Master of Science Thesis

How lateral movement affects front seat passengers

A user study during normal drive in three phases identifying improvement areas

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Master’s thesis in Industrial Design Engineering

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PREFACE

We who conducted this study are Agnes Andersson and Anna Olander, two master students studying Industrial design engineering at Chalmers University of Technology. We have been cooperating with the Safety Centre and Ergonomics department at Volvo Cars, which came up with the idea of the thesis.

We would like to give a special thanks to our two supervisors are Volvo Cars, Katarina Bohman and Pernilla Nurbo, who have been supervising us with great engagement and enthusiasm during the whole process. Furthermore we would like to thank our supervisor and examiner from Chalmers, Anna-Lisa Osvalder at division Design & Human Factors for her supportive supervising.

A person who deserves our gratitude is Tommy Gunderson, the handy man of Volvo Cars who is always there to help with practical issues. Also thanks to Alfons Massey at the Human Centric Lab and Anton Larsson at Autoliv for providing a lot of help with the belt prototype. Furthermore we would like to send thanks to Henrik Thorsén for his help with Catia and Oscar Tanemar for him helping us with testing belt forces.

Lastly we would like to thank all our test participants without whom this thesis would not have been possible.

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ABSTRACT

The development in the car industry is going towards autonomous cars where the border between a driver and a passenger is gradually diminished. In the future the driver will be more similar to a passenger since the driving will be outsourced to the car. There is a knowledge gap regarding the front seat passenger that needs to be filled with information. The passenger does not like the driver keep track of the road or use the steering wheel for support while riding in turns. Therefor they are likely to be more exposed to the lateral acceleration and lateral movement in turns.

The aim of this thesis was to investigate how lateral movement affect the front seat passenger. In order to do this three studies were conducted, including one pre-study to set the knowledge foundation and to find critical user groups and roads. The smaller tests that constituted the pre-study included a lot of driving and collecting velocities, lateral acceleration and estimated lateral movement. Among other things the pre-study resulted in a definition of normal driving in turns and a route for user study one, including interesting turns to investigate. Lastly, it resulted in an evaluation of the parameters affecting lateral movement on the front seat passenger and four parameters were chosen for user study one, body height, BMI, velocity and type of turn.

The result from the pre-study was used to design user study one, a user study including 26 participants with varying heights and BMI traveling in the front seat in a real traffic environment. The subjects were video recorded and interviewed which resulted in both quantitative and subjective data to analyse. The conclusion from user study one was that short people are most exposed to lateral movement in turns and the type of turns that generate the most lateral movement was found to be roundabouts driven in 28 km/h. One unexpected insight was that many of the subjects supported themselves on the mid panel and on the side support which decreased their lateral movement. This was mostly done by tall people which can partly explain why they were exposed to less lateral movement.

User study two focused on a critical user group and velocity, short people riding in 28 km/h, with 14 participants. The aim of this user study was to investigate how lateral movement of the front seat passenger is affected by road awareness, the ability to use support from the middle and side panels and lastly to evaluate a pre-pretensioning belt concept with the purpose to decrease lateral movement. This test was executed on a test route to ensure repeatability and efficiency. The subjects got assignments to do while riding in the turn to decrease their road awareness and take away the ability to support themselves on the side panels. During the test the subjects were also exposed to a tension belt during some of the turns to investigate their attitude towards it and whether it decreases lateral movement. The assignments did not increase lateral movement but most subjects did not appreciate doing activities while turning. None of the pre-pretensioning belts decreased lateral movement and the subject's attitudes towards them were scattered.

The study concluded in that lateral movement does sometimes result in non-optimal body positions but does not decrease the ride comfort during normal drive. If the passenger is doing an activity while riding in a turn, lateral movement decreases comfort and execution efficiency, something that needs to be further investigated in future studies to ensure high ride comfort for drivers of autonomous cars. There is a vast amount of ways to decrease lateral movement without decreasing velocity and only one was tested in this study. If the tension belt is to be further investigated, a stronger force should be applied and it is important that it is optional to use, since the experience of it is highly individual.

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INTRODUCTION

The introduction gives a background to the study and includes the aim, research questions and delimitations.

1.1 Background

Cars of today are developed with a high degree of security for the occupant. For many years protective steel frames, seat belts and airbags have been developed to reduce injuries in the event of a crash (Kent & Forman, 2014). Volvo Cars is a brand known for safety thinking and development of safe cars, amongst other things thanks to the invention of the three-point safety belt in 1959 (Volvo Cars, 2019). In the car industry the work with safety can be parted into two groups; (1) active safety and (2) passive safety. Active safety refers to systems in the car that alert or inform the driver to prevent an accident and passive safety refers to systems incorporated in the car that take action in case of a crash (Chens et al., 2011). Due to this extensive safety work, the occupants in the car are well protected if seated correctly in their seats with an optimal position in relation to the seatbelt and seat.

There have been studies made on children, seated in the rear seat, during evasive manoeuvres related to a pre-crash situation. One study carried out by Bohman et al. (2011) aimed at quantifying lateral movement of child occupants and seatbelt position relative to the child's shoulder comparing tall children on booster cushion (BC), short children on BC and short children on booster cushion with high back (BCHB). The main findings from this study was that short children on BC had a higher exposure to belt positions where the shoulder belt was off shoulder while the belt stayed on shoulder for both short children on BCHB and tall children on BC. From this Bohman et al. (2011) concluded that the length of the occupant and initial sitting posture are important factors for how much lateral movement an occupant is exposed to during evasive manoeuvres. Another study performed by Baker et al. (2018) investigated how children interact with the seat belt during evasive steering manoeuvres. They found that the initial seat belt position on the shoulder depended on the stature of the child but also weather a BC was used or not. Children with a low degree of initial seatbelt contact moved more laterally and had a seatbelt position near the shoulder edge or off shoulder. It could also be seen that children with a higher degree of initial belt contact moved less laterally and the seat belt moved less on the shoulder.

Combining the insights from Bohman et al. (2011) and Baker et al. (2018) it can be stated that the initial belt position in combination with the stature have the largest effect on shoulder seatbelt position and the exposure of lateral movement on children seated in the rear seat. However, as Tarriere (1995) states, the body of an adult is different from a child body, as it has higher mass and different proportions.

There have also been studies on adults in the front seat during crash avoidance manoeuvres. Reed et al. (2018) investigated the lateral and forward movement of the head in different evasive manoeuvres. They found that BMI and stature affect the lateral head movement and that age can affect the forward movement while gender did not have any affect. Seeing as this study investigated evasive manoeuvres it might be of interest to look at other types of manoeuvres than the most extreme. Is there any occurrence of non-optimal passenger position when it comes to torso position, head position or belt position during regular driving and what happens with the passenger in the front passenger seat? All this generates a knowledge gap regarding what happens with a grown person's position when exposed to lateral movement during normal drive and is therefore in need of investigation.

