THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

How Does it Feel and How is it Measured?

Assessing Sitting Comfort and Postures of Rear-Seated Car Passengers in Stationary and Driven Scenarios Over Time

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Cover:
Illustration of the collected measures in the upper left corner, including the subjective comfort experience, sitting posture, and seat belt fit, along with a car seat in the centre, and the data collection methods in the lower right corner, including interviews, questionnaires, and video recordings.

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Abstract

This licentiate focused on examining the effectiveness of short stationary studies versus long driving studies in evaluating sitting postures, belt fit, and sitting comfort in cars. The study employed a mixed-methods approach, in which 19 participants experienced two different test scenarios in the rear seat of a car: a stationary scenario in an indoor garage and a driven scenario on a predefined route in regular traffic, each lasting 45 minutes. The data collection methods captured objective and subjective data through video recordings, questionnaires, and interviews. The Wilcoxon's signed-rank test was used to identify significant differences in sitting postures and seat belt positions estimated by a machine-learning based algorithm, as well as differences in discomfort ratings between the scenarios and over time, while interviews were analysed thematically.

The findings revealed that shorter, stationary studies of three minutes effectively captured the average sitting postures and belt fit, while more extended studies were necessary to capture posture variations. The results emphasized the importance of longer driving studies for comprehensively assessing variations in shoulder belt positions, particularly for individuals with specific body shapes.

Additionally, the study emphasized the influence of the type of study scenario and duration on the comfort experience. Discomfort changes became noticeable after 15 minutes in both scenarios. Particularly, discomfort increased over time in the back, buttocks, thighs, and feet. Increased back discomfort was associated with participants adopting slumped postures. Furthermore, the type of scenario influenced the participants' emotions and behaviours, with the stationary scenario leading to increased awareness, boredom, and tiredness due to the lack of visual and haptic stimuli. In contrast, the driven scenario resulted in more natural movements and engagement in window-gazing.

Lastly, the study highlighted the complex relationship between posture data and discomfort perception. It suggested that movement ranges of the upper body were not directly associated with discomfort; rather, the movements were influenced by various factors, such as individual behaviour and strategies to mitigate discomfort. The results emphasized the complementary role of video recordings, questionnaires, and interviews in providing a comprehensive understanding of the comfort perception.

To conclude, this licentiate thesis contributes with valuable guidelines for efficient studies of sitting comfort and postures in cars, highlighting the influence of study scenario type and duration in the assessment of sitting comfort and postures in cars. It shows that shorter, stationary studies of three minutes capture the average posture and belt fit, while discomfort changes become notable after 15 minutes. Further, it emphasizes the need for extended driving studies to capture the full spectrum of variations in comfort, especially related to shoulder belt positions, and offers a nuanced view of how emotional states and behaviours are influenced by the study scenario. The study provides a deeper understanding of the interplay between posture data and comfort perception, underscoring the synergistic value of multiple data collection methods.

Keywords: Sitting comfort, sitting postures, seat belt fit, seat belt comfort, car passenger, driving studies, stationary studies, mixed-methods

Preface

This work was carried out at the Department of Industrial and Materials Science, at Chalmers University of Technology between March 2021 and November 2023. The research was conducted within the project *Car Passenger Safety – To the next level*, funded by FFI – Strategic Vehicle Research and Innovation, by Vinnova, the Swedish Energy Agency, the Swedish Transport Administration, the Swedish Vehicle Industry.

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Gothenburg, November 2023
Melina Makris

Appended Papers

The thesis includes an extended summary and the following appended papers:

Paper A
Makris, M., Bohman, K., Osvalder, A-L. (2023). Comparison of Sitting Postures and Shoulder Belt Fit of Rear Seat Car Passengers Over Time in Stationary and Driven **Conference proceedings International Research Council on the Biomechanics of Injury, IRCOBI, p. 690-707**

Contribution: Makris, Osvalder and Bohman planned the study. Makris conducted the study. Makris analysed the data with assistance from Bohman and Osvalder. Makris wrote the paper with feedback from Bohman and Osvalder. Osvalder conducted parts of the statistical analysis.

Paper B
Makris, M., Osvalder, A-L., Bohman, K. (2023). Comfort Experience of Rear Seat Car Passengers Over Time in Stationary and Driven Scenarios. **To be submitted.**

Contribution: Makris, Osvalder and Bohman planned the study. Makris conducted the study. Makris analysed the data with assistance from Osvalder and Bohman. Makris wrote the paper with feedback from Osvalder and Bohman. Osvalder conducted parts of the statistical analysis.

Additional Papers

Makris, M. Osvalder, A-L. (2022). Experimental Setup for Assessing Drivers' Experiences of Reclined Sitting Posture in Automated Vehicles. **AHFE International Conference on Applied Human Factors and Ergonomics, 60, 117-126**

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Chapter 1: Introduction

In recent decades, comfort has gained increased importance among car manufacturers, due to its role in reducing fatigue and increasing safety and long-term health. Customers have heightened expectations for car comfort, which has been associated with a feeling of well-being, luxury, and refreshment (Zhang et al., 1996), as well as a pleasant state or relaxed feeling of a human being in reaction to its environment (Vink & Hallbeck, 2012). Comfort is a subjective experience that can vary over time, and includes physical, psychological, and physiological aspects. Due to its subjective nature, an artefact cannot be comfortable per se; rather, it becomes comfortable (or not) when it is used (De Looze et al., 2003).

With the development of highly automated vehicles (HAVs), the driving task will be reduced, emphasizing the increased need for studies of passengers, as drivers to some extent turn into passengers. Furthermore, higher levels of automation are expected introduce innovative sitting solutions (Jorlöv et al., 2017; Koppel et al., 2019; Östling et al., 2019), requiring novel seat concepts. The automotive industry must keep up, not only with the customer demands, but also with safety requirements and the development of HAVs. Furthermore, as car passengers are not delimited to the driving task, they may adopt a wide range of sitting postures to maintain a comfortable posture and avoid discomfort. For car manufacturers to develop cars that offer comfort and safety, it is crucial to consider the comfort experiences and sitting postures of a wide range of passengers.

Sitting comfort, sitting postures, and belt fit in cars are related concepts, influenced by factors including seat properties, vehicle interior, vehicle dynamics, and performed activities. Both stationary and driving studies have been conducted to evaluate these three concepts in cars. In such studies, subjective comfort is often evaluated through interviews and questionnaires, while sitting postures and belt fit are typically measured through hands-on measurements and video recordings. Moreover, efforts have been made to find links between subjective ratings of discomfort and frequency of posture changes, but has found no potential association (Reed, 2020).

Various approaches (stationary and driving studies) and data collection methods (interviews, questionnaires, and video recordings) have been applied in studies of sitting comfort, postures and beltfit in cars. However, such studies are time-consuming and expensive, since they require prototypes in a laboratory or on road, as well as they typically involve comprehensive data collection using mixes-methods. To enhance efficiency, it is valuable to identify to what extent a shorter stationary study could be as useful a longer driving study, as well as when it comes to identifying whether comfort perceptions can be predicted by using video recordings.

Purpose and Research Questions

The purpose of this licentiate thesis was to identify and describe to what extent a short, stationary study could be as useful as a long driving study when exploring sitting postures, belt fit and sitting comfort in cars, and whether comfort perceptions can be predicted by using video recordings.

