figure 69. Neck adjustments seated in a freely chosen torso angle.

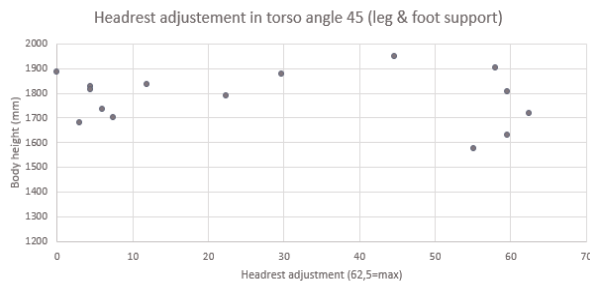


Figure 70. Neck adjustments seated in a 35-degree torso angle.

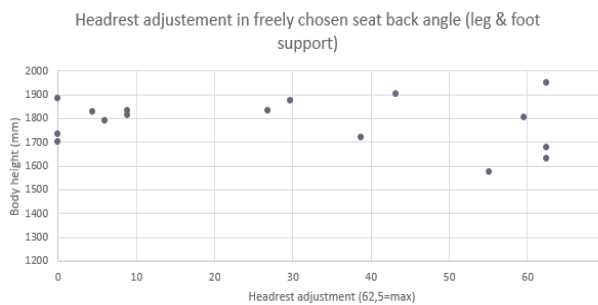


Figure 71. Neck adjustments seated in a 45-degree torso angle.

The test persons used the headrest from maximum (62,5 mm) to minimum (0 mm) in all the torso angles. Small differences can be seen between the charts, which means just some small changes were made on the headrest when changing torso angles. When comparing how people changed the headrest between an upright and a reclined torso angle, some wanted to move it forward and some wanted to move it backward. It is therefore hard to draw conclusions about what influences people's adjustment of the headrest, other than personal preferences.

Grading Comfort systems

In order to understand and analyze the results of which comfort systems the test subjects thought they would experience or experienced as the most comfortable, each place in the ranking was given a weighted point. The comfort system that a test person considered most important ranked in first place and received five points, the second most important comfort system received four points, the comfort system in third place received three points, the comfort system in

fourth place received two points and the comfort system considered least important, in fifth place got one point.

All test subjects' average scores from the various comfort systems were compiled in two tables. One table grading the comfort systems before trying them (Figure 72), and one table grading the comfort systems after trying them (Figure 73). The result showed that before the test persons tried the different comfort systems they thought back articulation would be the most important support system for their comfort followed by headrest, cushion extension, leg support and footrest. After trying the different support systems, the most important support system for their comfort were back articulation, followed by headrest and leg support on a shared second place and cushion extension and footrest on a shared fourth place. This means that leg support has gone from a fourth place to a shared second place and that footrest has gone from a fifth place to a shared fourth place. The advancement in positioning for the leg support and footrest suggests that the test persons values leg support and footrest higher after trying it than before trying it. This is also shown if looking at the average value. Leg support got an average value of 2,74 from the test persons before they had tried it and an average value of 3,11 after. Footrest got an average value of 2,16 before the test persons tried it and an average value of 2,58 after they tried.

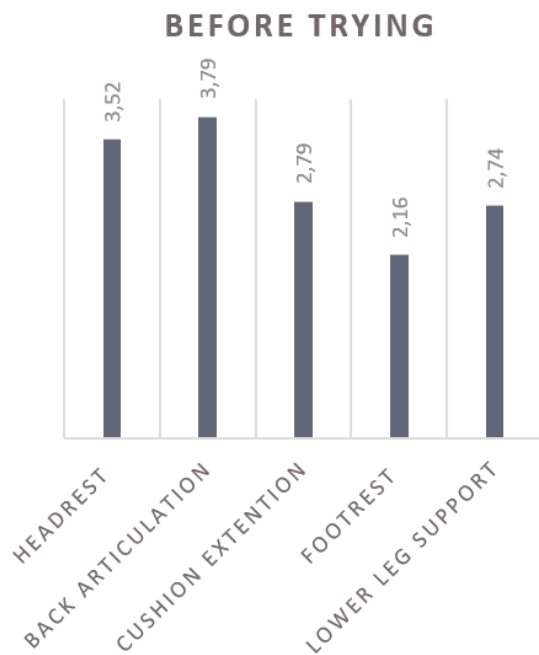


Figure 72. Grading of comfort systems before trying them.

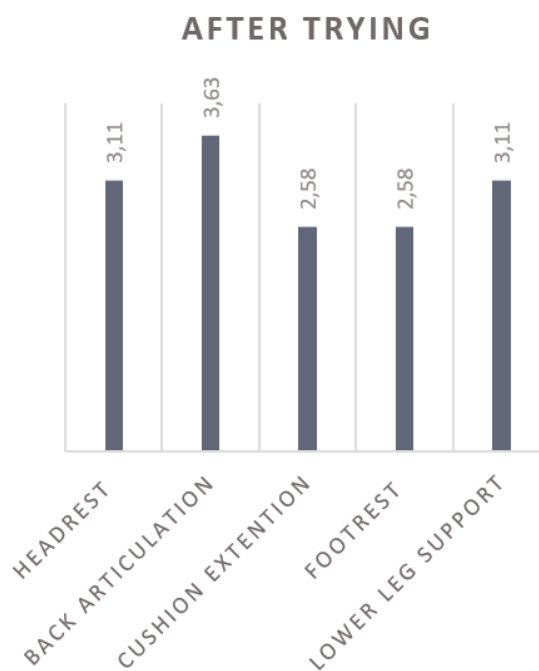


Figure 73. Grading of comfort systems after trying them.

The footrest and lower leg support got better ranking scores after the test tried the support systems than before trying.

When focusing on the back articulation, it shows that articulation is the support system most people think will be important for them

to sit comfortably, and it is also the support system people value the highest after trying. The back articulation got an average value of 3,79 from the test persons before they tried the support systems and an average value of 3,63 after they tried the support systems. If only one support system out of the five were to be chosen to be implemented in the chairs it would according to this test be most rewarding for the users with added back articulation.

Back articulation is ranked as the most important support system both before and after trying it.

If, instead of looking at the entire test group, the test persons are divided into subgroups based on body height, it turns out that there are certain tendencies regarding how people with different body heights value the different comfort systems. Due to the small number of test persons in each sub-group, these tendencies cannot be determined statistically, but the available data show that there may be a pattern in how people of different body heights value the comfort systems.

Looking at the results for how the test subjects in the short subgroup answered before trying the support systems they thought that back articulation would be the most important support systems for them to sit comfortably in a relaxed position. The back articulation was followed by headrest and cushion extension on a shared second place and leg support and footrest on a shared fourth place. Looking at the results from the short subgroup after they tried the different support systems shows a different valuation of the comfort systems. The comfort system valued as most important to be able to sit comfortably is the leg support, in descending order followed by back articulation, footrest, cushion extension and headrest. For the short subgroup the leg support has gone from shared fourth place to first place. The footrest

has gone from a shared fourth place to a third place.

The result for how the subgroup of middle-heighted people ranked the support systems before trying them are headrest, back articulation, leg support, cushion extension and footrest. When the middle-heighted subgroup ranked the support systems after trying them they still valued the support systems from most to least important in the order of: headrest, back articulation, leg support, cushion extension and footrest.

The result from the tall subgroup shows that they thought the most important support system before trying were back articulation, in descending order followed by headrest, cushion extension and footrest and leg support on a shared fourth place. When the tall subgroup ranked the support systems after trying them the sequence looked like the following: headrest, back articulation, cushion extension, leg support, and footrest. The tall subgroup gave the leg support a shared fourth place before trying, and a fourth place after trying. The footrest got a shared fourth place before trying and a fifth place after trying.

After testing, the shorter test group ranked the lower leg support highest while the middle heighted and tall test group ranked the headrest as most important.