During drive the passenger is exposed to lateral and longitude accelerations as the car drives through different turns and accelerates on to highways. What happens with the occupant's position, is there any cases where the occupants might be exposed to non-optimal seating position both in relation to seat and seatbelt? The driver is aware of how the road condition changes, is prepared when steering manoeuvres are required and has a steering wheel to hold on to, to support themselves and preserve a good position. Looking at the passenger on the other hand, full road awareness cannot be expected at all times and steering manoeuvres could provoke a non-optimal seat position. So what is known about movement and its' effect on the front seat passengers today?

Another aspect that needs to be taken into consideration is the continuous development of autonomous cars. As described by Maurer et al. (2016), automated technologies have been incorporated into cars for decades, inventions such as lane departure warning systems and adaptive cruise control setting the tone of development. They further state that the continuous increase of information and communication technologies will likely boost the development of autonomous drive (AD) vehicles. The future of AD will totally redefine what it means to be a driver meaning that the limit between what a driver is and what a passenger is will continuously dissolve. As it is today the driver has a lot of things to keep them seated in a good position, as mentioned above, that the passenger doesn't have. For example the driver has a steering wheel that provide support on curvy road sections. They also have continuous high road awareness. Both of these aspects speaks for the case that a passenger likely will be affected more by lateral movement. The knowledgebase of the behaviour of the driver is extensive. Since the driver has been in focus for so long, the passenger has been left in a somewhat grey area. In order to develop the cars of tomorrow a greater understanding for the front seat passenger is needed, this study aims to fill this information gap.

1.2 Aim

The aim of this thesis is to evaluate the effects of lateral movement on the front seat passenger in terms of shoulder belt position, head position, comfort and perceived safety. To support this aim a number of research questions have been formulated as follows;

- How does lateral movement affect shoulder belt position and head position?
- How does lateral movement affect ride-, belt- and seat-comfort?
- How does lateral movement affect passengers' perception of safety?
- Are there any aspects connected to lateral movement on front seat passengers?
- How can the possible aspects and the ride of the front passenger be improved without compromising belt position, head position, comfort and perceived safety?

1.3 Deliverables

To reach the aim data was collected and quantified via user studies on front seat passengers during normal drive. Quantitative data was collected by measuring lateral movement of passengers, shoulder belt position and passenger head position. Qualitative data was collected with interviews during the user tests to evaluate perceived comfort and safety. The data collection was done in three separate studies that are based on each other; pre-study, user study one and user study two. Each study generated the following deliverables;

Pre-Study

- Define normal drive
- Identify velocities and types of turns that generate lateral movement on front seat passengers
- Identify and select parameters to investigate in user study one

User study one

- Define how the critical parameters affect;
    - shoulder belt position
    - passenger head position
    - perceived comfort
    - perceived safety
- Answer the question whether there is an issue with lateral movement in terms of shoulder belt position, passenger head position, perceived- comfort or safety

User study two

- Define how lack of arm support effect passenger lateral movement
- Define how adding assignments affect acceptance of lateral movement
- Define how belt tension effect the passengers lateral movement

1.4 Delimitations

First, the study only focused on the front seat passenger. More specific the passengers was adults, excluding elderly and people with impairments. One reason for excluding children, elderly and people with impairments was that for a novel study with in an area it is natural to look at the most common cases before widening the knowledge base with other cases. The subjects for this study was Volvo Cars employees.

The setting where the study was performed was limited to normal drive in Sweden, in this case meaning driving on regular roads with normal drive style excluding evasive manoeuvres. The first study was performed on public roads outside of Volvo Cars Torslanda and the second study was performed on a test track at Volvo Cars Torslanda. The tests were performed using a Volvo S90 T5 with a non-ventilating SPA seat. Only the upper body (torso, head and shoulder belt) was considered when evaluating passenger lateral movement. This means that legs, pelvis and lap belt will be excluded from this study.

1.5 Report outline- description of report structure

This report constitutes of a chapter with theory and terminology, three studies (pre-study, user study one, user study two) in one chapter each and lastly discussion and conclusion. Each study has a method, result, discussion and conclusion since each study is separate even though they build on each other. The first study, the pre-study is divided in chapters with separate methods and results. There is though one discussion and conclusion for the whole pre-study.

THEORY AND THERMONOLOGY

In the following chapter theory and terminology that has been used throughout the study will be presented. Comfort, restraint systems in cars and normal drive are topics that was investigated.

2.1 Comfort and discomfort

When talking about comfort it is crucial to also talk about discomfort. Since comfort and discomfort are bearing concepts for this project it is important to come to turns with what the concepts mean. According to Looze et al. (2003) the concepts are still under debate but some things can be stated. Comfort can be seen as a personal, subjectively-defined construct. It is something that the subject perceive as a reaction to their environment, subjectively defined by personal nature (Looze, et al. 2003). According to a study made by Zhang et al. (1996) subjects describe comfort with feelings like relaxation and well-being. The same study indicated that discomfort was described by subjects with feelings like pain, tiredness, soreness and numbness which would be inflicted by biomechanical factors. These indications have later been confirmed in a study by Helander and Zhang (1997). Another interesting finding from the study by Helander and Zhang (1997) was that low scores on discomfort could be associated with a full spectra of scores on the rated comfort. High scores on discomfort on the other hand generated a steep decrease on comfort scores. This would imply that discomfort are higher up in the hierarchy and has a greater impact on the subject. As Helander and Zhang (1997) describe it, discomfort has a dominant effect in the perception of comfort/discomfort.

Due to the different natures of comfort and discomfort they should not be measured using the same scales (Helander, 2003). Another important aspect to keep in mind is that, as mentioned by Hägg et al. (2015), comfort and discomfort are not static states but can vary over time. They further state that an experience of instant comfort does not exclude the possibility of perceived discomfort later on and that there is a difference between comfort during a longer time and instant comfort.

2.2 Restraint systems in cars

Together with the air bag and car deformation, the seat belt is a central part of the cars passive safety system according to Kent and Forman (2014), Kahane (2000) and Glassbrenner and Starnes (2009). They all agree that the belt alone saves thousands of lives in car crashes each year.

Kent and Forman (2014) describe the basic idea with the passive safety system in the car as reducing the occupant's kinetic energy as much as possible before hitting the car interior. All parts of the safety system contribute to this in different ways. A lot of kinetic energy is absorbed by the car front deformation. The seat belt and the air bag collaborate in applying force on the occupant. The main point with the belt is to apply as much force as possible on the occupant, without causing injury, during an as long period of time as possible to decelerate the occupant before hitting the car interior. This decreases injuries and fatality in car crashes. Therefor the distance between the occupant and the car interior is of high importance. In order to maximize the applied force without causing injuries it is important that the force is applied on an as big area as possible and on strong structures, like the pelvis, shoulder, chest and other skeleton parts. (Kent & Forman, 2014)

The positive effects of the seat belt are though dependant on the belt position, both to steer the movement and to make sure that the force is applied on strong structures (Kent & Forman, 2014; Fong et al. 2015). During a crash it is important that the hip does not move downwards, since that increases the risk of pelvis rotation and belt slide off. The torso should have a forward, vertical orientation to make sure that the force is applied on the shoulder (Kent & Forman, 2014). According to Fong et al. (2015) dispositioning of the belt can occur by either a mismatch between the occupant's anthropometric data and the belt geometries or deliberate miss use by the occupant. If the occupants experience discomfort they risk putting the belt in a misposition like under the armpit or behind the back. Fong et al. (2015) further define optimal belt fit as the belt positioned on the middle of the shoulder and non-optimal belt fit as off-shoulder position, across the top of the shoulder or in contact with the neck.