The objective was to identify the potential impact that study scenarios and duration have on the sitting postures, belt fit and comfort perception of belted rear-seated car passengers, by comparing stationary and driven scenarios over time. Furthermore, the objective was to investigate the relation between subjective comfort data retrieved from questionnaires and interviews, and objective posture data retrieved from video recordings. The objectives are addressed through the following research questions:

RQ1: What potential influence do stationary and driven scenarios and time have on the sitting postures and shoulder belt fit of rear seat passengers?
RQ2: What potential influence do study scenarios and time have on sitting comfort experience of rear seat passengers?
RQ3: How is the subjective discomfort perception associated with objective posture data in terms of ranges of positions?

Thesis Outline

The thesis is structured in the following way:

1. **Introduction** provides background on the research topic, states the purpose, and poses the research questions.
2. **Frame of References** presents previous research within the field.
3. **Methodology** specifies how the research was conducted to answer the posed research questions.
4. **Findings of Appended Papers** provide the main findings from Paper A and Paper B, regarding the influence which study scenarios and time have on the sitting postures, belt fit and comfort perception. The chapter addresses RQ1 and RQ2, respectively.
5. **Ranges of Positions in Relation to Discomfort Perception** provide the analysis and findings of the discomfort perceptions of the participants who moved within the widest and narrowest ranges of positions, investigating whether there is a link between subjective discomfort perception and objective posture data. The chapter addresses RQ3.
6. **Guidelines** provide the take-away findings regarding when to conduct which type of study, in terms of stationary or driving scenario, duration, and data collection methods.
7. **Discussion** presents how the results are interpreted, how they contribute to the existing research and discusses the implications of the utilised methodology.
8. **Conclusion** presents the conclusions and implications of the thesis.

Chapter 2: Frame of References

In the scientific literature, comfort is defined as an individual's pleasant or relaxed feeling in response to their physical environment (De Looze et al., 2003). Comfort is a is a subjective experience that can change over time and is influenced by physical, psychological, and physiological aspects. Physical comfort is associated with the absence of physical loads (Vink & Hallbeck, 2012), characterised by relaxed muscle activity, minimal static loads, low tissue pressure, low shear forces and low strain on joints and ligaments (Vink & Lips, 2017). Psychological comfort is linked to sensory experiences such as visual, auditory, and haptic senses. In this context, sensory input acts as a channel connecting the individual's sense or feeling with the environment (De Korte et al., 2012; Vink & Hallbeck, 2012). Physiological comfort refers to the extent to which external exposure leads to internal responses and depends on the physical capacity of the individual. Due to the subjective nature of comfort, an artefact cannot be comfortable per se; rather, it becomes comfortable (or not) when it is used (De Looze et al., 2003).

Beyond this generally agreed-upon comfort definition in scientific literature, the definition of comfort has been under debate. One perspective divides the concept of comfort into two different states: comfort presence and comfort absence. Within this distinction, comfort is achieved in the absence of discomfort and vice versa (Hertzberg. 1958, Floyd and Roberts 1958). This perspective means that when there is absence of discomfort, nothing is experienced (Bishu et al., 1991), implying that comfort presence is not necessarily associated with positive feelings (Branton, 1969). To notice comfort, more should be experienced (Vink et al., 2005). Another perspective considers comfort a bipolar phenomenon where comfort is positioned at the extreme positive end, whereas discomfort is positioned at the extreme negative end of a continuum with a neutral point in between. In this perspective, different levels of comfort are achieved when there are more positive experiences than expected (Vink et al., 2005). In accordance with this view, a continuous scale for evaluating different levels of passenger comfort was developed (Richards et al., 1978).

Sitting Comfort

When designing for sitting comfort, it is important to know the elements which contribute to levels of comfort and discomfort. A model describing factors underlying the sitting comfort and sitting discomfort, as well as the relationship between these factors has been presented. In this model, comfort and discomfort are viewed as distinct entities (De Looze et al., 2003), where discomfort is associated with descriptors such as fatigue, restlessness, pain, strain, and circulation, while comfort is related to impression, relief, energy, well-being, and relaxation (Zhang et al., 1996). Both comfort and discomfort are influenced by external factors, presented on context level, including physical environment and task, product level, including physical features, and internal factors on human level (De Looze et al., 2003). When it comes to sitting discomfort, the external factors on context and product level can yield human responses depending on the human's physical capacity and processes. For instance, physical characteristics of the environment, the activity performed, and the product used, may expose the seated person to loads on the body, causing internal doses of muscle activations and biomechanical responses, affecting the sitting discomfort. When it comes to sitting comfort, the external factors on context level may also involve psychosocial factors including satisfaction and social support, whereas the factors on the product level also include aesthetic design. In the comfort part of the model, factors on the human level are instead related to individual expectations and emotions (De Looze et al., 2003).

In addition, the literature has provided insights into seats and pressure distribution. For example, the optimal seat angle has been defined (Harrison et al., 2000) and a backward-leaning position has been suggested to reduces pressure on intervertebral discs (Wilke et al., 1999). Further, the uniformity of the pressure distribution of the seat back and seat pan has been shown to be correlated with comfort (De Looze et al., 2003). The comfort of the armrest plays a smaller role (Vink et al., 2005). Other comfort elements, such as softness, armrest material and texture appear to be of lesser importance.

Comfort in Transportation Systems

When it comes to comfort in transportation systems such as trains, cars and airplanes, the seat and controls such as steering wheel or shifting gear are important elements influencing comfort, but factors such as view, climate, noise and vibration also influence the comfort experience (Vink et al., 2005). End-users, individuals who occupy these seats, play a crucial role in identifying aspects that need improvement in terms of comfort or discomfort. Comfort studies in vehicles often centre around the subjective perception of physical discomfort, since comfort is typically not expressed in terms of more or less comfort (De Looze et al., 2003; Helander & Zhang, 1997).

Studies have employed both subjective methods such as questionnaires and interviews, and objective methods such as pressure mats tracking the pressure distribution to assess sitting discomfort (Helander & Zhang, 1997; Fenety et al., 2000; De Looze et al., 2003). Subjective ratings of physical discomfort appear to align with objective measures of pressure distribution (De Looze et al., 2003) in car seats. In addition, efforts have been made to find associations between subjective ratings of discomfort and frequency of posture changes in cars, but has found no potential association (Reed, 2020). Hence, the standard method for measuring sitting discomfort comprises subjective assessments such as questionnaires and interviews.

Studies of Comfort, Postures Belt Fit in Cars

When further designing for comfort and safety in cars, it is crucial to understand that sitting comfort, sitting postures, and belt fit in cars are related concepts. Various methods have been applied to study these concepts, including collection of both subjective data of comfort perception and objective data of sitting postures and seat belt fit, in both stationary and driving studies.

Studies of sitting comfort in cars have employed subjective comfort collection, in terms of questionnaires or interviews, when comparing different concepts. For instance, children compared two restraint systems by rating their perceived discomfort of the seat and seat belt on 5-point scales (Jakobsson et al., 2011) and on 6-point scales (Osvalder et al., 2013). The questionnaires were filled in at systematic time intervals capturing discomfort changes over time during ride. The latter also followed up on participants' perceived comfort through semi-structured interviews, asking the probing question "why" to achieve a deeper understanding of the responses and comfort perception (Osvalder et al., 2013). More structured interviews have also been conducted in comfort studies in cars, collecting adult participants' subjective comfort perceptions on two front seat positions (Bohman et al., 2019), and in investigations of seat belt fit and perceived comfort of older adults (Osvalder et al., 2019).