The differences between the responses of the different subgroups may be due to the fact that some in the short subgroup do not reach the headrest in a good way (Figure 74) and therefore do not value it in the same way as the tall ones do. The tall ones who can use the support from the headrest in a different way may have higher requirements for it to function and be comfortable. It would therefore be reasonable to think that the support system affects their comfort to a higher degree and as a result it becomes more highly valued. The difference between the subgroups may partly be because tall people

may have a leg length that makes it difficult to get proper support for the calves from the leg support, and therefore do not think it adds to the comfort. Short people might value the leg support more because they proceed from usually having little or no support for their lower legs and feet, while tall people often have some sort of foot support from the floor. The leg support also covers a larger part of the lower leg for short people than it does for tall people. This leads to a percentage-wise larger relief surface for shorter people and the pressure on the leg is therefore distributed on a bigger area.



Figure 74. Test person not using the headrest.

Comparing (overall and leg+foot) comfort with different support systems

Average values were used to analyze the results of the perceived comfort for overall, and leg and foot comfort when testing the different support systems and the different torso angles. The mean value for when the test persons sat in a freely chosen seat back angle showed that they experienced the highest comfort when they had to sit with both footrest and leg support, second highest comfort when they sat with only the leg support, then with only the footrest and the least comfort was experienced when the test persons sat without both footrest and leg support (Figure 75). The overall comfort and

the leg and foot comfort at a 45-degree torso angle showed that the highest comfort was experienced by the test subjects when they used leg and foot support, second highest comfort rates came when they sat with only foot support, then only leg support and the lowest rated comfort was when they were seated without both leg and foot support. The result for the overall comfort and the leg and foot comfort when the test subjects tested without, with one or with both supports at a 35-degree torso angle was similar to the result at a 45-degree torso angle. The comfort was rated highest when using both leg and foot support, then with only foot support, only leg support and the comfort was rated as least comfortable when neither the leg support nor the foot support was used.

The highest comfort was experienced by the test subjects when they used leg support and foot support together.

The test subjects rated the comfort lowest when sitting without both footrest and leg support.

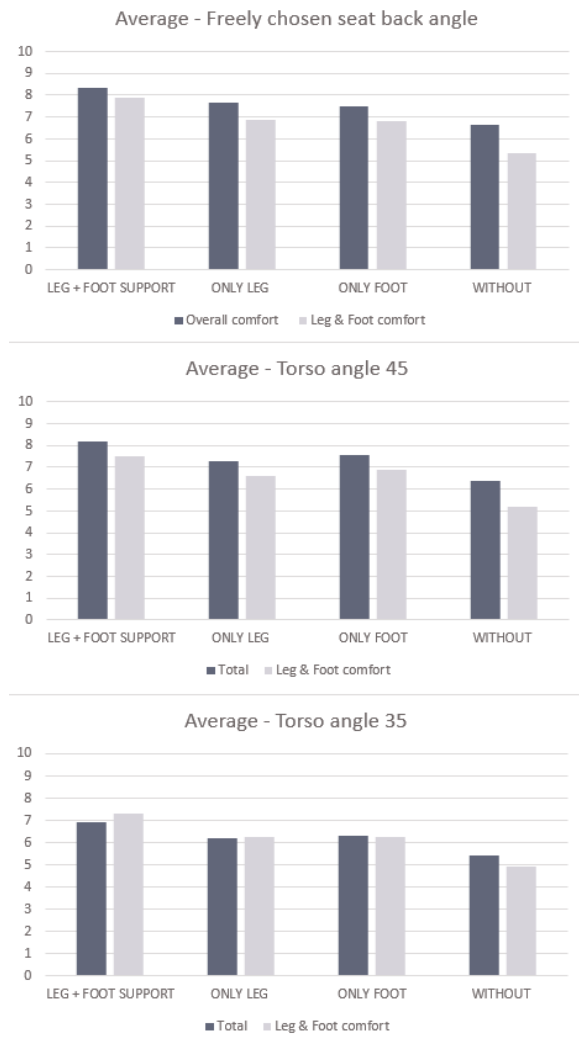


Figure 75. Comparing overall/leg & foot comfort in different torso angles.

Comparing the results between the different torso angles shows that at a torso angle of 45 and 35 degrees, the comfort is perceived to be higher with only footrests than with only leg support, while at a freely chosen seat back angle the comfort is perceived as higher when using only leg support than with only footrests. The difference in perceived comfort of the leg support and footrest between the 35- and the 45-degree torso angles and the freely chosen torso angle may be due to the majority of the test persons chose a torso angle above 45 degrees when choosing freely. This results in a more backward leaning position. According to literature by Caballero-Bruno et al. (2022) it is more natural to have equal support over the whole body when in a reclined position. The leg support covers and

gives support to a bigger area than the footrest, which may be the reason why test persons prefer leg support over footrest when they themselves get to choose torso angle. The leg support offers a more natural body position. Comments from the test persons during the test confirms this theory. A test person sitting with a freely chosen torso angle and only leg support says:

“Feels like you get support everywhere.”
-TP 31

While another test person sitting with a 35-degree torso angle and with only foot support says:

“In this upright position, the leg support doesn’t do much”. – TP 20

Comparing using only the lower leg support or only the footrest, the torso angle might affect which of the support systems is most comfortable to use.

Instead of comparing the average value of the whole group, it is possible to divide the group into the subgroups short, medium and tall, based on their height. When comparing test persons ratings when they sit with both leg support and footrest or only with leg support or footrest (Figure 76), it can be seen for a freely chosen torso angle that short people rated the comfort slightly higher than middle-heighted and tall people.

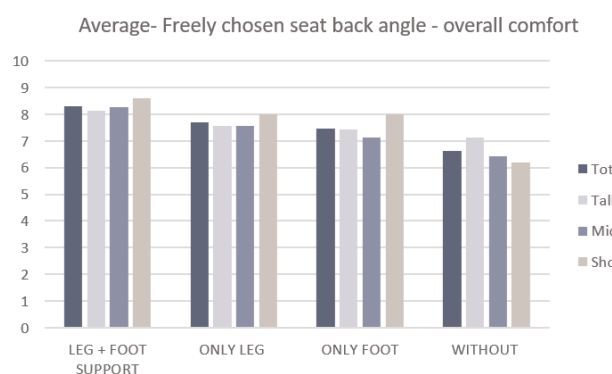


Figure 76. Average value for the support systems in a freely chosen back angle (subgroups).

However, the opposite is true when it comes to sitting without leg support and foot support. Then short people rate the comfort as worse than medium and tall people do. This difference could be due to the fact that short people rarely reached down to the rig floor during the test and therefore completely lacked support from the calf and down, while slightly taller people got some form of support for their foot from the rig floor. This means that short people sit in a more unnatural position than those who are taller.

The average value for the overall comfort and the leg and foot comfort when the test subjects sit with a torso angle of 45 and 35 degrees does not show any clear patterns. However, even with a 45- and 35-degree torso angle the short subgroup rate *without leg+foot* lower than the other height groups.

However, it should be borne in mind that the differences between the responses of the height groups are not statistically demonstrable because there are not enough people from each height group for that. In order to investigate whether these tendencies are correct, further tests need to be carried out.

Comparing overall comfort and leg and foot comfort with test persons seated with different support systems

When comparing the average value from overall comfort with the average value from leg and foot comfort (Figure 75), overall comfort is rated higher everywhere except from *leg+foot* and *only leg* when seated with a 35-degree torso angle. The fact that the leg and foot comfort for *leg+foot* and *only leg* is rated higher than the overall comfort at a 35-degree torso angle may be due to the fact that many thought that 35 degrees was far too upright to be a resting position, and the overall comfort was thus worse. Although the torso angle felt too upright, the leg support

still felt comfortable. Quotes from two test persons seated with both leg and foot support in a 35-degree torso angle says:

“It is from the stomach upwards that it becomes uncomfortable.” – TP 18

“For the legs it is still nice.” – TP 22

Sitting more reclined in the freely chosen torso angle and in the 45-degree torso angle will make the lack of leg and foot support more noticeable. With a 35-degree torso angle, the position is more upright and the need for leg support and foot support is, consequently, lower.