In rear-end crashes the head restraint plays a vital role when avoiding whiplash injury (Jakobsson, 2004). An important factor is the head rotation that significantly increases the risk of head injury (Sturzenegger et al., 1994; Jakobsson et al., 1994; Silverbåge-Carlsson et al., 2003).

2.3 Speed limits

Drivers have to follow the prevailing traffic rules depending on geographical location. What rules and laws that apply varies between countries but the laws in Sweden are concordant to many other countries due to the UN convention form 1968 (Transportstyrelsen, 2019). When it comes to speed regulations it is the ones responsible for the road that decide the speed limit. In Sweden the national Trafikförordningen (1998:1276) decides and describes whom is responsible for what road. It is the county that sets the speed limit for all roads within a densely packed living area and the county government that decides the limits on roads outside densely packed living areas (Transportstyrelsen, 2019). Although different institutions care for the speed limits for different roads there are some overall regulations that follow. The base speed limit is an overall concept that is valid when no speed limit signs are present. The base speed limit for a densely packed living area is 50 km/h and outside of a densely packed living area it is 70km/h. On highways the base speed limit is 110 km/h (Korkortskolan, 2019; Korkortonline, 2019).

2.3 Method theory

In the following section the theory of the methods used for collecting and analysing data will be described. The pros and cons with the methods will be described as well as their typical use situation.

2.3.1 Data collection methods

A big part of the study is to collect data, which can be done in various different ways. The methods used in this study will be described here.

Literature study

A literature study is described by Osvalder et al. (2010) as a way of getting background information for a study. The aim with the literature study can be to get an overview of the present information status within the field. The information can be found by searching in for example databases, on the internet, published articles and books.

Objective and subjective data

Collected data can be either objective or subjective depending on how it was collected. Objective data is typically some sort of direct measurements. It can also be collected via observations of for example how many times a test person does a certain action. Objective data takes no account of what the user is experiencing, feeling or thinking. (Osvalder et al, 2010)

When the person in the system is assessing their experience the result is subjective data. Their assessment can for example be about their comfort or body strain. What defines the data as subjective is that it comes directly from the user either in verbal or written form. As a contrast to objective data that is specific, subjective data gives an image of the usage situation as a whole. (Osvalder et al, 2010)

Test subjects

When choosing subjects for a test there are a qualitative dimension and a quantitative dimension to consider. Within the qualitative dimension the choice of subjects can be either statistic or theoretical and representative or critical. A statistic selection of subjects mean choosing them randomly while a theoretical selection means choosing people based on certain important attributes. Choosing representative subjects entails a smaller group of people that can represent the whole user group and they can be either statistically or theoretically chosen. A critical selection can only be theoretical since it means choosing people within the user group that have more needs. The idea is that if the needs of this critical group are met, then the needs of all users will be met. (Kottler, 1994)

The quantitative dimension handles the amount of subjects. As many subjects as possible is the best way to make sure that all user needs are found but the general idea is to have enough people to be able to say that the result is statistically significant. If the goal is to compare two groups of people, a big enough amount of people is needed from each group that is to be compared. There are many opinions on how many people that are needed. Nielsen (1994) state that 6-7 subjects is enough for a qualitative usability test, while for a quantitative test more subjects are needed. According to Virzi (1992) and Lewis (1994) 12-20 subjects give a good statistic base of information.

Semi structured interviews

Interviews are a typical example of a method that results in subjective data since the person in the system gives their opinion. Interviews can be either structured, semi structured or unstructured. What type to choose depends of what kind of information the interview aims to result in. Semi structured interviews are as the name implies a mix between a structured and an unstructured interview. Like a structured interview it involves predefined questions that are asked but instead of following a certain order the interviewer can choose to alternate between the questions. Just like in a structured interview follow up questions can be used to capture attitudes, emotions and reasons for opinions. The result of such an interview can thus be both qualitative and quantitative since it involves predefined questions but the order can be alternated and follow up questions can be asked. (Osvalder, Rose & Karlsson, 2010). The interviewer can ask question verbally but can also use scales or written questions giving the subject room to think for themselves before discussing how they answered.

When using a semi structured interview method probing can be used which is an interview technique that stimulates the interviews to talk and express their feelings. The technique is to follow up their answers and get them to give away more information than in their first answer. (Eigidus, 2016)

Semantic differential scales

A semantic differential scale is according to Bradley and Lang (1994) an acknowledged method to use to elicit attitudes towards concepts, products situations or similar. It was created by Mehrabian and Russell (1974) and the original version has 18 bipolar adjective pairs and a 9 point rating scale. The results of the scale can be translated in to pleasure, arousal and dominance.

Observations

Observation is an objective method that aims to collect information about how people behave in different situations of interest (Kylén, 2004). According to Osvalder et al. (2010) observations give understanding of a user situation without effecting it. They describe further that observations can provide information about the users that the users themselves might not be aware of. The actual user behaviour in the investigated scenario. However observations can’t be used to understand the users’ attitudes and emotions towards certain situations. The observation can be documented either by writing, photographing or video recording and can give both qualitative and quantitative results.

When an observation is done in the natural context, it is direct. The opposite is called indirect and is executed in an artificial environment. Observations in the real environment are often done in the beginning of a product development process while a constructed situation is used for detailed knowledge within a certain area. Furthermore observations can be systematically structured which means that they have a specified schedule that is being followed. This kind of observation is often used later in the development process when interesting events and data is known beforehand. (Osvalder et al., 2010)

An observation can also be direct or indirect in terms of the observer's degree of participation. In an indirect observation the observer is not present in the system and the situation is observed afterwards via for example discreet cameras. When the observation is direct the observer is present in the context and is observing with senses. (Osvalder et al., 2010)

2.3.2 Analysing methods

KJ-method

The method is according to Spool (2004) a way to arrange detailed information in to areas and themes. It can be executed by one person but is preferably executed by a group. Ideas, quotations and other types of information is then written down on separate notes and arranged in to categories depending on their content. This creates a mapping of the main opinions of the subjects and a mapping of the content pf all of the collected data. The method is often used to analyse transcripts from unstructured or semi structured interviews.