Objective data on sitting postures, belt fit and behaviour has typically been collected through video recordings (Andersson et al., 2010; Jakobsson et al., 2011; Osvalder et al., 2013; Arbogast et al., 2016; Baker et al., 2018; Reed, 2020; Reed et al., 2022). Observations from the video recordings are often analyzed through qualitative approaches where the sitting postures, belt fits or behaviours are categorized manually by a team of staff. This task typically involves extracting video frames at systematic time intervals, before manually coding them into specific categories (Jakobsson et al., 2011; Osvalder et al., 2013; Reed, 2020; Reed et al., 2022). In contrast, quantitative approaches postures have involved of Kinect sensors (Arbogast et al., 2016; Reed et al., 2019), or custom-made video tracking software (Baker et al., 2018) estimating body poses of passengers in vehicles.

Both stationary and driving studies have been conducted to investigate sitting postures, belt fit and sitting comfort. Stationary studies, typically conducted in laboratory settings using moch-ups, allow for more detailed, hands-on measurements of postures and belt fit. Detailed measurements of posture and belt fit have been collected through a 3D coordinate measurement system (FARO Edge Arm), digitizing body landmark locations and seat belt positions in 3D (Reed et al., 2013; Jones et al., 2020; Baker et al., 2021a). Although the FARO Edge Arm is a portable device, it can be heavy and bulky and requires calibration in the environment it is to be used in, which limits its use to stationary studies. Postures and joint angles of children seated on belt-positioning boosters have also been studied in stationary studies, measured using XSENSE MVN Awinda, a non-invasive inertial measurement unit (Miyata et al.,)-based 3D motion capturing system in a stationary study (Baker et al., 2021b). Such sensors provide continuous measurements of the body posture and joint angles.

Driving studies offer a more dynamic setting compared to stationary studies. There are two primary types of driving studies: field operational test (FOT) and naturalistic driving studies (NDS). Field operational tests are often conducted with a limited number of test drivers, either on closed test tracks or on predefined routes in real traffic (Jakobsson et al., 2011; Osvalder et al., 2013). In NDSs, participants use the car in their daily routine over an extended period (Paone et al., 2015; Arbogast et al., 2016; Reed, 2020; Reed et al., 2022). Such studies have been conducted to collect data on driving behaviour in a natural, real-world setting to enhance our understanding of the relationships between behaviour and driving situations. The objective data on sitting postures, belt fit and behaviours, can further be utilised in the development of human body models (HBMs), and further to investigate the influence of passengers sitting postures in crashes (Leledakis et al., 2022).

Combining subjective and objective data in studies of sitting comfort, sitting postures and belt fit in cars, provided valuable insights, revealing that activities and perceived discomfort influence the adopted sitting posture and the seat belt fit (Osvalder et al., 2013). The seat belt, a critical safety feature that saves lives and reduces the risk of injury when travelling in cars (Kahane, 2000), must accommodate occupants in various sitting postures. The optimal belt fit has been defined as the shoulder belt being placed on the mid-portion if the shoulder (Fong et al., 2016), whereas the optimal position of the lap belt has been defined as the belt positioned below the anterior-superior iliac spine, in contact with the upper thigh (Reed et al., 2013; Reed et al., 2012).

In addition to activities and perceived discomfort, factors including body shape, anthropometry, fat distribution, and body mass index (BMI) affect the seat belt fit (Reed et al., 2013; Reed et al., 2012) (Coxon et al., 2014) (Fong et al., 2016). Individuals with higher BMIs tend to position the shoulder belt closer to the neck and higher on the abdomen, regardless of age and sex (Bohman et al., 2019).

As passengers are not constrained by the driving task, they have increased freedom to engage in other activities and move more freely. This emphasizes the importance of studying their sitting comfort, postures, and belt fit. Furthermore, with higher levels of automation in cars, the need for studies of passengers increases, as drivers are transitioning into passengers.

In summary, comfort is a complex construct influenced by a variety of factors. Sitting comfort, posture, and seat belt fit in cars are related concepts, which have been investigated through subjective and objective data collection methods in both stationary and driving studies. The studies are time-consuming and expensive, involving prototypes in a laboratory or on the road, and comprehensive data collection using mixed methods. To improve efficiency, it's essential to determine the comparative utility of shorter stationary studies versus longer driving studies and whether comfort perceptions can be predicted using video recordings.

Chapter 3: Methodology

This chapter describes the methodology used to address the three Research Questions (RQs) of this thesis. One user study was conducted, applying mixed methods to address the RQ1-RQ3 (Figure 1). The objective of the study was to identify the potential impact that study scenarios and duration have on the sitting postures, belt fit and comfort perception of belted rear-seated car passengers. This objective was addressed through Research Questions 1 and 2, presented in Paper A and Paper B, respectively. Furthermore, the objective was to investigate the relation between subjective comfort data retrieved from questionnaires and interviews, and quantified posture data retrieved from video recordings. This objective was addressed through Research Question 3, presented in Chapter 5. The three Research Questions were phrased as follows:

RQ1: What potential influence do stationary and driven scenarios and time have on the sitting postures and shoulder belt fit of rear seat passengers? (Paper A)
RQ2: What potential influence do study scenarios and time have on sitting comfort experience of rear seat passengers? (Paper B)
RQ3: How is the subjective discomfort perception associated with objective posture data in terms of ranges of positions? (Chapter 5)

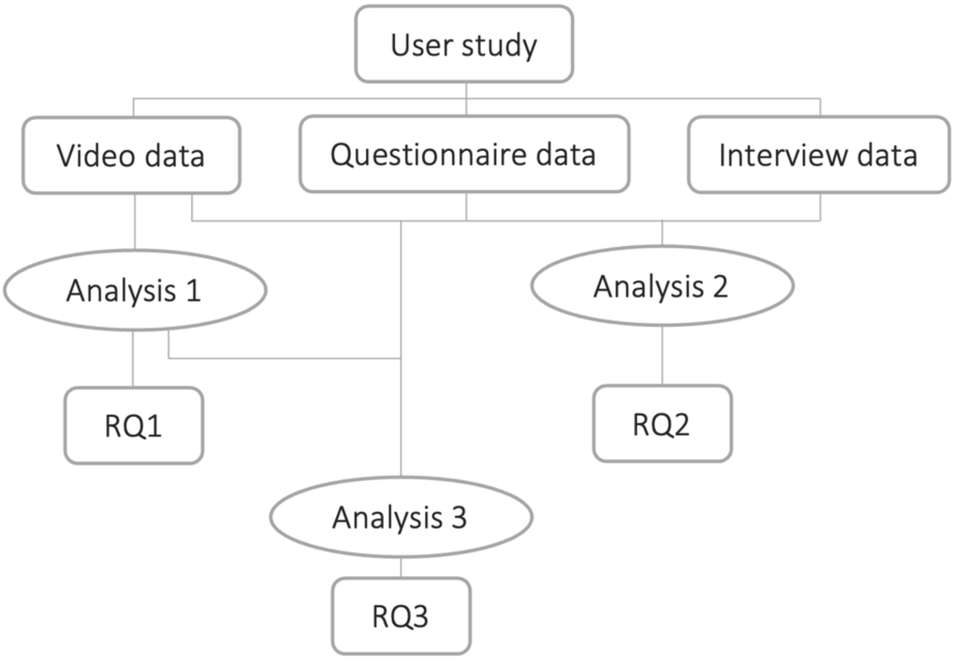

Figure 1. An overview of the research approach. Research Questions 1 and 2 are presented in Paper A, and Paper B, respectively, while Research Question 3 is addressed in Chapter 5.