In general, the difference between overall comfort and leg and foot comfort is smaller when the test subjects sit with a 35-degree torso angle compared to when they sit in a freely chosen and with a 45-degree torso angle. This difference is a result of the overall comfort being judged as very comfortable when sitting in a freely chosen or a 45-degree torso angle, while sitting in a 35-degree torso angle the overall comfort is not perceived as restful and thus becomes more equal to the leg and foot comfort, which is otherwise not perceived as good as the overall comfort. The reason why the leg and foot comfort are not perceived to be as good as the overall comfort may be that the leg support was not adjustable in height. From the *leg support design test* there is data showing that many people want the leg support either a little higher or a little lower from the line at the wooden board to make it more comfortable. The comments from the leg support design test that explain why a certain rating was chosen, shows that many wished that the leg support could be angled up more and think it would have been more comfortable. These reasons may be the background to why leg and foot comfort is generally considered worse than the comfort on the rest of the body.

Comparing comfort in different torso angles (overall + leg and foot comfort)

Comparing how the comfort is rated for overall comfort and leg and foot comfort between the different torso angles shows that the freely chosen torso angle is considered most comfortable when sitting with both leg support and footrest, when sitting with only leg support and when sitting without both footrests and leg support (Figure 77). In contrast, a 45-degree torso angle is considered most comfortable when sitting with only foot support (Figure 78). Sitting at a 35-degree torso angle is considered the least comfortable both in terms of overall comfort and leg and foot comfort. This is regardless of sitting with both leg support and footrests, with only leg support, with only footrests or without both leg support and footrests. The reason why 35 degrees is perceived to be the most uncomfortable is stated in the comments from the *comfort systems test* to be because 35 degrees is perceived to be too upright for a resting position regardless of the supports one sits with. 35 degrees is considered less restful. Comments from two test persons says:

“Not nearly as nice as before. It would have been difficult to sleep or rest here.” – TP 29

“Based on it being supposed to be a relaxed position, not so good.” – TP 30

Sitting at a 35-degree torso angle is considered the least comfortable both in terms of overall comfort and leg and foot comfort.

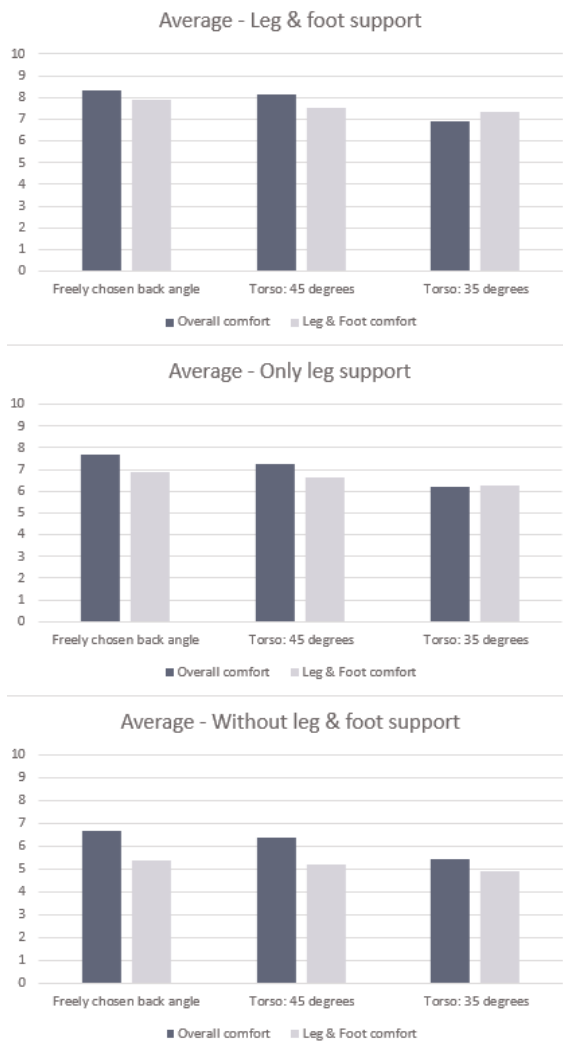


Figure 77. Comparing comfort (leg & foot support, only leg support, without leg & foot support).

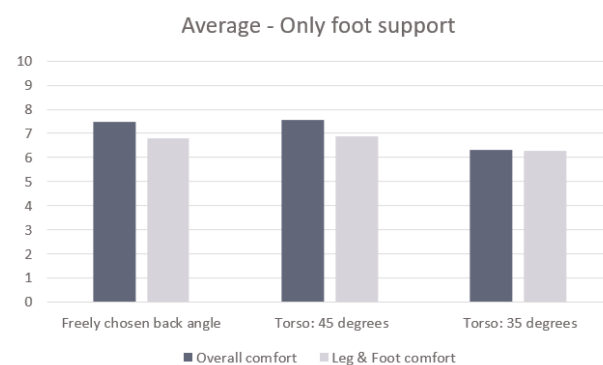


Figure 78. Comparing comfort (only foot support).

When comparing the short, medium and long length groups and their answers, the length groups answer quite similarly, but one thing stands out a little. It is that tall people experience a higher overall comfort than other height groups when they sit at a 45-

degree torso angle, regardless of whether they sit with both leg support and footrest, only leg support, only footrest or with both leg support and footrest. Why tall people experience the highest comfort and higher than other height groups when sitting at a 45-degree torso angle is difficult to know from the test results, but according to test comments it could be because some tall people had better contact with the leg support when they sat a little more upright than their freely selected torso angle. They have commented that when they sit with a 45-degree torso angle they get the best leg feel, the leg rests well on the leg support and the pressure on the lower thigh from the cushion adjustment is less than sitting with the freely chosen torso angle.

Comparing overall comfort and leg and foot comfort with test persons seated in different torso angles

The overall comfort is almost always perceived as more comfortable than the leg and foot comfort, see example in Figure 77 and Figure 78. The exception, when leg and foot comfort is higher than overall comfort, is when seated with lower leg and foot support in 35 degrees and with only leg support in 35 degrees. When sitting with leg and foot support in 35 degrees the leg and foot comfort is rated almost half a rating step higher, with overall comfort 6,9 and leg and foot comfort 7,3. The difference when sitting with only leg support in 35 degrees is very small and the two comfort ratings are almost equal, with leg and foot comfort at 6,26 and overall comfort at 6,21. The biggest difference in comfort is a 0,8-rating step. This difference in perceived comfort appeared when test persons were seated with only leg support in a freely chosen torso angle. The difference between the overall comfort and leg and foot comfort is greatest when the test persons are seated without lower leg and foot support. The result is considered reasonable because the comfort score for the overall comfort can be outweighed by the fact

that it is comfortable for the rest of the body, while the comfort score for the feet and legs is worse because support systems are missing.

The overall comfort is almost always perceived as more comfortable than the leg and foot comfort.

Comparing different test types

Test two were divided into four test types, testing the same things but in different orders. Half of the test persons started without leg and foot support and half started with leg and foot support. Half of the test persons tested the 35-degree torso angle before the 45-degree torso angle and the other half did it the other way around with the 45-degree angle before the 35-degree angle. What could be seen between these four groups is that all four groups rate the comfort almost the same regardless of sitting with and without the leg and foot support when they start grading. However, the ones starting with foot support then lower their grade when seated without leg and foot support while the ones starting without leg and foot support raise their grade when seated with leg and foot support. This result shows that there is a difference in how people answer depending on in which order they try the support systems.

5.4.2 Summary Comfort Systems Tests

The summary from the comfort systems test is divided in seat adjustments, grading comfort systems and comparing comfort with different support systems and torso angles.