2.3.3 Design methods

The design process

A design process is a series of steps with activities with the goal to succeed with a mission, improving a situation. The goal can be to develop something within various areas such as a physical product, an interface or a service. A design process can be iterative which means that it does not follow linear steps but repeats steps in an undefined order. Being process oriented and not solution oriented in a design process is seen as an important trait for designer. It means not stopping at the first idea, but continuing to find alternative solutions. This increases the chance of the optimal solution being found. (Nilsson et al., 2015)

Brainstorming

The goal with brainstorming is to create a big amount of ideas and was developed by Osborn (1967). This method is preferably done in a group with paper and pencils. When taking part in brainstorming, there are certain rules to follow. First of all it is forbidden to criticise, this is not the time to evaluate practical details or negative aspects with ideas. Secondly the participants should aim for crazy or weird ideas, everyone should feel encouraged to come up with crazy and impractical ideas. Thirdly it is encouraged to combine ideas with each other and build on other people's ideas. Lastly, quantity is prioritised before quality; try to come up with as many ideas as possible. During the session it is good to have leader that comes up with themes to brainstorm about and limits the time for each theme. The ideas can be either written or painted. (Nilsson et al., 2015)

PHASE ONE

Pre-study; setting the scope for upcoming studies

The pre-study is an explorative phase of the project that aims to get insights in the field and to find interesting areas within the field to investigate further in user study one.

3.1 Deliverables

The deliverables of this study are as follows;

- Definition of normal drive
- Identify velocities and types of turns that generate lateral movement on front seat passenger
- Identify and select parameters to investigate in user study one

The tests performed in the pre-study are rather unstructured and exploratory, like tests should be in the beginning of the process. The same car was used in all of the following tests, a blue Volvo S90 T5 equipped with a comfort seat. The results will primarily be applicable on this type of car and seat.

3.2 Defining normal drive

3.2.1 Method

It is of high interest to keep this study as natural as possible to find out whether there is an issue with lateral movement or not during a normal drive setting. Therefor it is a necessity to create a definition of what normal drive is, what type of roads, what velocities and what lateral accelerations that should be used throughout the study to be able to say that it was performed during normal drive. Since it is lateral movement that is under investigation for this study it is specifically normal drive in turns that is of interest.

Collect data

To define normal drive in turns a couple of hours of regular driving had to be recorded. The car was equipped with recording devices that logged velocity, lateral acceleration and GPS coordinates were used (figure 1). Four cameras were placed around the occupant, three were mounted on the dashboard while one was placed in the ceiling on the left side of the occupant. The cameras on the dashboard record a straight forward video and two slightly tilted forward videos. The two slightly tilted cameras were one Kinect camera and one real sense camera recording 3D video. The recording equipment called Dewesoft saved all the data in a collected file that could be viewed in a similar way as a movie clip. Four hours of material were collected of the car driving in densely packed living areas, outside of densely packed living areas, and highroad/highway. The four hours were distributed on three separate trips;

- Allingsås to Volvo Torslanda (1h)
- Volvo Torslanda to Hällered (1h 45 min)
- Hällered to Volvo Torslanda (1h 15 min)

These types of roads were chosen after how the base speed limits are defined (korkortskolan, 2019; korkortonline, 2019). So a normal drive setting is defined by driving on roads in densely packed living areas and roads outside densely packed living areas excluding roads with a lot of bumps, grit roads, road with high inclination and super curvaceous roads.

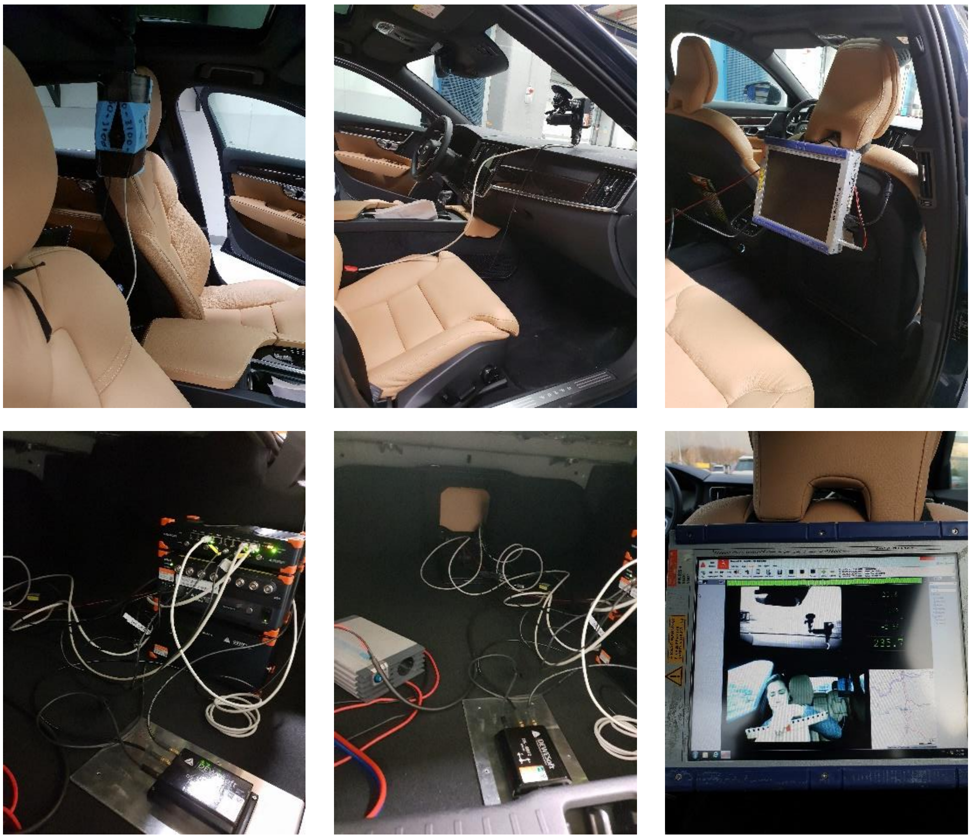


Figure 1 Equipment in test car

Analyse data

To analyse the collected data the recorded file was scanned. With help of the map and its GPS coordinates, turns could be identified. For each identified turn the velocity and lateral acceleration was noted. The acceleration was noted as positive regardless the direction of the turn that generated the acceleration. The position of the car was recorded on a map from where the direction of the turn could be noted. Turns driven in a velocity below 7, 5 km/h was not recorded since it would not generate any lateral movement worth looking into. All of the noted data was then divided into speed intervals. The intervals used were:

- 7,5-17 km/h
- 18-36 km/h
- 37-54 km/h
- 55-72 km/h
- 73-110 km/h

These intervals were selected with the base speed limits in mind, 50 km/h, 70 km/h and 110 km/h, (korkortskolan, 2019; korkortonline, 2019). Due to the fact that densely packed living areas is a rather large concept that speed interval used in these areas were divided into three to make sure that different kinds of roads would be represented. To visualize the data collected each speed interval was plotted as a box plot with the lateral acceleration on the y-axis and the velocity on the x-axis.

3.2.2 Result

The four hour drive generated 154 turns. The distribution of these turns can be seen in table 1.

Table 1 Percentage of velocity spans during the drive

Speed interval	7.5-17 km/h	18-36 km/h	37-54 km/h	55-72 km/h	73-110 km/h
Distribution	13 %	27%	14%	16%	31%

Meaning that most turns occur in the interval 73-110 km/h followed by 18-36 km/h.

Plotting the collected data in a box plot diagram shown in figure 2.