User Study Procedure

The study aimed to determine the extent to which a short, stationary study could be as useful as a long driving study in exploring sitting postures, belt fit, and sitting comfort in cars. Additionally, the study sought to investigate whether comfort perceptions could be predicted through the analysis of video recordings. To accomplish this, a user study was designed using mixed methods (see Paper A and Paper B). The study included a participant group with an average age of 45 years, comprising ten females and nine males. Each participant experienced two test scenarios while seated in the rear seat: a stationary scenario in which the car remained stationary in an indoor garage, and a driven scenario in which the car followed a predefined route in regular traffic, lasting for 45 minutes each. In the stationary scenario, participants were seated in the car alone, while the driven scenario involved the presence of the test leader driving the car. The participants listened to podcasts or music of their choice through headphones connected to their mobile phones during both scenarios. They were instructed not to use their phones for any purpose other than starting and pausing their audio media and not to talk to the test leader, except if they wanted to terminate the test.

Data Collection and Analysis

A mixed methods approach was used, collecting both quantitative and qualitative data parallelly (Creswell & Plano Clark, 2017). Video recordings, questionnaires and interviews were collected, corresponding to objective and subjective data. The video data was collected to enable describing *which* postures and belt fit which participants adopted. The subjective data was collected to enable describing *when* discomfort occurs and *where* in terms of for which body region. The subjective data rather aimed to explain the reasons *why* discomfort was perceived, in terms of what it was associated with. By combining these methods, a deeper understanding of participants' behaviours and factors influencing their sitting postures, belt fit and comfort can be achieved.

Video Recordings of Sitting Postures and Belt Fit

Sitting posture and belt fit data were collected through video recordings during the entire 45-minute scenarios (Paper A). Their front and inboard side views were recorded in 3D by two cameras attached inside the car. A machine learning (ML)-based algorithm, based on previous work (Hartleitner et al., 2022) and further refined to fit the specific car environment, was employed to estimate the x (fore-aft), y (lateral), and z (vertical) positions (Figure 2) of the head and jugular notch, a body landmark henceforth referred to as upper sternum (Figure 2). It also estimated the shoulder belt position by calculating the distance between the upper sternum and centreline of the shoulder belt, henceforth referred to as shoulder belt distance (Figure 2). In the lateral and vertical directions, the measurement error of the estimated key point positions was approximately 10 mm in y- and z-direction, while the error in x-direction was approximately 20 mm.

Figure 2. Definition of the coordinate system (left), head position (centre), and upper sternum position (right) as well as shoulder belt distance (right).

Questionnaires and Interviews about Sitting Comfort and Seat Belt Comfort

Sitting comfort and seat belt comfort data were collected through questionnaires and interviews, along with the video recordings of postures and belt fit. The questionnaires comprised a body part discomfort map along with two sets of questionnaires about their perceived (1) sitting discomfort and (2) seat belt discomfort. The questionnaires were systematically completed at intervals throughout the 45-minute scenarios, to assess how the sitting discomfort experience changes over time. After each scenario, the participants were interviewed with a semi-structured approach while seated in the car. The interviews focused on the overall sitting comfort experiences and the seat belt comfort in each scenario over time.

Analysis 1: Sitting Postures and Belt Fit

Analysis 1 (Paper A) focused on how the potential influence that scenarios (stationary and driven) and time have on the sitting postures and shoulder belt fit of rear seated car passengers. The Wilcoxon signed-rank test was employed to analyse whether the two scenarios had significantly different effects ($p \leq 0.05$) on the 3D positions (the xyz coordinate) of the head and upper sternum, as well as on the shoulder belt distance, during the total 45 minutes for each participant. The Wilcoxon signed-rank test was also used to test if the stationary scenario in the initial three minutes had significantly different effects on the 3D positions (the xyz coordinate) of the head and upper sternum, as well as for the shoulder belt distance, compared to the stationary scenario in the total 45 minutes.

Descriptive statistics were used to present an overview of the average positions of the head and upper sternum in x-, y-, and z-directions, as well as the average shoulder belt distance. The 5-95 percentile ranges of head and upper positions that participants moved within in each scenario and over time were also analysed using descriptive statistics, along with the ranges which the shoulder belt distance varied within. A manual analysis of the video recordings was performed to characterize the belt position. The manual analysis also included observations of video data of the participants with the widest ranges of positions, with the aim to identify patterns of how behaviours vary between scenarios and over time in the stationary scenario.

Analysis 2: Sitting Comfort and Seat Belt Comfort

Analysis 2 (Paper B) focused on how the potential influence that scenarios (stationary and driven) and time have on the sitting comfort and seat belt comfort of rear seated car passengers. The analysis included data from questionnaires and interviews, along with the video recordings. The Wilcoxon signed-rank test for paired observations was used to identify significant differences ($p<0.05$) in discomfort ratings between the two scenarios, and over time, for the 19 participants. In addition, the information retrieved from the body part discomfort map before each scenario was used to increase the understanding of whether any of the perceived discomfort during the tests could be related to prior discomfort issues.

The interview data from the 19 participants were transcribed verbatim in Swedish and analysed using an iterative thematic analysis. The first part of the thematic analysis had a deductive character, where the interview data were coded according to predefined categories, such as a comparison between scenarios and comparison over time. The second part of the thematic analysis had an inductive character, where new themes were extracted from broader themes without any predefined categories. The video recordings of 15 participants were manually observed to increase the understanding of the postures and belt fits which participants referred to in their interviews.

Analysis 3: Ranges of Positions in Relation to Discomfort Perception

Analysis 3 (Chapter 5) addressed the third research question, investigating the association between the subjective comfort perception and with the objective data in terms of the ranges of positions that the participants adopt. The objective posture data of the 13 participants were utilised to identify which participants who moved within the widest and narrowest ranges respectively of head or upper sternum positions in either the stationary or the driven scenario. The five participants who moved in a wider range (longitudinal, lateral, or vertical directions) than the median range of all participants were defined as the participants moving in the widest ranges of positions. Similarly, the five participants who moved within a narrower range (longitudinal, lateral, or vertical directions) than the median range of all participants were defined as the participants moving in the narrowest ranges of positions.

The video recordings of the identified participants were then manually observed to increase the understanding of the postures and belt fits they referred to in their interviews. Their interviews were analysed starting with a deductive approach where discomfort related to their upper body regions was annotated, followed up by an inductive approach for describing what their experienced discomfort was associated with.

Chapter 4: Findings of Appended Papers

This chapter provides the main findings from Paper A and Paper B, which both are based on the same study, but focused on different data and utilized different analysis methods. The summary starts with the findings from Paper A, addressing Research Question 1. Following that, it provides the findings of Paper B, addressing Research Question 2.

Findings Paper A: Sitting Postures and Belt Fit

Paper A concerns the influence of study scenarios and time on sitting postures and belt fit and focuses on the objective data retrieved from video recordings. A summary of the findings from Paper A are presented below, addressing Research Question 1:

RQ1: What potential influence do stationary and driven scenarios and time have on the sitting postures and shoulder belt fit of rear seat passengers?

Head and Upper Sternum Between Scenarios

The comparison between the stationary and driven scenarios showed no statistically significant differences in the sitting postures (3D positions of the head and upper sternum). The descriptive statistics showed that the average head and upper sternum positions were similar in both scenarios in all directions (differences smaller than the measurement error, i.e., <20 mm in the x-direction, and <10 mm in the y- and z- directions). In both scenarios, the average lateral positions of the head and upper sternum remained centred around the origin of the y-axis. In both scenarios, the range of the head positions, as well as upper sternum positions was similar (differences <20 mm in the x-direction, and <10 mm in the y- and z- directions).

Shoulder Belt Distance Between Scenarios

The shoulder belt stayed on the shoulder for all participants during both scenarios. The comparison between the stationary and driven scenarios showed no statistically significant differences in the shoulder distance. Descriptive statistics showed that average vertical distance from the upper sternum to shoulder belt was similar in both scenarios (difference <10 mm). The range in which the shoulder belt distance varied was also similar in both scenarios (differences <10 mm).