Seat adjustments:

- The chosen back angles on the seat go from 31,5 to 70,3 degrees where the majority chose to sit in a torso angle over 45 degrees.
- The difference between the test groups indicates that there still could be a connection between the chosen torso angle and use of leg and foot support.

- Most of the test persons wanted to adjust the leg support higher than maximum.
- The test persons wanted to have the footrest in 30-50 degrees from the floor, and body height might affect the preferred angle.
- Most people did not change the footrest angle during the test.
- Body height and individual preferences affect how close people want to sit to the footrest.
- Some people wanted to change their distance to the footrest when using it together with a lower leg support.
- People generally wanted to sit closer to the footrest when sitting more reclined.
- People wanted to use back articulation more when sitting reclined than when sitting upright.

Grading comfort systems:

- The footrest and lower leg support got better ranking scores after the test persons tried the support systems than before trying.
- Back articulation is ranked as the most important support system both before and after trying it.
- After testing, the shorter test group ranked the lower leg support highest while the middle heighted and tall test group ranked the headrest as most important.

Comparing comfort with different support systems and torso angles

- The highest comfort was experienced by the test subjects when they used leg and foot support together.
- The test subjects rated the comfort lowest when sitting without both footrest and leg support.

- Comparing using only the lower leg support or only the footrest, the torso angle might affect which of the support systems is most comfortable to use.
- Sitting at a 35-degree torso angle is considered the least comfortable both in terms of overall comfort and leg and foot comfort.
- The overall comfort was almost always perceived as more comfortable than the leg and foot comfort.

5.4.3 Answering Hypothesis and Questions

This section includes answers to the user tests questions.

Questions:

- ***Is there a latent need for lower leg and/or foot support?***
Yes, when seated in a relaxed position. Since the comfort is perceived as higher when test persons use lower leg and foot support there is a need for the support systems.
- ***How do users value the different comfort systems of a car seat?***
According to the test result from the five tested seat support systems they are after testing valued in the following order from most important to least important:
 1. Back Articulation
 2. Headrest and Leg Support
 4. Cushion Extension and Footrest
- ***Are there any general seat adjustments the user makes to increase the comfort when using lower leg and foot support?***
A general seat adjustment could be seen in the *leg support design test* where all test persons wanted to sit tilted when using the lower leg support. The other adjustments made

were individual preferences. However, it is seen that users seated with a more reclined torso tend to want the leg support all the way up and even requested an even bigger angle adjustment on the leg support.

- ***How is the perceived comfort affected by the torso angle when using lower leg and foot support?***
According to test results the free torso angle is considered to be the most comfortable when using both the leg and foot support, followed by the 45-degree torso angle. The comfort is perceived as worst when the test persons sat at a 35-degree torso angle.

Hypotheses:

- ***A lower leg support and a foot support will increase comfort in a relaxed position during non-driving scenarios.***
This hypothesis is proven since results from the test show that the comfort is perceived as higher with the leg and foot support than without.
- ***It is more comfortable to use lower leg and foot support together than using them separate.***
Proven. According to test results the comfort is higher when the leg and foot support are used together than when used separately.
- ***The leg and foot comfort will be perceived as most comfortable with the torso angle in 45 degrees.***
Disproved. The leg and foot comfort are only perceived as most comfortable in a 45-degree torso angle using only foot support. When seated with only leg support or with and without both the leg and foot support the free torso angle is perceived as most comfortable.

- **To maximize comfort while using the lower leg and foot support users will change the back articulation from design position to a more angled position.**

Disproved. Users did not change the back articulation particularly when testing with or without the leg and foot support. Showing that there is no

connection between using leg and foot support and the back articulation. However, the torso angle affected how much the users wanted to articulate their back showing a connection between torso angle and back articulation. The greater the torso angle, the more the back articulation was used.

5.5 Guidelines and Final Design

Following section presents the guidelines and the final design. The guidelines are divided in design guidelines and adjustment and position guidelines for the lower leg support and the footrest.

Guidelines: Lower leg support

Table 5 and Figure 79 presents the design guidelines for the lower leg support and Table 6 and Figure 80. Adjustment and position guidelines: Lower leg support. presents the adjustment and position guidelines for the lower leg support.

Table 5. Design guidelines: Lower leg support.

Radius at the upper and lower edge	Minimum 15 mm
Side support on the right and left side of the legs	Highest point: 20-40 mm from the flat surface.
Foam thickness	20 mm
Foam hardness	5KPa
Width	390-440 mm
Height/ Length	210-240 mm (Length up to 290 mm possible if adjustment in z-axis is possible).

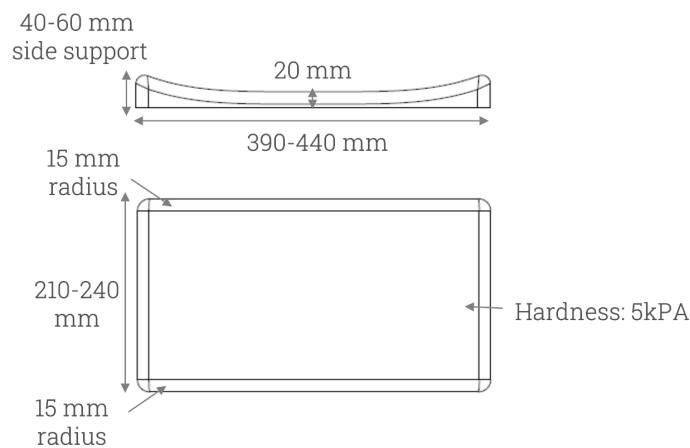


Figure 79. Design guidelines: Lower leg support.

Table 6. Adjustment and position guidelines: Lower leg support.

It should be possible to adjust the lower leg support in x-direction.	
The lower leg support should be possible to adjust in z-direction.	Adjustment range: 40mm (20mm down and 20mm up from design position).
It is desirable, but not required to have the length of the lower leg support possible to adjust.	190-290 mm
It should be possible to adjust the angle of the lower leg support.	40-85 degrees
It should be possible to move the lower leg support under the car seat while driving/not in use.	Minimum in line with car seat.
Design position of the lower leg support.	Same centerline as car seat with the upper edge 45 mm down from the cushion edge.

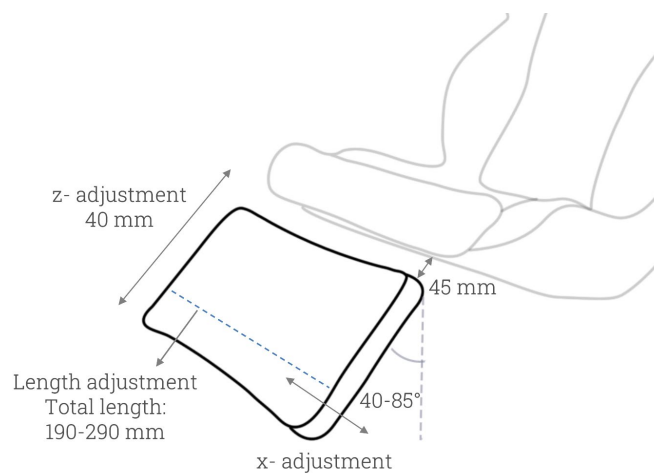


Figure 80. Adjustment and position guidelines: Lower leg support.

Guidelines: Footrest

Table 7 and Figure 81 presents the design guidelines for the footrest and the adjustment and position guidelines are presented in Table 8 and Figure 82.

Table 7. Design guidelines: Footrest.

Height	Up to 440 mm
Width	Up to 460 mm
Surface shape	The footrest should have a flat surface.