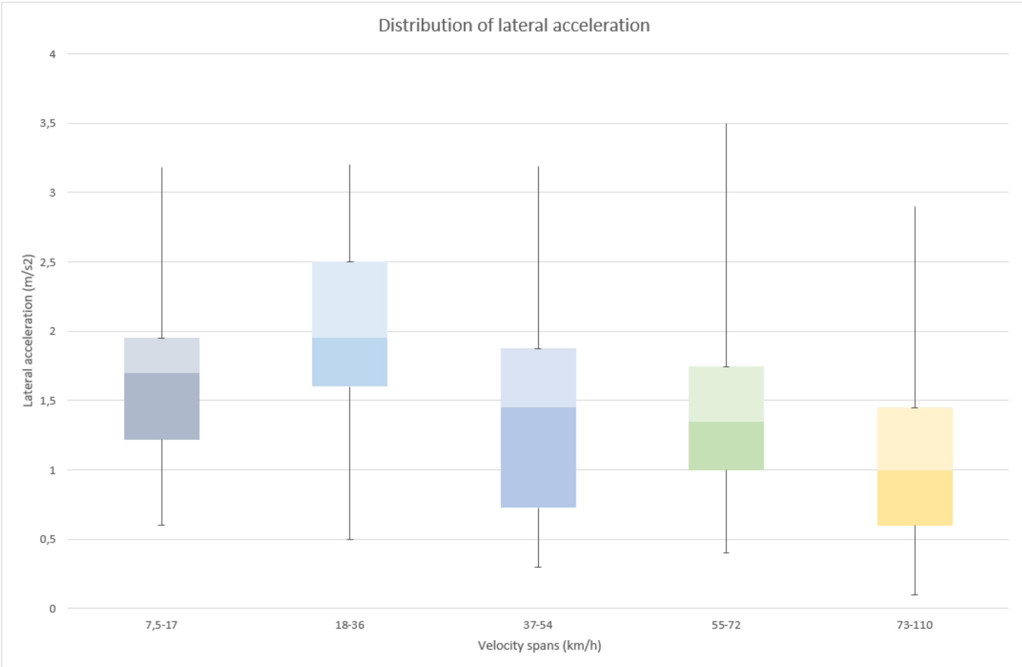


Figure 2. Distribution of lateral acceleration.

In figure 2 it can bees seen that there are cases of lateral acceleration between 0.5-3 m/s^2 present in all speed intervals. However it is clear that the speed interval that frequently generates the highest lateral acceleration is 18-36 km/h while driving in normal conditions. The normal acceleration span for driving in the speed interval 18-36 km/h is 1.5-2.5 m/s^2 but higher accelerations are present.

3.3 Explorative driving 1

3.3.1 Method

In this test the experience of different turns and velocities were tested. The aim was to create an understanding of what the passenger situation is today during normal driving conditions. Looking at the results gathered when defining normal drive it could be found that the velocities 18 – 36 km/h would be the most interesting velocity span. Explorative drive 1 was therefore performed within this speed interval but other velocities were also tested to make sure that no interesting aspects were overlooked. During the test the longitudinal seat position was alternated to see how the altered seat belt geometry affected the lateral movement and the experience of lateral movement. In the first part of the test the passenger had a longitudinal position above the middle and in the second half the position was changed to a position behind the middle, as can be seen in figure 3 and figure 4.

Figure 3 Subject seated above middle

Figure 4 Subject seated behind middle

The test consisted of a 1.5 h unplanned drive in the surroundings of Torslanda (figure 5) with start and end point at Volvo Cars Torslanda PVE. The test was executed in a real environment. Furthermore the test was executed in a direct and unstructured manner, (see section 2.3 observations).

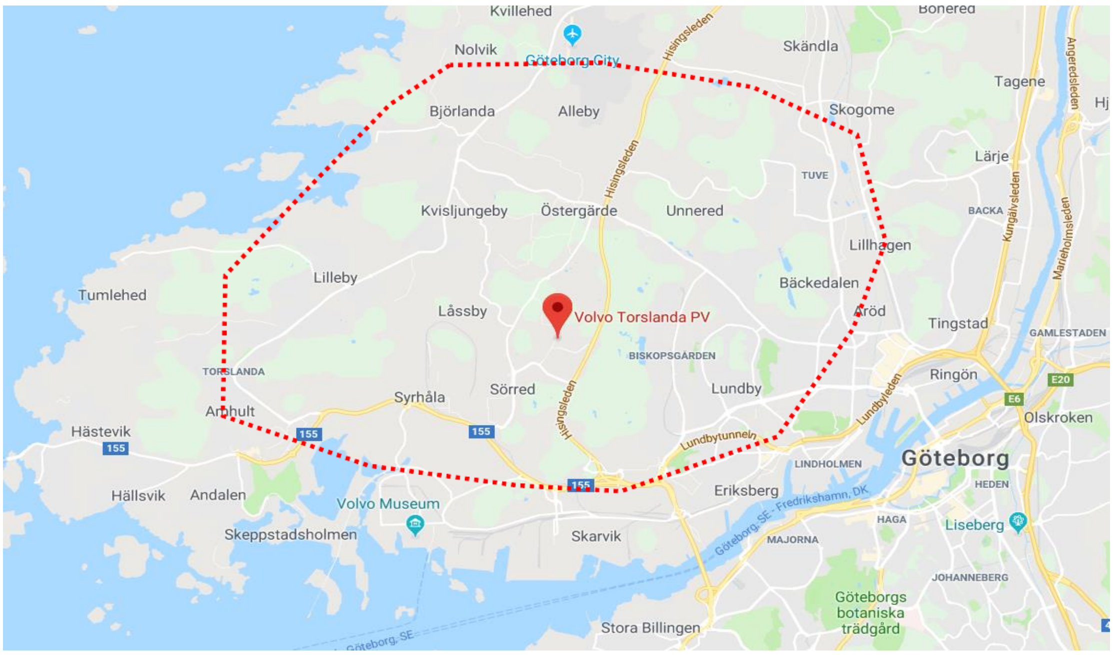


Figure 5 Area where the drive was performed.

In this test there was no camera in the car. The test leader was driving while the subject was seated in the front passenger seat collecting data by taking notes in each turn. The subject recorded the velocities in each turn and how the turn was experienced. Separate forms were used for the different seat positions (Appendix A).

3.3.2 Result

In table 2 the results from explorative driving 1 can be seen. It seems as though all velocities generate some lateral movement and that the belt sometimes got close to the neck. The most movement was detected in the roundabouts driven in 18 – 36 km/h. The difference between the longitude positions is however not as clear. In some of the turns the passenger noted more movement with the backward position than in the forward position but in other turns the movement was the same.

Table 2. Result from explorative driving 1.