Head and Upper Sternum Over Time in the Stationary scenario

The comparison of the initial three minutes and in the complete 45 minutes of the stationary scenario, showed no statistically significant differences in the sitting postures (3D positions of the head and upper sternum. The average positions of the head and upper sternum were similar (differences <20 mm in the x-direction, and <10 mm in the y- and z- directions) in the initial three minutes and in the complete 45 minutes of the stationary scenario. Over time, the average lateral positions of the head and upper sternum remained centred around the origin of the y-axis.

During the three first minutes, the head moved within smaller range of positions in all directions compared to the total 45 minutes (x=37mm, y=35mm, and z=14 mm smaller ranges, respectively). Likewise, during the three first minutes, the upper sternum moved within smaller range of positions in the y- and z-directions compared to the total 45 minutes (y=19mm and z=11 mm smaller ranges). The range of the upper sternum positions in x-direction was similar during the first three minutes compared to the complete 45-minute scenario (difference <20 mm).

Shoulder belt Distance Over Time in the Stationary Scenario

The comparison between the initial three minutes and the complete 45 minutes of the stationary scenario showed no statistically significant differences in the shoulder belt distance. The range of the shoulder belt distance was similar during the first three minutes compared to the complete 45-minute scenario (difference <20 mm). During the first three minutes of the stationary scenario, the range of the shoulder belt distance was smaller (26 mm) compared to the range during the total 45 minutes.

Findings Paper B: Sitting Comfort and Seat Belt Comfort

Paper B concerns the influence of study scenarios and time on fit and focuses on the passengers' subjective comfort perception retrieved from questionaries, interviews, and video recordings. A summary of the findings from Paper B are presented below, addressing Research Question 2:

RQ2: What potential influence do study scenarios and time have on sitting comfort experience of rear seat passengers?

Sitting Comfort

In both scenarios and over time, the overall sitting discomfort received ratings corresponding to no or low discomfort in the Likert-scales. No significant differences were observed in the perceived overall discomfort between the scenarios. The overall sitting discomfort significantly increased ($p<0.01$) in both scenarios when comparing the initial ratings with those after 15, 30 and 45 minutes. An additional significant ($p<0.05$) discomfort increase was shown between 15 and 45 minutes in the stationary scenario.

Upper Body

In the stationary scenario, the discomfort ratings of the head significantly increased ($p<0.05$) over the 45 minutes, but not over the same time in the driven scenario. In the interviews, participants mentioned that they found the head restraint physically uncomfortable, not supporting the head adequately. A few mentioned that head discomfort was more noticeable in the stationary scenario compared to the driven scenario, associated this with increased resting towards the head restraint in the stationary scenario.

Over the 45 minutes in the stationary scenario, the discomfort ratings of the arms significantly ($p<0.05$) increased, but not over the same period in the driven scenario. In the interviews, arm discomfort was associated with the lack of arm support. After 45 minutes in the stationary scenario, the arm discomfort ratings were significantly ($p<0.01$) higher compared to after 45 minutes in driven scenario, although the interviews did not reveal any explanations for arm discomfort differences between the scenarios.

In both scenarios, the ratings of back discomfort significantly increased over the 45 minutes of sitting ($p<0.01$ in the stationary scenario, and $p<0.05$ in the driven scenario). These results were consistent with the interviews, where several participants mentioned increased physical discomfort over time in the back. Increased back discomfort was associated with increased fatigue, numbness, reduced circulation, or a need to stretch. The video recordings showed most participants who reported back discomfort also adopted more slumped postures over time.

In both scenarios, the discomfort ratings of the buttocks and thighs increased significantly after 45 minutes compared to the initial experience ($p<0.01$ in the stationary scenario, and $p<0.05$ in the driven scenario). The ratings aligned with the interviews, where participants mentioned increased buttock and thigh discomfort over time. When asked how the comfort experience could be improved, participants mentioned wanting a longer seat pan for increased thigh support.

Lower Body
In the stationary, the discomfort ratings of the legs significantly increased ($p<0.01$) over 45 minutes, but not in the driven scenario. Half of the participants expressed that they would like to have more leg room to be able to stretch their legs. Two participants associated the increased leg discomfort in the stationary scenario with reduced leg movements, due to the lack of car movements. Although, no significant difference was found when comparing the leg discomfort ratings after 45 minutes in the stationary scenario with the driven.

In both scenarios, the discomfort ratings of the feet increased significantly after 45 minutes compared to the initial experience ($p<0.01$ in the stationary scenario, and $p<0.05$ in the driven scenario). A few participants mentioned increased physical discomfort in the feet, describing a tingling sensation or numbness in the feet over time. In the interviews, feet discomfort was associated with physical constraints.

Other Differences in Sitting Comfort Experiences Between Scenarios
When the participants compared their comfort experiences between the two scenarios, the most frequently mentioned differences were related to visual and haptic stimuli, with around half of the participants mentioning these aspects. In the interviews, seven of them expressed the absence of haptic stimuli in the stationary scenario was linked to the lack of car movements. Referring to this, four participants noted that they adjusted their posture more naturally when the car was in motion. Moreover, nine participants mentioned the absence of visual stimuli, as the view remained consistent during the stationary scenario in the garage. Among the ten participants who addressed the lack of stimuli in the stationary scenario, four discussed that it led to increased feelings of tiredness or boredom. Within the group of ten participants, seven reported increased self-awareness during the stationary scenario due to the lack of distractions. They also mentioned increased awareness of their sitting posture and perceived discomfort during the stationary scenario compared to the driven scenario.

Seat Belt Discomfort
The overall seat belt discomfort ratings did not significantly differ over the 45 minutes in either of the scenarios. In the driven scenario, the shoulder belt discomfort significantly increased ($p<0.01$) over 45 minutes. No significant differences were observed over time in the stationary scenario The video recordings showed that the shoulder belt moved across the chest and towards the neck for six participants during the drive. These participants had specific body shapes in terms of a larger chest, pronounced abdominal fat, shorter sitting height, or higher BMI. Their shoulder belt had a similar initial position during their stationary scenario but did not move towards the neck to the same extent as in the driven scenario. The discomfort ratings of the shoulder belt against the neck showed no significant differences over time, nor between the scenarios.

Chapter 5: Ranges of Positions in Relation to Discomfort Perception

In this chapter, the discomfort experiences of the five participants who moved within the widest (Figure 3) and the five participants who moved within the narrowest (Figure 4) ranges of head and upper sternum positions are described. The combination of the questionnaire ratings and the interviews indicated that both groups in general perceived little to no sitting discomfort. In Table 1, the number of participants who mentioned discomfort related to their upper body is presented.

Table 1. An overview of the number of participants who mentioned discomfort related to their upper body, n=2x5.

	Narrowest ranges (n=5)	**Widest ranges** (n=5)	**Difference between ranges**
Head	3	3	0
Arms	1	0	-1
Back	1	3	2
Buttocks	3	1	-2
Shoulder belt	2	1	-1
Lap belt	0	1	1

Head Discomfort

Three (P9, P15, P18) out of the five participants who moved within the widest ranges of positions mentioned discomfort related to their heads (Figure 3b, Figure 3d-e). Two of them related the discomfort to inadequate head support (P9, P15)(Figure 3d, Figure 3d), whereas the third associated head discomfort with having a slumped posture (P18)(Figure 3e). The manual analysis of the video recordings of these three participants indicated that they had little to no contact with the head restraint. Similarly, three (P11, P17, P19) out of the five participants who moved within the narrowest ranges of positions mentioned discomfort related to their heads (Figure 4b, Figure 4e-d) . All of them related the discomfort to inadequate head support. The video recordings of these three participants indicated that two of them had little to no contact with the head restraint (P17, P19) (Figure 4e-d), whereas one of them rested against the restraint with their eyes closed the entire sitting apart from when responding to the questionnaires (P11) (Figure 4b).