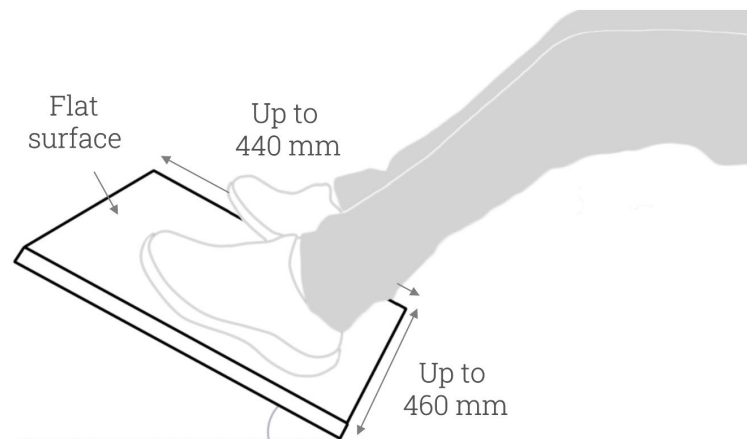


Figure 81. Design guidelines: Footrest.

Table 8. Adjustment and position guidelines: Footrest.

It should be possible to adjust angle of footrest.	30-50 degrees
It should be possible to adjust the distance between the car seat and footrest.	280-620 mm
The footrest should be positioned so it can be used together with a lower leg support.	

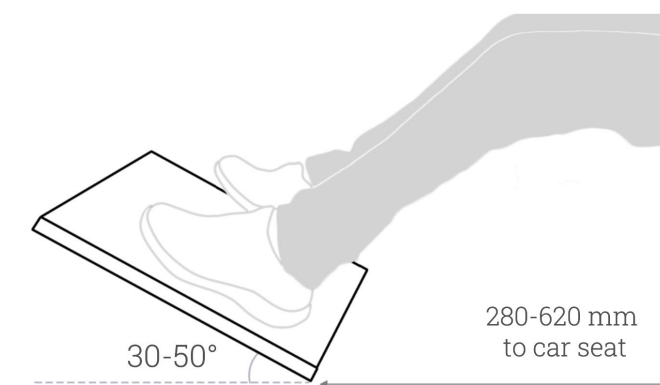


Figure 82. Adjustment and position guidelines: Lower leg support.

Final design

Figure 83, Figure 84, Figure 85 and Figure 86 presents the final design of the lower leg support and the prototype seen in Figure 87, Figure 88, and Figure 89. The prototype consists of similar materials as in the prototypes used in the user tests. The base of the prototype is a wooden board, the padding is foam with the hardness of 5 kPa and it is covered by a thin fabric. The size and shape of the final prototype follows the presented guidelines. The hardness and thickness of the foam was decided from the tests in first loop of the project where 5kPa was experienced as most comfortable and 20 millimeter was enough for padding.

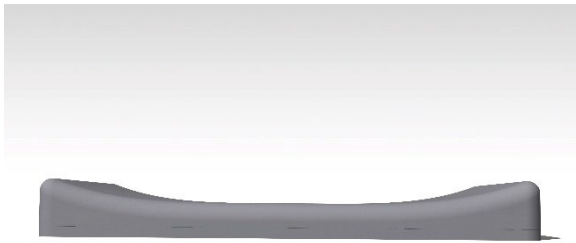


Figure 83. Final prototype (sideview).

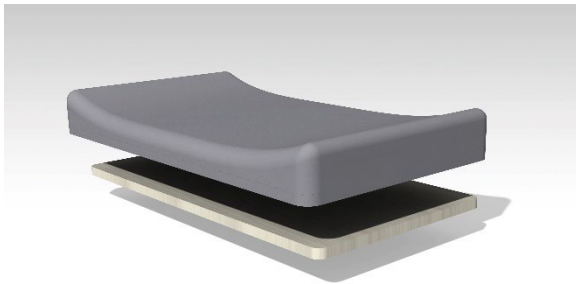


Figure 84. Final prototype, components (1).



Figure 85. Final prototype, components (2).

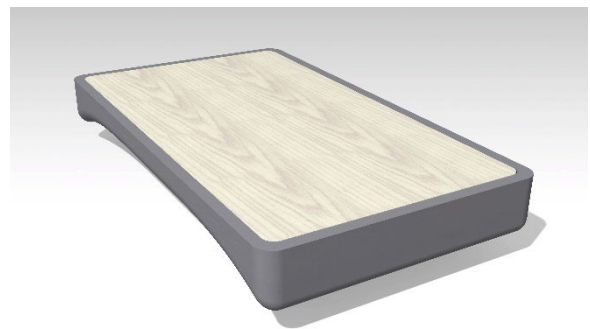


Figure 86. Final prototype showing wooden board.



Figure 87. Car seat with final leg support prototype.



Figure 88. Final leg support prototype (sideview).



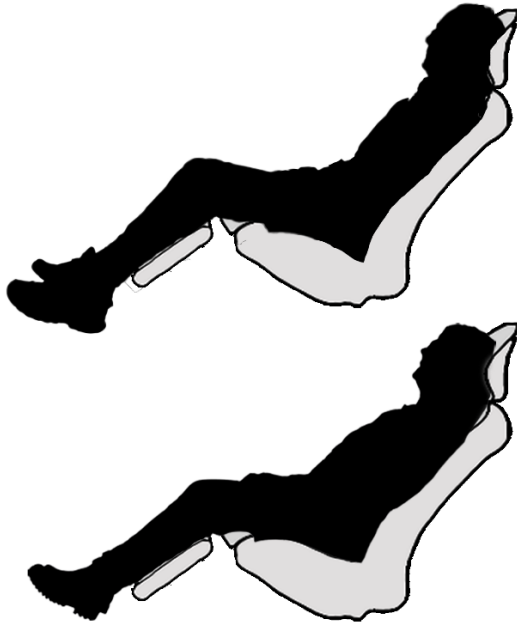
Figure 89. Final leg support prototype (above).

In the *leg support design test*, people liked the prototypes with side support most where 47% preferred *shape 5* and 40% *shape 4*. The ones who preferred *shape 5* described it gives them more freedom to vary their leg position than when seated with *shape 4*. Since the ability to vary posture is an important parameter to increase comfort (Callaghan & McGill 2001), a prototype with only side support, as *shape 5*, was therefore chosen for the final design. The foam is 40mm thick at the highest point of the side support which is 10mm lower than *shape 5* from the *leg*

support design test. The reason why the side supports are 10mm lower is because the radius was increased to get a smoother transition that would disturb shorter test subjects less when the leg support was down, and they were sitting in driving position. In addition, the tests also showed that very few sat with their legs so far out that they went against the outermost part of the leg support. The increased radius at the top of the side support should therefore not change how the lower leg support is experienced when seated with it.

The width is 420mm which is in between the width of B1 and B2 from the *leg support design test*. This width was chosen because all prototypes (B1, B2 & B3) were accepted by a large part of the test persons and since B2 was preferred by most test persons, 420mm which is slightly smaller will cover a wide user group. Additionally, when testing the width of *shape 5*, 400mm and 440mm was the most preferred widths by both short and tall test persons. Therefore, a dimension in between was chosen for the final width.

The chosen height for the final prototype was 240mm since it was the height most people from all length-groups accepted from the *leg support design test*. Although H3 (290 mm) was most preferred, there is a risk it will be too long and create discomfort for shorter people if it is not possible to move it up enough in the z-direction. Figure 90 shows how a male taller than the 50th percentile male and a female shorter than a 50th percentile female are seated in the chair with the leg support.



*Figure 90. Male and female seated with leg support.
Authors own figure.*

From the *leg support design test*, the upper and lower edge of the prototype was mentioned as irritating when the test persons felt discomfort. Since small radiuses can be connected to discomfort (Mellqvist & Vicini, 2022), it was decided to do a 15 millimeter radius on the edges to prevent this feeling by creating a smoother transition. The radiuses will make the flat surface slightly smaller (210mm), but this will not be a problem since even the smallest prototype (190mm) have been widely accepted during the tests.