Velocity km/h	**Longitudinal seat positon above middle**	**Longitudinal seat position behind middle**
7,2 - 18	10 km/h in left turn, small lateral movement	
18 - 36	Little movement during normal left turn Roundabout, more movement, both body and head movement. First strong right movement, then strong left movement	Roundabout a lot of movement, belt near neck.
36 - 54	Roundabout, seat belt on the neck when in middle of roundabout turning to the left	Soft turns gives more movements in this seat position
54 - 72	Turn in road, felt movement	Turn in road, felt movement

3.4 Explorative driving 2

3.4.1 Method

This test was divided in to two parts, one that focused on velocity and lateral acceleration and the other on lateral acceleration and lateral movement. The aim with the test was to see what velocities gave the highest lateral acceleration. The test started with the presumption that driving on roads with sharp turns and high velocity would generate lateral acceleration. The second part of the test aimed to identify a connection between lateral acceleration and lateral movement on the front seat passenger.

Part 1

The first part of explorative drive 2 started at Volvo Cars Torslanda, went via Björlanda Sport hall and ended at Tuve Sport hall. The test leader was driving and the observer was seated in the rear seat. The observers' task was to observe a screen mounted on the back of the front passenger seat that showed real time data of the cars current state. Data visualized was car GPS coordinates on map, velocity and lateral acceleration. The data was collected from the cars CAN-system via the "testability"-output (output that provides all signals from the car) connected to software called Dewesoft. In each turn the observer noted the following (Appendix B);

- Type of turn (GPS coordinates)
- Velocity
- Lateral acceleration

The noted data provided information on what velocities that gave the highest lateral accelerations.

Part 2

The second part of explorative drive 2 started at Tuve sport hall and ended at Volvo Cars Torslanda. For this part a camera mounted on the dash board recording the front seat passenger with a view straight forward. Like in part one, the test leader was driving, but the observer took on a role as a subject instead and was seated in the front passenger seat. Data collected was;

- Lateral movement of front seat passenger
- Type of turn (GPS coordinates)
- Velocity
- Lateral acceleration

3.4.2 Result

In this section the results from explorative driving 2 will be presented divided in the parts 1 and 2.

Part 1

The results from explorative driving 2 can be found in table 3 and it shows that most of the turns had an acceleration around 2.5 m/s^2. The highest acceleration measured was 3.5 m/s^2, which was measured while driving 30 km/h in a roundabout and a T-crossing. .

Table 3: visualizing the collected data; type of turn, wat velocity that was driven and the lateral acceleration generate. A negative avlue on the acceleration means that it was collected in a left turn.

Type of turn	**Velocity (km/h)**	**Lateral acceleration (m/s^2)**
T crossing right	15	2.5
Round about left	23	-2.5
T crossing left	30	-2.5

Turning road right	70	1.5
Roundabout left	20	-2.5
Roundabout left	30	-3.5
T crossing right	30	3.5

Part 2

One interesting turn was the one seen in picture a) figure 6. The lateral acceleration was 4.48 m/s² and the turn resulted in a lot of lateral movement. Another interesting observation was that when majority of the turn was over and the lateral acceleration decreased to 1.15 m/s^2, the passenger moved a lot in the opposite direction (picture b) figure 6), as if the muscles were still working against the acceleration which created a movement in the opposite directions.

A short while after the turn the passenger continues sitting tilted to the right while the lateral acceleration has increased to 2.61 m/s^2, but in the other direction (figure 6 b)). Another insight was that when the sun was strong it affected the video so that it was difficult to see the passenger and the seat belt. This needs to be considered for the following tests.

Figure 6 a-b. a) Subject outboard movement while exposed to a lateral acceleration of 4, 5 m/s² b) Subject inboard movement while exposed to lateral acceleration of 1, 2 m/s².

3.5 Explorative driving 3

3.5.1 Method

The aim with explorative drive 3 was to identify and test a possible route for user study one. Explorative drives 1 and 2 showed what type of turns and velocities which were of interest to investigate. The results (see 3.2) showed that driving through t-crossings and roundabouts in 18-36 km/h generated the highest lateral acceleration and largest movement. Therefore it is important that the test route include these types of turns. Based on this information a map was used to find a route that included the turns of interest. The identified route was then tested to make sure that it contained what was intended and to see the duration of the route.

The test leader was driving and the subject was seated in the front passenger seat. The data collected was;

- Lateral movement of front seat passenger
- Type of turn (GPS coordinates)
- Velocity
- Lateral acceleration

The route started at Röra byväg, went via Sörredsvägen and Björlandavägen towards Björlandahallen, and back again. The route contains three roundabouts, one T-cross and two obtuse turns (figure 7). Each turn was analysed afterwards. For each turn the point where the largest lateral acceleration was identified. For this point the velocity and a picture of the passenger was noted and collected. An assessment was made on the picture of how much the passenger had moved.

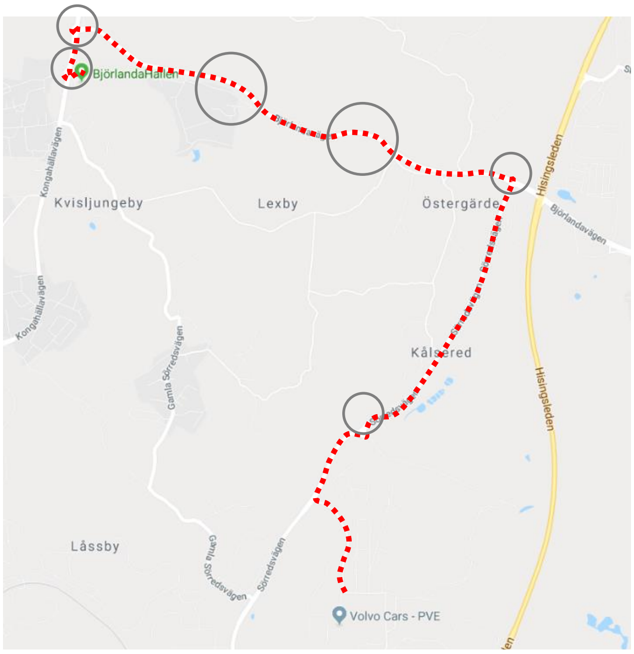


Figure 7 Route for explorative driving 3, circles mark turn of interest

3.5.2 Result

In table 4 the result from explorative driving 3 is presented. According to the result the tested route provided the sought types of turns as well as the correct velocities, meaning that both conditions were met. T-crossings and roundabouts are included in the route and velocities between 18 and 36 km/h were measured. The relevance of the tested route can also be confirmed by the lateral movement assessed from the video footage. The most lateral movement was generated in the second and fourth turn, measuring 25 and 30 mm in both directions. The velocity was through these turns 27 km/h and 22 km/h which is within the span 18-36 km/h. The acceleration was relatively high in all of the turns, measuring between 2.1 and 3.6 m/s^2.

Table 4 results from explorative drive 3.