Arm Discomfort

One participant who moved within narrowest ranges of positions mentioned arm discomfort (P11, Figure 4b). This participant explained that the arms felt a bit stiff and related the discomfort to a morning workout. No one of the participants who moved within widest ranges of positions mentioned arm discomfort.

Back Discomfort

Three of the participants who moved within widest ranges of positions leaned their upper bodies towards the door on their right-hand side and they also adjusted their posture frequently (P2, P9, P15) during the stationary scenario (Figure 3a-b, Figure 3d). All three reported back discomfort that they associated with fatigue over time. One of them said that the lack of distractions led to increased awareness of their sitting posture, increasing the need to adjust the posture during the stationary scenario (P2, Figure 3a). All of them also mentioned that they were aware of their sitting comfort in the stationary scenario, due to the lack of stimuli. Only one of the participants who moved within the narrowest ranges mentioned back discomfort and associated it with fatigue as well as with a previous back injury (P11, Figure 4b).

Figure 3a. P2 maintained a wide range of positions in the stationary scenario, where they leaned towards the door, having no contact with the head restraint in the stationary scenario.

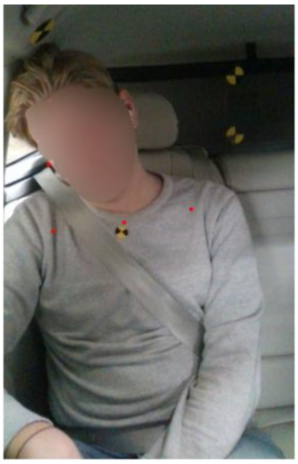

Figure 3b. P9 maintained a wide range of positions in the stationary scenario, where they leaned forward and towards the door, having no contact with the head restraint.

Figure 3c. P14 maintained a wide range of positions in the driven scenario, where they leaned towards the centre seat while holding onto the ceiling handle and engaging in window-gazing.

Figure 3d. P15 maintained a wide range of positions in the stationary scenario, where they leaned towards the door, having no contact with the head restraint.

Figure 3e. P18 maintained a wide range of positions in the stationary scenario, where they had a slumped posture with no contact between the shoulders and seat back, nor between the head and head restraint.

Figure 3. The five participants who moved within the widest ranges of positions in one or both scenarios.

Buttock Discomfort

Three of the participants who moved within narrowest ranges of positions mentioned discomfort in their buttocks (P11, P17, P19), which they associated with a previous inflammation, numbness, and fatigue, respectively (Figure 4b, Figure 4d-e). The video recordings of these three participants indicated that they maintained motionless postures as they were resting or window-gazing. One of the participants who moved within widest ranges of positions mentioned discomfort in the buttocks, associated with keeping a sharp angle between the thighs and the calves, increasing the pressure in buttocks (P18, Figure 3e).

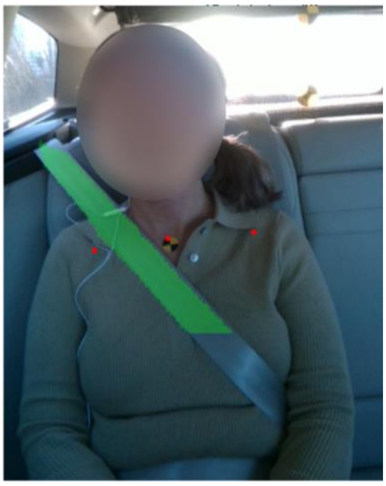

Figure 4a. P10 maintained a narrow range of positions in the driven scenario, where they altered between engaging in window-gazing and resting against the head restraint.

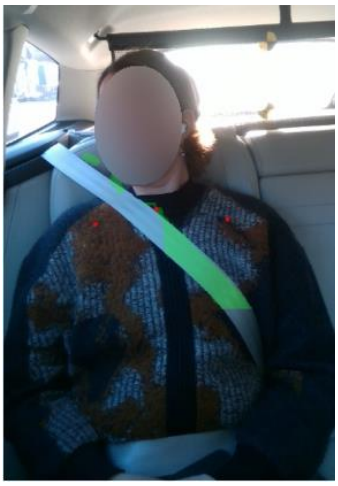

Figure 4b. P11 maintained a narrow range of positions in the driven scenario where they altered between engaging in window-gazing and resting against the head restraint with eyes closed.

Figure 4c. P16 maintained a narrow range of positions in the stationary scenario and kept a still posture while resting against the head restraint with their eyes closed.

Figure 4d. P17 maintained a narrow range of positions in the driven scenario and kept an upright posture with their shoulders in contact with the seat back, while engaging in window-gazing.

Figure 4e. P19 maintained a narrow range of positions in the stationary scenario and kept a still, upright posture with their shoulders in contact with the seat back.

Figure 4. The five participants who moved within the narrowest ranges of positions in one or both scenarios.

Shoulder Belt

Two of the participants who moved within narrowest ranges of positions mentioned discomfort related to the shoulder belt (P16, P19), (Figure 4c, Figure 4e). One of them related the discomfort to that the belt was close to the neck (P16, Figure 4d) and said that the pressure from the shoulder belt was reduced when the back against the head restraint. The other participant (P19, Figure 4e) related the shoulder belt discomfort with increased pressure on the sternum. This participant kept a straight posture with the shoulders against the seat back, showing no signs of a slumped posture. Among the participants who moved within the widest ranges of positions, one mentioned discomfort related to the shoulder belt (P15, Figure 3d) due to an unpleasant feeling as it moved towards the neck.

Lap Belt

One participant (P18, Figure 3e), who moved within widest ranges of positions mentioned discomfort related to the lap belt, associated it with pressure from the lap belt against the hip and abdominal region. No one of the participant who moved within narrow ranges of positions mentioned discomfort related to the lap belt.

Chapter 6: Guidelines on Studies of Sitting Comfort, Postures and Belt Fit in Cars

The findings presented in Paper A and Paper B, and Chapter 5 were merged into guidelines on how to conduct studies of sitting comfort, postures and belt fit in cars.

Study Scenario and Duration

- Stationary studies of 3 min may be suitable for investigate sitting postures and belt fit in early stages of the car seat development process.
- Stationary studies of 15 minutes may be suitable to capture initial discomfort changes.
- Stationary studies of 45 minutes may be suitable to capture additional discomfort changes.
- Stationary studies of 45 minutes may be suitable to capture a wider range of sitting postures. compared to the initial three minutes.
- Driving studies may be suitable to capture variation of seat belt fit, especially among participants with specific body shapes.
- Driving studies may be suitable to capture discomfort related to the seat belt.
- Driving studies may be suitable to capture naturalistic behaviours, corresponding to the real-world usage, as the context may affect the behaviour, in turn influencing their posture and perceived discomfort, but also their emotions and factors related to comfort.

Data Collection Methods

- Questionnaires such as Likert-scales and body discomfort map are suitable for testing pre-defined hypotheses, for example regarding discomfort of different body regions.
- Questionnaires are suitable when investigating *if* any discomfort is perceived and *where* (for which body region).
- Questionnaire responses collected in systematic time intervals within a larger period of time may be suitable for investigating *when* discomfort occurs, and *how* discomfort changes.

- Interviews offer a more comprehensive insight into the individual's rationale, increasing the understanding of questionnaire responses. They are suitable when investigating *what* the perceived discomfort is associated with.
- Interviews offer the possibility for a more explorative approach, where comfort may be explored beyond pre-defined hypothesis. They are suitable when investigating *what* other factors affected their perceived discomfort or comfort experience in general, such as personal preferences and individual rationale, beyond what is covered in questionnaires.