06

DISCUSSION

6. DISCUSSION

This project has aimed to investigate how added support systems for lower legs and feet in Volvo cars are valued by users and if it can increase comfort. Since the future opens for new possibilities with new technologies, there is a possibility to investigate how this new reality could be accommodated to maintain or increase the comfort in cars during non-driving scenarios. The project has also been investigated how lower leg and foot support should be designed to improve the comfort in sitting positions during non-driving scenarios. During the project dimensions, shapes and sizes have been investigated in order to understand how to design a leg support and foot support that maximizes users' comfort when seated in the car. This project has contributed to increased knowledge about which dimensions of a leg support are perceived as comfortable for a large user group, and an increased understanding of how comfort can be increased through adjustment in different directions. The insights on which important factors increases a user's comfort can be used to create added value for the car user in non-driving scenarios.

6.1 Research Question One

How should lower leg and foot support be designed to increase comfort in a seated position for the Swedish population, from the 5th percentile female to the 95th percentile male?

The lower leg support should be designed as an enveloping shape with side support. Radius on the edges and a foam padding will increase the comfort. The lower leg support should provide a surface where the pressure can be evenly distributed on the calves. The possibility to change its angle and position in x- and z-direction will make the lower leg support comfortable for the whole population.

The footrest should have a flat surface with possibility to change its angle. It is important to have the possibility to change the distance to the footrest.

6.2 Research Question Two

How do users value lower leg and foot support during non-driving scenarios?

In the *comfort systems test*, it was seen that users valued the lower leg support and footrest high since using the comfort systems got higher comfort rating than sitting without them. Using the lower leg support and footrest together was rated higher than using them separately. Additionally, using the support systems in a reclined torso angle was rated as more comfortable than sitting upright. When comparing different comfort systems, the footrest and lower leg support got better ranking scores after the test persons tried them than before trying which means there is a chance users have latent need for the support systems and that they will value it higher after time of use.

6.3 Result Discussion

The reason for the different test types was to avoid that a torso angle or a support system received a better or worse rating depending on the test order. Since some differences could be seen depending on if the test persons started with or without the leg and foot support, the test order affects the result and hence, different test types help to keep the results more realistic. Carrying out the test as different test types thus made the result more reliable.

During the *comfort systems test*, the different length-groups rated the different comfort systems and the torso angles slightly different. Since the number of test persons for each test group were too small to be able to draw statistical conclusions, these differences can only be seen as tendencies. However, it would be interesting to do further testing in this area to confirm if the trends are correct.

The *comfort systems test* showed a tendency in the result that shorter people feel less

comfortable without leg and foot support than medium and tall people. This may be because most medium height people and all tall people reached down to the floor of the rig when the tilt was adjusted to the design position. Most short ones did not reach down to the rig floor and their legs and feet therefore became dangling. If the cushion tilt had had the adjustment possibility, short people might have adjusted the chair differently into a position where they could reach the rig floor, and the result might then have been closer to the other length-groups. A reflection based on this is that the comfort is higher if you have somewhere to place your feet compared to if they are dangling. It is difficult to know how shorter test persons would have chosen to adjust their seat if they had been allowed to use the tilt. A guess is that the shortest percentiles often do not reach down to the floor in a good way when sitting in a relaxed position in a chair, whether it is in a car or not. A leg support and footrest in the front seat of the car can therefore be an opportunity to create added value especially for the shorter users who might otherwise not have the opportunity for such comfort.

Comfort was the focus in this master thesis and therefore the vehicle package and its limitations in space was not considered during the study. Since the roominess has a big impact on comfort (Kolich, 2008), it is crucial to test the support systems in a setting with limitations from a vehicle package for future development. This will be important in order to understand how it will affect the comfort and peoples seat adjustments as well as to identify if compromises in the design is needed. For instance, there is a chance people want to be able to look out the windows if they are positioned in a car which can affect their adjustments of the torso angle and back articulation. Even though the project did the user tests without the vehicle package the results are interesting since they show how users want to be seated without the limitations and restrictions that are present in the cars that are on the market today. Therefore, the test results from this project

are useful for future cars, where it has not yet been defined what the inside should look like, and what dimensions it should have. The data from the project can also be used for the cars that exist today, as a starting point for what to test, and as a reference point to compare new data with.

It should be kept in mind that testing statically and dynamically is different and static testing may produce different results than dynamic testing. Further testing in a moving car is therefore recommended to get a better understanding of how the comfort is affected. Since the project only included static testing, the results are more reliable for the non-driving scenario or waiting while charging than the non-driving scenario of riding in an autonomous car. The reason is that the car is stationary while charging and moving in the scenario of riding in an autonomous car. Movements in a rolling car can affect comfort and could possibly show that users want even more support on the sides of their legs than what was shown during the static tests. The movements from a rolling car could also indicate that side support feels imposing instead of embracing when the car is in motion. To know how comfort is affected in motion, more studies therefore need to be done.

During both tests the user got to grade their comfort based on how they felt at the moment. Since the test were limited in time, the test subjects had to grade the comfort as soon as they sat down with the new leg and foot support, or the new torso angle and they have thus graded their instant comfort and not the comfort over time. Some people mentioned that they felt comfortable at the moment, but they did not know how they would feel over time, something that needs to be further explored. Further testing over a longer period is therefore recommended in order to examine if the same shapes and measurements are still preferred or if the user experiences something else when they have been seated with the leg support and foot support for a longer time period. Since the final prototype gives the user more freedom

to change position, we believe in our solution and think it will work during a longer time period as well. The reason is that the ability to change position is important to maintain comfort (Callaghan and McGill, 2001), and the final prototype provides that possibility. However, if a prototype that did not allow the user to change position were chosen, it would have been more important to investigate how the comfort are experienced over time.

During the *comfort systems test*, when the cushion tilt could not be used, almost all test persons had the leg support in its maximum position. This result could be seen in two ways. On one hand, it shows that an angle smaller than the now maximum position of 54 degrees is less useful. And that only a few prefers a smaller leg support angle. On the other hand, the result makes it hard to know what angles people want on the leg support. If there had been a bigger adjustment range there would probably be a bigger spread in the result, hopefully showing in which angle most people prefer to have their leg. Since most people during the *comfort systems test* put the leg support in its maximum position and commented that they wanted the leg support to go higher up, it is hard to know how much that is. However, during the *leg support design test* it was investigated with different wedges and the small wedge was accepted by 80% and the big wedge was accepted by 73%. Showing that an increased adjustment range somewhere between 15 and 30 degrees are accepted or even preferred by a large part of the users. The adjustment angle would although need to be investigated further without the cushion tilt since the *leg support design test* was done with the cushion tilt. Without the cushion tilt, the desired increased adjustment angle might be different, since the correlation between the cushion tilt and the leg support angle is not established.

The importance of the right measurement of the seat cushion for the leg to lay flat on the

leg support was noticed during the *leg support design test*. The cushion extension adjustment was set to design position both during the *leg support design test* and the *comfort systems test*, and the test persons were not allowed to change it. This simulated a seat without cushion adjustment, but since it became evident that the upper leg length is decisive for how comfortable a user experiences the leg support, it is recommended to do further user testing in that area. During both the *leg support design test* and the *comfort systems test*, several tall people mentioned a lot of pressure on the femur, where the seat cushion ended. A test where the cushion adjustment could be used would probably also result in a better overall comfort for tall people, since they commented they usually use the cushion adjustment in its outer position to sit more comfortably while driving.

A further recommendation for future research would be to investigate the shape of the leg support further, since only one type of side support was tested during the *leg support design test* and the final prototype is made according to the test result. Further investigation is recommended to focus on where the side support should start and which radius that is perceived as most comfortable. Do people prefer a bigger radius starting closer to the middle of the leg support or do they prefer a smaller radius starting further out? Which height of the side support is needed for the user to get the embracing feeling from the leg support that they liked during the test? Another parameter to investigate is the radius on the top and bottom edge of the leg support and how that affects the height measurement.

In both tests, the car seat was set to a predefined position which may have affected the test persons chosen seat adjustments. Further research on peoples preferred positions in relaxed scenarios is recommended as well as tests with different

predefined positions in order to investigate its impact on the result.