Turn number	Type of turn	Velocity (km/h)	Acceleration (m/s^2)	Lateral movement (mm)
1	T-crossing without lights, right turn	6	2.1	Movement for other reasons

2	Roundabout left, on the way out	27	3.6	25 both directions
3	T-crossing with lights, left turn, middle of turn	21	2.57	10 both directions
4	Roundabout left, middle of turn	22	2.8	30 both directions
5	Roundabout left	22	2.9	20 right, 30 left

3.6 Seat position and belt wrapping

3.6.1 Method

For this test the seat position parameters effect on the belt wrapping was investigated. Belt wrapping means to what extent the belt surrounds the shoulder of the passenger and likely has big impact on the belt comfort and lateral belt position. The variables investigated on the seat were (figure 8);

- Longitude position
- Seat height
- Backrest recline
- Belt outlet belt position

Hypotheses on how the seat variables would affect wrapping were formulated as follows;

- High seat height will result in high belt wrapping.
- Longitude seat position far back will result in low belt wrapping.
- High backrest recline will result in low belt wrapping.
- High Belt outlet height adjuster will result in low belt wrapping.

Figure 8. Seat parameters investigated

A static test was conducted when the subject was seated in the front passenger seat passenger while the test leader alternated the seat parameter and documented the outcome. A picture was taken on the subjects shoulder for each seat position to document the wrapping. The person being tested was female with the height 1.67 m, sitting height 0.9 m, waist circumference 0.71 m and BMI 20.1.

Table 5 shows the different variable combinations that were investigated. Each parameter had three set points; one upper extreme (UE), one lower extreme (LE) and a middle (M) point. One picture was taken where all parameters were set at their middle point as a reference picture. Two pictures were taken on each parameter one on each extreme point while the other parameters were left untouched in the middle point. The process was then repeated for each parameter, generating a total of 9 pictures including the reference picture. All pictures were then compiled in a table to be able to compare the wrapping degree. An assessment of a wrapping factor (WF) was applied to be able to differentiate the wrapping between the pictures. (1) equals low wrapping and (5) high wrapping. To decide if a variable had a large effect on belt wrapping a delta between the extreme wrapping factors was calculated. A delta (ABS) equal to or larger than three lead to the conclusion that the variable had high effect on belt wrapping.

ABS (WF UE - WF LE) >= 3 → high effect on belt wrapping

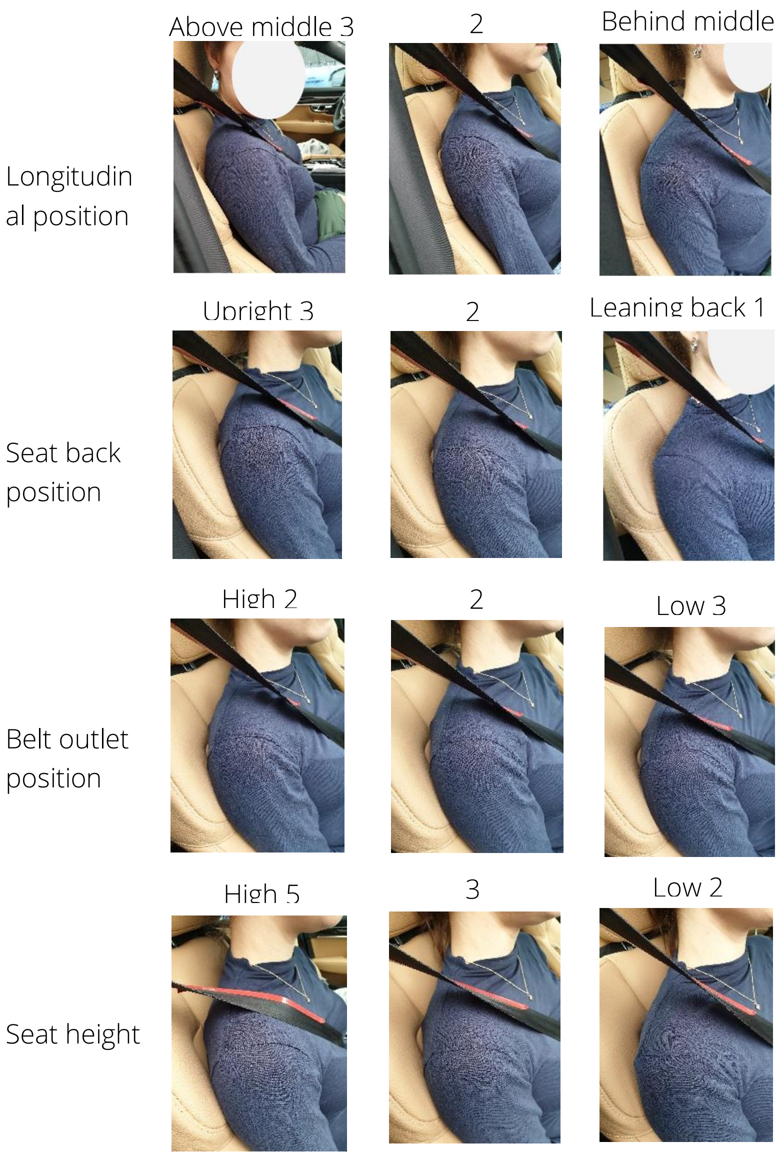
Table 5 A visualization of all 9 seat position combinations that were documented

Seat position	Longitudinal position	Seat height	Backrest recline	Belt outlet belt position
Reference	M	M	M	M
Longitudinal pos.	UE	M	M	M
	LE	M	M	M
Seat height	M	UE	M	M
	M	LE	M	M
Backrest recline	M	M	UE	M
	M	M	LE	M
Belt outlet belt pos.	M	M	M	UE
	M	M	M	LE

3.6.2 Result

In table 6 and 7 the results from the test evaluating the effect of seat parameters and belt wrapping. The pictures are organised in different rows based on the parameter that is being altered. The left column are pictures of the above middle, upright or high positions, the middle column the middle position and the right column the behind middle leaning back or low position.

Table 6. The effect of belt parameters on belt wrapping



Difference
2
2
1
3

Table 7 Difference in belt wrapping

Looking at the pictures in table 7 the biggest difference in wrapping in wrapping is achieved by altering the seat height while the lowest effect on belt wrapping is gotten by the Belt outlet position. The seat heights were asserted as the highest and lowest that are used while the belt outlet position where in the top and the bottom. Both the longitudinal position and the backrest recline angle effect the belt wrapping, but not as much as the seat height.

The same conclusions can be drawn from the rated wrapping degree between 1 and 5 above each picture. The right column where the differences between the highest and lowest wrapping are shown is interesting when finding the most important parameters for belt wrapping. As discussed earlier the lowest difference is generated from the Belt outlet position meaning that it has the lowest effect while the seat height got 3 which is the largest difference. With the results from table 6 and table 7 the hypotheses can be confirmed or dismissed.

- High seat position will result in high belt wrapping.

This hypothesis is confirmed by the result, the picture with high seat position resulted in the most wrapping of all.

- Longitudinal position far back will result in low belt wrapping.

This hypothesis can be confirmed by the picture representing the backward longitudinal position. The belt has no connection with the shoulder.

- Back seat position will result in low belt wrapping.

The picture representing backward recline angle has the least wrapping of all. Therefor the hypothesis can be confirmed.

- High Belt outlet position will result in low belt wrapping.

This hypothesis will be dismissed due to the vague results from altering the Belt outlet. The difference in wrapping is low between the different positions.