- Video recordings provide objective data suitable for analysing observed sitting postures and belt fit. This data is suitable when describing *which* postures and belt fit were adopted.
- Video recordings provide objective data which may be suitable for comparing observed sitting postures and belt fit over time.
- Video recordings provide objective data of the posture and belt fit, which can complement the questionnaire ratings and be helpful when investigating the postures and belt fit associated with the questionnaire ratings.

Chapter 7: Discussion

This thesis, based on an empirical study of stationary and driven scenarios over time, has yielded valuable guidelines for conducting efficient studies of sitting comfort and postures in cars. These guidelines provide insights into the appropriate study scenarios, durations, and data collection methods tailored to various purposes and stages of car seat development. They serve as a valuable reference for the planning and execution of future car sitting comfort studies.

The study in Paper A addressed RQ1, aiming to compare the effects of stationary and driving scenarios on rear seat passengers' sitting posture and belt fit over time. Comparing the stationary and driven scenarios, no statistically significant differences were found of passengers' average head, upper sternum, or shoulder belt positions. Nor were any statistically significant differences found of the average head, upper sternum, or shoulder belt positions over time in the stationary scenario. For most participants, the average shoulder belt position remained consistent in both scenarios, but for participants with specific body shapes, the shoulder belt tended to move closer the neck in the driven scenario. Average belt, head, and sternum positions showed similarities between the first three minutes and the total 45 minutes of the stationary scenario, but the position ranges were wider over the full 45 minutes. The findings implied the potential of conducting simplified stationary studies when investigating head, upper sternum, and shoulder belt positions, in terms of conducting stationary studies with shorter durations, without the need for complete driving studies. However, longer driving studies are necessary to capture variations for the head and upper sternum positions. When it comes to people with specific body shapes, longer driving studies are also needed to capture variations in shoulder belt positions.

The study in Paper B addressed RQ2, aiming to compare the effects of stationary and driving scenarios on rear seat passengers' sitting comfort and seat belt comfort. No statistically significant differences were observed in the overall sitting discomfort experience between the scenarios, however the overall sitting discomfort increased over time in both scenarios, notably already after 15 minutes. In the stationary scenario, an additional increase in overall discomfort was noted between 15 and 45 minutes.

In both scenarios, physical discomfort was primarily experienced in the back, buttocks, thighs, and feet, with participants adopting slumped postures if they experienced back discomfort over time. In the stationary scenario, the head discomfort increased over time, but not in the driven scenario. This was associated with different contextual factors. The interviews revealed that the absence of stimuli in the stationary scenario resulted in increased self-awareness, tiredness and boredom when compared to the driven scenario. In contrast, in the driven scenario the participants were more likely to engage in activities like window-gazing and adopting more natural postures in response to visual and haptic stimuli.

The overall seat belt discomfort ratings showed no statistically significant differences between the scenarios, nor over time. The driven scenario caused more shoulder belt discomfort, especially for participants with specific body shapes, as the shoulder belt tended to move across the chest and toward the neck during the drive. To conclude, the type of scenario appeared to influence behaviours, psychological and physical comfort factors, as well as shoulder belt discomfort.

Ranges of Positions in Relation to Discomfort Perception

The third research question explored the potential link between the subjective discomfort perception and the objective posture data from the video recordings. By establishing such a link, it could be possible to only use objective video data to describe sitting discomfort in cars. This in turn can lead to less time-consuming studies when evaluating comfort of car seats in the development process. The results from the questionnaires and the interviews indicated that the participants in general perceived low to no sitting discomfort, and that the results were similar regardless of if the participants showed the widest or narrowest ranges of positions.

Head discomfort was related to inadequate head support and mentioned by three of the participants in the group with the narrowest ranges of positions, and by three of the participants in the group with the widest ranges of positions. This can be an indication of that head discomfort occurs regardless of wider or narrower movements. No arm discomfort was found among the participants in the two groups, except for one participant who associated the arm discomfort with a previous workout, which thereby was not related to the range of positions.

A slight difference was observed in back discomfort between the groups. Three participants who moved within the wider ranges of positions mentioned this, compared to only one participant who moved within the narrowest ranges of position, who related the back discomfort to a previous injury. In contrast, buttock discomfort was mentioned by three of the participants who moved within the narrowest ranges of positions, whereas only one participant mentioned buttock discomfort in the other group. These results may suggest that back discomfort was slightly more prominent among participants who moved within the wider ranges of positions, while buttocks discomfort might be more prominent among participants with narrow ranges of movements.

No evidence of increased lap belt discomfort related to range of positions could be found due to the small differences between the groups. Shoulder belt discomfort was mentioned by two of the participants who moved within narrowest ranges of positions, and by one of the participants who moved within the widest ranges. Interestingly though, one of the participants who moved within the narrowest ranges was observed resting against the head restraint during large periods of the test sessions, mentioning that the pressure from the shoulder belt was reduced when adopting this posture. This may indicate a rationale where the participant adopts a certain posture as a strategy to avoid discomfort.

The objective data that was utilised to identify the participants who moved within the widest and narrowest ranges, only comprised data of the upper body. Therefore, the analysis focused on discomfort related to the upper body. Studies of the lower body postures and the associated discomfort related to these body regions are of great interest but require different analysis methods.

It is worth noting that reduced movement, in some cases, was linked to behaviours such as resting or almost falling asleep, rather than feelings of comfort or absence of discomfort. It is also reasonable to consider that increased postural movements or adjustments may serve as a preventive strategy to avoid discomfort, rather than a direct indication of discomfort. Hence, the position ranges in which each participant moves within might instead be related factors such as behaviour or individual rationale for avoiding discomfort.

This study was limited to one vehicle with a spacious rear seat, where the participants in general perceived little or no sitting discomfort. For example, in a smaller car, the sitting discomfort experience may be more pronounced, and then clearer associations might show between the participants' ranges of positions and discomfort. Further, this study focused on objective measurements of movement ranges, while other measurements of movements could be considered, such as the frequency of posture adjustments. Although, a laboratory study found no potential association between subjective discomfort ratings from questionnaires and increased frequency of movement, collected through video recordings (Reed et al., 2020).

To conclude, the findings from this study showed no clear association between movement ranges and comfort perceptions. It is important to emphasise that the sample size should be taken into consideration when generalizing these findings, as each group included five participants each. This limitation was due to the availability of position range data for only 13 of the 19 participants. Further studies are essential to explore the relationship between movement ranges and discomfort experiences, with the aim to determine whether subjective discomfort can be reliably predicted using only objective data retrieved from video recordings.

Guidelines on Studies of Sitting Comfort, Postures and Belt Fit in Cars

This section discusses the provided guidelines found in Chapter 6 on how to conduct empirical studies of sitting comfort and postures in cars, which have been developed based on the analysis on the results presented in Paper A, Paper B and Chapter 5. As the guidelines suggest, indications of the average head, upper sternum, and shoulder belt positions can be obtained from short, stationary studies. However, it is important to consider the physical variations of individuals, especially of people with specific body shapes such as larger chest, pronounced abdominal fat, shorter sitting height, and higher BMI. If the initial observation in a stationary study shows that the shoulder belt is placed close to the neck on an individual, it may be reasonable to assume increased variations of shoulder belt positions over time during drive. When applicable in the car seat development process, it is therefore necessary to conduct longer driving studies to investigate the movement ranges, as well as to detect variations in shoulder belt positions over time, especially to capture shoulder belt movements of individuals with specific body shapes.