6.4 Process Discussion

When performing analysis of the *leg support design test* it sometimes was hard to compare the results since some answers were vague or unclear. Some answers were also tweaked instead of choosing between existing options. In the second user test, we were more determined to stick to the form and make sure we had clear answers to every question.

Having an iterative process was beneficial for the project where testing was made in several steps. Different insights could then be identified in each test which had a positive impact on the development. Testing in different phases also made it possible to include more test persons that could influence the final design. How the users described their experienced comfort during the tests often related to the prototypes or sitting positions they previously had tried. It was therefore useful to have a bunch of different prototypes or positions to test and compare in both tests. It also engaged the users to find their favorite prototype and what was important for them when focusing on comfort. Including test persons with different anthropometrics was also very useful where each person could represent their length group and freely share their thoughts based on their personal experience.

Both user tests started with the users being introduced to the scenario of relaxing or sleeping in an autonomous car for an hour and they were told to have the scenario mind when answering the questions during the whole test. It felt like the scenario helped the users to get a feeling of what they were supposed to test, and it gave them something to relate to and have in mind. This was seen as a useful tool since several users came back to and reasoned accordingly to the scenario when they answered the questions. However, part of the scenario was that the users would

be seated in the car for an hour and during that time rest or sleep. Including that timeframe might have affected how people answered when grading the comfort. This meant we had to remind them to grade based on how they felt at the moment, something some found difficult. The experience is therefore that one must be careful with specifying times in the scenario when wanting to investigate how the user feels at the moment.

There were also some variations between the different test types during the *comfort systems test*. Results shown a trend that people starting without leg and foot support later on graded sitting with leg and foot support as more comfortable than the ones that were seated with the leg and foot support from the beginning. This result shows that test order matters when it comes to trying with and without one or both of the comfort systems, and that the results are affected by it.

During the *leg support design test*, it could be seen that many test persons used the cushion tilt in its maximum or close to maximum position, since it helped to raise the leg support. Even though the angle between the seat and the leg support were the same, the distance between the leg support and the rig floor became bigger enhancing the feeling of a more raised leg support. During the *comfort systems test*, there were some technical difficulties with the cushion tilt and cushion extension, resulting in these two support systems to be adjusted into their design position and not to be moved during the test. When the tilt where in design position during the *comfort systems test* it became evident that more people commented that they wanted the leg support to be more adjustable in another angle. This was seen even in the *leg support design test*, but more test persons commented on it during the *comfort systems test* which may be because there was no possibility to adjust the cushion tilt. If test

persons had the possibility to adjust the cushion tilt, they might have felt a smaller need to adjust the leg support angle. Therefore, the need for an increased adjustment angle for the leg support versus the need for a big cushion tilt range could be discussed. Could a big cushion tilt range make up for a smaller leg support adjustment angle, or are both needed for the user to achieve maximum comfort? This would need to be further investigated and it is one of the recommendations for future studies.

07

CONCLUSION

7. CONCLUSION

The aim with this master thesis was to investigate the need for lower leg and foot support and how they should be designed to increase comfort for the Swedish population, from the 5th percentile female to the 95th percentile male. This study has contributed to knowledge about users' preferences of support systems in relaxing, non-driving scenarios which can be used as a base for future research and development of support systems in autonomous cars. The main focus when developing the lower leg support was to find the most comfortable dimensions for a wide user group. The guidelines can therefore be used as a basis of comfort when deciding on which compromises can be done because of design, safety or manufacturing requirements. Additionally, using the lower leg support together with a footrest was rated as most comfortable in this study. Furthermore, insights on shape, dimensions and seat adjustments from this study can be implemented to increase comfort.

REFERENCES

- Antropometri.se. (n.d.) *Hur används antropometri?* [Antropometri.se](https://antropometri.se)
- Bubb, H., Grünen, R. E., & Remlinger, W. (2021). *Automotive Ergonomics* (3 ed.). Springer Nature. https://doi.org/10.1007/978-3-658-33941-8_7
- Caballero-Bruno, I., Wohllebe, T., Töpfer, D., & Hernández-Castellano, P. M. (2022). The effect of seating recline on sleep quality, comfort and pressure distribution in moving autonomous vehicles. *Applied Ergonomics* 105. <https://doi.org/10.1016/j.apergo.2022.103844>
- Callaghan J. P., & McGill S. M. (2001). Low back joint loading and kinematics during standing and unsupported sitting. *Ergonomics*, 44 (3), 373–381.
- Ching- Chow, Y. (2013). An analytical methodology for identifying the latent needs of customers. *Total Quality Management & Business Excellence*, 24 (11-12), 1332-1346.
- Gyi, D. E. (2012). Driving posture and healthy design. In *Automotive ergonomics: driver-vehicle interaction* (pp. 123-132). CRC Press.
- Harrison, D. D., Harrison, S. O., Croft, A. C., Harrison, D. E., & Troyanovich, S. J. (2000). Sitting biomechanics, Part II: Optimal car driver's seat and optimal driver's spinal model. In *Journal of Manipulative and Physiological Therapeutics* (pp. 37-47). Elsevier BV.
- Hussain, R., & Zeadally, S. (2019). Autonomous Cars: Research Results, Issues, and Future Challenges. *IEEE Communications Surveys & Tutorials*, vol 21 (2), 1275- 1313. [IEEE Xplore Full-Text PDF:](#)
- Hägg, G. M., Ericson, M., & Odenrick, P. (2015) *Physical load*. Work and technology on human terms. Prevent.
- InCharge. (2020). *Hur lång tid tar det att ladda en elbil?*
- [Så lång tid tar det att ladda en elbil | Vattenfall InCharge](#)
- International Ergonomics Association. (n.d.) *What Is Ergonomics (HFE)?*. [What Is Ergonomics \(HFE\)? | The International Ergonomics Association is a global federation of human factors/ergonomics societies, registered as a nonprofit organization in Geneva, Switzerland. \(iea.cc\)](#)
- Jorlöv, S., Bohman, K., & Larsson, A. (2017). Seating Positions and Activities in Highly Automated Cars. IRCOBI Conference. Antwerp, Belgium. Pp. 13-22.
- Kolich, M. (2008). A conceptual framework proposed to formalise the scientific investigation of automobile seat comfort. *Applied Ergonomics*, 39 (1), 15–27.
- Larsson, A., & Östling, M. (2019). *Occupant activities and sitting positions in automated vehicles in china and Sweden*. Conference for the Enhancement of Safety Vehicles. Eindhoven, Netherlands, 2019.
- Mellqvist, A., & Vicini, S. (2022). Comfortable vehicle surfaces. Luleå university of technology.
- National Highway Traffic Safety Administration. (2015). *Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey*. <https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115>
- National Institute for Occupational Safety and Health. (2022). *Anthropometry*. [Anthropometry | NIOSH | CDC](#)
- Octavio, J. J., Bohman, K., Logan, D., Raphael, W., & Jimenez, L. Q. (2019). Seating configuration and position preferences in fully automated vehicles. *Traffic injury prevention*, 20(2), pp. 103-109.
- Openshaw, S., & Taylor, E. (2006). *Ergonomics and design a reference guide*. Allsteel. [54490.indd \(oregonstate.edu\)](#)

Paker, F. (2022). First Stage of Automotive Concept Design; Driver Positions (H-Point). *Art and Design Review*, 10, pp. 419-435. doi: 10.4236/adr.2022.104033.

Pfleging, B., Rang, M., & Broy, N. (2016). *Investigating user needs for non-driving-related activities during automated driving*. Proceedings of the 15th International Conference on Mobile and Ubiquitous Multimedia.
<http://dx.doi.org/10.1145/3012709.3012735>

Pohl, T. (2021). *How the Automotive Industry is Driving Toward a Sustainable Future*.
[How The Automotive Industry Is Driving Toward A Sustainable Future \(forbes.com\)](https://www.forbes.com/sites/tom-pohl/2021/05/11/how-the-automotive-industry-is-driving-toward-a-sustainable-future/)

SAE International. (2008). *Motor Vehicle Seat Dimensions* (SAE J2732). www.sae.org

SAE International. (2022). *Surface Vehicle Standard* (SAE J4002).
https://www.sae.org/standards/content/J4002_202202

SAE International. (2023). *Standards Development*. [Standards Development - SAE International - Standards](https://www.sae.org/standards/content/J4002_202202)

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104 (1), pp. 333-339.
<https://doi.org/10.1016/j.jbusres.2019.07.039>

Volvo Cars. (2023). *Car safety*.
[Car safety | Volvo Cars - Indonesia](https://www.volvocars.com/indonesia/safety)

Zhang, L., Helander, M. G., & Duruy, C. G. (1996). Identifying Factors of Comfort and Discomfort in Sitting. *Human Factors*, 33(3), pp. 377-389.

APPENDIX

Appendix A – Leg support design test invitation

Appendix B – Leg support design test form

Appendix C – Comfort systems test invitation

Appendix D – List of test persons

Appendix A – Invitation leg support design test

Hi!

We are two students currently doing our master thesis at the Ergonomics department at Volvo Cars. In our master thesis we are investigating if lower leg support in the driver's seat can increase comfort in a relaxed position during non-driving scenarios. You are now invited to participate in our user test during week 12. The test will only take 45 minutes and will be held in the PVF building. Check out our doodle to fill in the time slots for when you can participate. We will make a schedule and get back to you with a selected time during next week. We would really appreciate your participation in this study! Of course there will be fika!

Doodle:

Hope to see you soon!

Best regards,

Carolina and Emilia

Hej!

Vi är två studenter som just nu gör vårt examensarbete hos ergonomigruppen på Volvo Cars. I vårt examensarbetsprojekt undersöker vi om underbensstöd i förarsätet kan öka komforten i en avslappnad position under scenarion när man inte själv kör bilen. Du är nu inbjuden att delta i vårt användartest under vecka 12. Testet tar bara 45 minuter och kommer hållas i PVF huset. Gå in på vår doodle för att fylla i vilka tidsslotter du har möjlighet att delta i testet. Vi kommer sedan att göra ett schema och återkomma med vilken tid du får under nästa vecka. Vi skulle uppskatta ditt deltagande i det här testet väldigt mycket. Självklart kommer vi bjuda på fika!

Doodle:

Vi hoppas att vi ses snart!

Varma hälsningar,

Carolina och Emilia

Appendix B- Leg support design test form

Testperson:

1) Eventuellt: Fyll i godkännande av att spara personuppgifter

2) Stolsjusteringar

- a) Gå igenom stolsjusteringar och låt de testa på stolen.
- b) Sätt 45 grader ryggvinkel och benstöd i maxläge.
- c) Deltagaren ställer in övriga inställningar så att det blir bekvämt.
- d) Kontrollera ryggvinkeln igen.
- e) Säg att de ska bara ändra igen när de känner att det behövs.

3) Notera valda inställningar

- a) Nackstöd:
- b) Artikulering:
- c) Stolshöjd:
- d) Dyntilt:
- e) Framåt/ bakåt:
- f) Ryggvinkel:

4) Bredd

O= Optimal/bäst, A = acceptabel/okej, D = oacceptabel/dålig

- Vad tycker du om den här bredden?
- Vilken bredd är din favorit/föredrar du?
- Vilken/vilka bredder känns acceptabla?
- Finns det någon bredd du inte tycker om alls? Varför?

	380 mm/ B1	440mm / B2	490mm / B3
Kommentarer:			
O/A/D			
Bäst:			

5) Höjd

- Vad tycker du om den här höjden?
- Vilken höjd är din favorit/föredrar du?
- Vilken/vilka höjder känns acceptabla?
- Finns det någon höjd du inte tycker om alls? Varför?
-

	190 mm/ H1	240mm / H2	290mm / H3
Kommentarer			
Justering i höjdled?			
O/A/D			
Bäst			

6) Kilar

Liten kil- Kommentar:

- Hur känns det att sitta med den lilla kilen?
- Tror du att du hade använt ett så här stort justeringsområde som kilen simulerar?

Stor kil- Kommentar:

- Hur känns det att sitta med den stora kilen?
- Tror du att du hade använt ett så här stort justeringsområde som kilen simulerar?

Allmänt:

- Vilken/vilka av kilarna känns acceptabla?

7) Form 4:

- Vad tycker du om den här prototypen?
- Vilken är din favoritbredd?
- Finns det någon bredd du inte tycker om alls?

Bredd	Bäst	O/A/D	Kommentar
Mitten			
4cm			
8 cm			
12 cm			

Övergripande kommentar:

8) Form 5:

- Vad tycker du om den här prototypen?
- Vilken är din favoritbredd?
- Finns det någon bredd du inte tycker om alls?

Bredd	Bäst	O/A/D	Kommentar
Mitten			
4cm			
8 cm			
12 cm			

Övergripande kommentar:

9) Frågor om det optimala stödet:

- a) Föredrar du när det finns en form eller föredrar du när det är platt?

b) Vilket är ditt favoritstöd?

c) (Favoritstödet) Hur bekvämt/komfortabelt är benstödet? - fyll i på en skala. Hade man velat ha det på något annat sätt som inte går att tillgodose som det är utformat nu?



Kommentar:

d) Testpersonen får testa sitt favoritstöd i 35 graders ryggvinkel - känns det mer eller mindre bekvämt? Varför?

e) Testpersonen får testa favoritstödet i nerfällt läge i en tänkt körposition - hur känns det nu? Varför?

Appendix C – Comfort systems test invitation

Hi!

We are two students currently doing our master thesis at the Ergonomics department at Volvo Cars. In our master thesis we are investigating comfort systems in car seats and if these can increase the comfort in a relaxed position during non-driving scenarios. You are now invited to our user test during week 14, where you have the opportunity to test comfort systems to the future AD chair and give your opinion on how you think it affects the comfort. The test will only take 30 minutes and will be held in the PVF building. Check out our doodle to fill in the time slots for when you can participate. We will make a schedule and get back to you with a selected time as soon as we can (at latest next week). We would really appreciate your participation in this study!

Doodle:

Hope to see you soon!

Best regards,

Carolina and Emilia

Hej!

Vi är två studenter som just nu gör vårt examensarbete hos ergonomigruppen på Volvo Cars. I vår masteruppsats undersöker vi komfortsystem i bilens stolar och om dessa kan öka komforten i en avslappnad position under icke-körande scenarier. Du är nu inbjuden till vårt användartest under vecka 14, där du har möjlighet att testa komfortsystem till den blivande AD-stolen och ge din åsikt om hur du tycker att de påverkar komforten. Testet tar bara 30 minuter och kommer hållas i PVF-huset. Gå in på vår doodle för att fylla i vilka tidsslotter du har möjlighet att delta i testet. Vi kommer sedan att göra ett schema och återkomma med vilken tid du får så snart vi kan (senast nästa vecka). Vi skulle uppskatta ditt deltagande i det här testet väldigt mycket.

Doodle:

Vi hoppas att vi ses snart!

Varma hälsningar,

Carolina och Emilia

Appendix D – Test person list

Test persons leg support design test:

test person	body height (mm)
TP1	1841
TP2	1900
TP3	1988
TP4	1848
TP5	1880
TP6	2030
TP7	1872
TP8	1900
TP9	1690
TP10	1630
TP11	1573
TP12	1660
TP13	1610
TP14	1570
TP15	1592
extra 1	1732
extra 2	1743

Test persons comfort systems test:

test person	body height (mm)
TP16	1560
TP17	1805
TP18	1680
TP19	1703
TP20	1460
TP21	1828
TP22	1613
TP23	1576
TP24	1902
TP25	1630
TP26	1877
TP27	1720
TP28	1790
TP29	1950
TP30	1815
TP31	1835
TP32	1885
TP33	1835
TP34	1734