Furthermore, collecting questionnaire data in systematic time intervals over an extended period may be suitable for investigating *when* discomfort occurs, and *how* discomfort may change over time. However, collecting subjective responses with short intervals may increase the participants' awareness and prompt them to be more attentive and critical of their comfort perception. Yet, this method could be useful in the car seat development process, as it may accelerate detection of discomfort issues in developed concepts.

In early stages of the car seat development process, stationary studies can be conducted to assess discomfort in various body regions and over time, identifying issues associated with fatigue, inadequate support, or physical constraints. Stationary studies of 15 minutes can capture initial changes in overall discomfort, whereas additional changes in discomfort can be captured between 30 and 45 minutes. In later stages of the car seat development process, when driving studies are feasible, they should be conducted to assess a more holistic comfort experience. Driving studies capture discomfort over time, but also more naturalistic behaviours and emotions affecting the overall comfort experience, as well as variations of the seat belt fit. Findings from driving studies correspond better to the comfort experience of the real-world situation. An iterative process, combining stationary studies (with shorter or longer duration) and driven studies, as well as collecting data using mixed-methods will provide multiple perspectives allowing for nuanced results in the car seat development process, as emphasized in previous research (Karlsson & Rosenblad, 1998).

The guidelines presented in this thesis hold potential for a broad range of age groups, encompassing youths, adults, and the elderly. However, when conducting studies involving children, it is reasonable to assume that customized methods that consider their specific needs and maturity levels will be needed, as emphasized by previous studies of children in cars (Jakobsson et al., 2011; Osvalder et al., 2013). Furthermore, the guidelines presented can be applied in studies involving passengers seated in the center of the back seat and in the front seat of a vehicle. These positions offer similar opportunities in terms of activities and sitting postures as in tested in the present study, making the guidelines highly relevant and adaptable. Conversely, when it comes to studies of the driver, the applicability of these guidelines may be limited. Drivers typically face greater physical constraints due to the requirements of steering, operating pedals, and gear shifting. For driver-specific studies, alternative guidelines may be more suitable. Nevertheless, the presented guidelines may be usable for studying new types of seats or interior concepts, such as reclined seats in automated vehicles. An initial stationary study could capture physical discomfort issues of a reclined seat concept, while the driven study could capture the overall sitting comfort experience, influenced by feelings of trust towards the automated vehicle, or motion sickness.

Implications of the Study Method

The methods used in the study presented in Paper A and Paper B have been used in previous studies of sitting comfort in cars. For instance, studies have encompassed video recordings to observe sitting postures and behaviours (Andersson et al., 2010, Jakobsson et al., 2011; Osvalder et al., 2013; Arbogast et al., 2016; Reed, 2020; Reed et al., 2022) and evaluations of perceived comfort has been collected through questionnaire scales and interviews (Osvalder et al., 2013; Bohman et al., 2019). Studies of both sitting postures and comfort experiences have been conducted in stationary scenarios in laboratory settings using mock-ups (Reed et al., 2013, Reed et al., 2016, Bohman et al., 2019; Baker et al., 2021b), as well as in driving studies over time (Jakobsson et al., 2011; Osvalder et al., 2013). This section discusses the implications of the study data methods used in the stationary and driving scenarios over time.

In the study, no unexpected events occurred during the driven scenarios. However, it should be emphasized that driving studies are more uncontrollable compared to stationary studies (Johnson & Baker, 1974). External factors like traffic congestion, weather conditions and the driver's presence may influence the participants' experiences and should be considered when performing driving studies. When it comes to the stationary scenario, a more stimulating environment with more activity than an indoor garage may be assumed to yield more similar behaviour as during a driving study.

When it comes to the duration of the study, a 15-minute break was scheduled between the scenarios to reduce the influence of discomfort from the first scenario. However, a few participants still reported discomfort before their second scenario, suggesting that the break might not fully eliminate discomfort for all participants. Yet, the 15-minute break was considered sufficient in mitigating the influence of physical discomfort, as no overall patterns indicating persistent physical discomfort were observed in the body part discomfort map. Extending the break would increase the test procedure, which already lasted 2.5 hours per participant, and might have reduced the number of participants willing to participate. Further, the results are assumed to apply for sitting up to 45 minutes. Studies of longer sitting durations are however needed to capture discomfort changes beyond 45 minutes, as comfort is a time-dependent experience (Vink & Hallbeck, 2012).

Instructing the participants not to use their phones may have influenced their behaviour as the activity of scrolling on their phones was eliminated. Moreover, they were interrupted twice (after 15 and 30 minutes) to respond to the questionnaires. This may have affected their behaviour and posture, as they placed the questionnaires in their lap while responding, using pen and paper. It may be reasonable to assume that another activity, or not assigning any activity at all, could yield different behaviours and postures.

The mixed-methods approach, comprising collection of video data, questionnaire data and interview data, provided multiple perspectives that contributed to valuable findings of sitting comfort in cars, which is consistent with previous studies using the same type of methods (Osvalder et al., 2013). Video recordings allowed for manual observations of sitting postures and belt fit over time, along with estimations of the head, upper sternum, and belt positions at five frames per second. This enabled a comprehensive analysis of the positions over time and between scenarios, as well as analysis of position ranges in relation to subjective discomfort. The systematic questionnaires assessed the perceived discomfort over time and between scenarios. Lastly, the interviews facilitated a deeper understanding of the participants' perceived discomfort in terms of what the discomfort related to, reasons for adopting specific sitting postures and belt fit and their overall comfort experience.

As the sitting comfort experience is subjective, participants may have different reasons for their questionnaire ratings, such as previous references, expectations, context, and individual rationale (Vink et al., 2005). For instance, participants may adjust their posture or seat belt over time as a strategy to prevent discomfort (Paper B and Chapter 5). Without the video data and interviews, it may be difficult to interpret the discomfort ratings, as they do not provide a description of which sitting posture or belt fit they relate to and the rationale behind the ratings, explaining why discomfort occurs. Consequently, the study confirmed that a combination of video recordings, questionnaires and interviews complemented each other providing more nuanced information, as emphasized in literature (Creswell, 2014).

Chapter 8: Conclusions

This thesis, based on an empirical study conducted in both stationary and driven scenarios over time, has provided valuable guidelines that serve as the foundation for conducting efficient studies on sitting comfort and postures in cars.

The findings demonstrated the potential for conducting simplified studies of sitting postures and belt fit in cars. Shorter, stationary studies of three minutes capture the average posture and belt fit, while longer studies are needed to capture the variations in postures. For people with specific body shapes, longer driving studies are necessary to capture variations in shoulder belt positions.

In addition, the findings revealed that the type of study scenario and the duration influenced the comfort experience. In both scenarios, similar increases in discomfort were captured over time, already after 15 minutes. Discomfort in the back, buttocks, thighs, and feet increased in similar ranges over time in both scenarios. Increased back discomfort over time was associated with participants adopting slumped postures.

Furthermore, the type of scenario influenced the participants' emotions and behaviours which affected the comfort experience. The stationary scenario led to more awareness, boredom, and tiredness due to the lack of haptic and visual stimuli. In contrast, in the driven scenario, the participants moved more naturally and engaged in window-gazing.

Lastly, the findings highlighted the complexity of interpreting posture data in association with discomfort perception. There was no evidence of a direct association between ranges of upper body movements and perceived discomfort. Rather, increased, or reduced movements may occur due to various reasons, such as behaviour (e.g., sleeping or window-gazing) and individual rationale (e.g., strategies to avoid discomfort). Hence, the study confirmed that the combination of video recordings, questionnaires and interviews complemented each other, providing multiple perspectives and nuanced results.

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