3.7 Belt outlet position and belt wrapping

3.7.1 Method

Based on the result from the test of seat position and belt wrapping the Belt outlet height effect on wrapping needed to be further investigated. The aim was to find out if Belt outlet belt position could have a larger impact if other seat variables were altered at the same time. The hypothesis for the test was formulated as follows;

- The Belt outlet position has low overall effect on belt wrapping regardless of the position of other seat position variables.

The same subject was used for this test as the previous. In order to decide if the Belt outlet position has low overall effect on the wrapping degree 12 photos were taken. Two pictures were taken on each variables extreme position, one with high Belt outlet belt position and one with low Belt outlet belt position. The variables were;

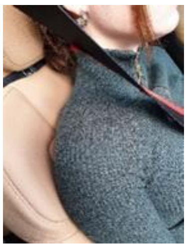
- Longitudinal seat position
- Backrest recline
- Seat height

Working with one variable and Belt outlet belt position, the other two variables were locked in their middle position. The pictures were compiled in a table and an assessment of a wrapping factor (1)-(5) was made. To decide if the variable had a high effect on belt wrapping a delta was calculated in the same manner as the test above.

3.7.2 Result

In table 8 and 9 the results from the test on the effect of the Belt outlet on belt wrapping are presented. The pictures are organized in columns depending on the Belt outlet position and in rows depending on the other parameter alternated.

Table 8

	Belt outlet high	Belt outlet low		Belt outlet high	Belt outlet low
longitudinal position forward			longitudinal position backward		
recline upright			recline backward		

seat height. high

seat height. low

Table 9 Rating of wrapping when wrapping is variated in combination with other parameters.

Seat parameters		**Belt outlet**			**Belt outlet**	
		High	Low		High	Low
Longitudinal position	Above middle	2	3	Bellow middle	1	2
Back seat position	Upright	1	2	Leaning back	3	4
Seat height	High	3	4	Low	2	3

Looking at table 8 and table 9 the belt outlet has low effect on belt wrapping. The difference in wrapping degree between the high and low Belt outlet position (table 9) is 1 for all parameters.

3.8 Seat parameters and belt position

3.8.1 Method

Apart from belt wrapping on shoulder another important factor regarding the belt is the shoulder belt position, both in terms of lateral position on the shoulder and the distance between the belt and upper sternal notch (figure 9). The aim of this test was to determine how the seat position parameters affect lateral shoulder belt position and belt edge distance to neck. Based on the results from the tests made on wrapping the hypothesis was drawn that Belt outlet position will have low effect on belt shoulder position and belt edge distance to neck while longitudinal position, backrest recline and seat height will have higher effect.

The same subject was used as in the previous tests. The subjects was seated in the front passenger seat of the car while the test leader altered the seat variables and documented the results. The method for collecting data is the same as when investigating seat position effect on belt wrapping. The only difference is that the pictures were taken straight in front of the subject instead of on the subjects shoulder.

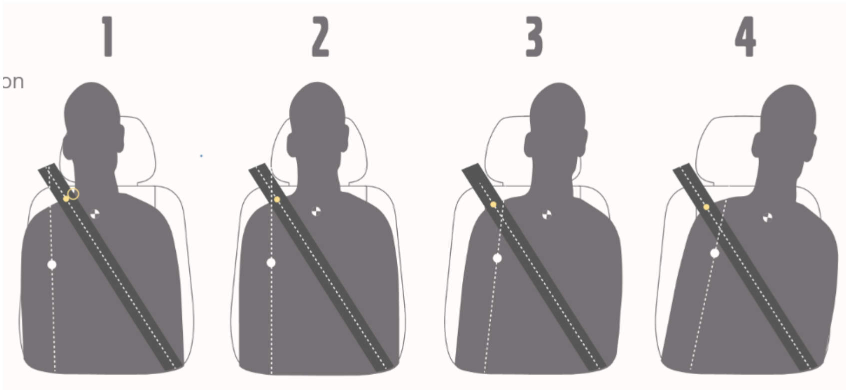


Figure 9 Shoulder belt positions

To determine the shoulder belt position an orange line was drawn on each picture along the right side of the body through the armpit A shoulder belt position factor (SBPF) was assessed where 1 means that the belt touches the subjects neck, 2 means that the shoulder belt midline crosses the shoulder outline between the neck and the orange line, 3 means that the shoulder belt midline crosses the shoulder outline outside the orange line and 4 means that the shoulder belt midline doesn't cross the shoulder outline (Figure 9). To determine the effect each parameter had on the shoulder belt position a SBPF was assigned to each picture and a delta was calculated for each parameter.

Measuring belt edge distance to neck is hard since there is no definite point to measure to. Therefore the decision was made to measure the distance normal to the belt edge to suprasternal notch (Figure 10). Suprasternal notch was selected since it is a point that is easy to locate. The distance from suprasternal notch to the belt edge will here on be referred to as the comfort measure. A circular sticker was placed on the subjects' suprasternal notch to facilitate the analysis. To determine the effect each variable had on the distance between suprasternal notch and the belt edge a delta was calculated for each variable.

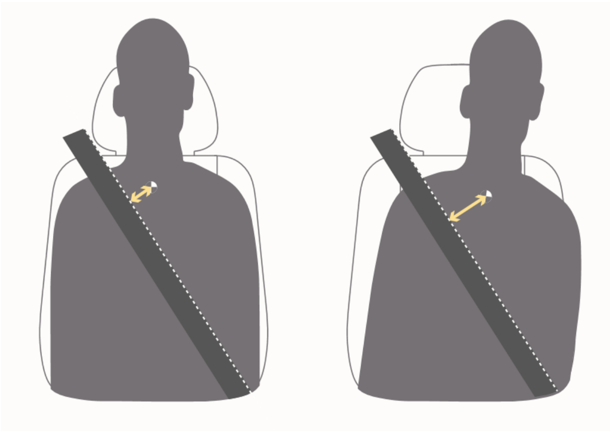


Figure 10 Comfort measure

3.8.2 Result

Longitude max forward

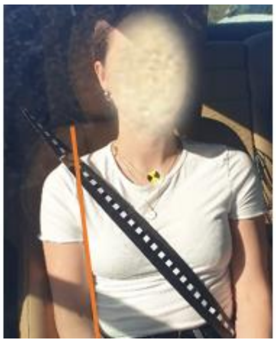
Shoulder placement: 2
Comfort: 35 mm

Longitude max backward

Shoulder placement: 3
Comfort: 55 mm

Delta shoulder position: 1
Delta comfort measure: 20 mm

Longitude seat position has impact on the shoulder belt position and the comfort measure.



Belt outlet max down

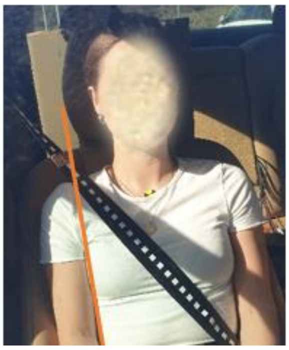
Shoulder placement: 3
Comfort: 73 mm

Belt outlet max up

Shoulder placement: 2
Comfort: 46 mm

Delta shoulder position: 1
Delta comfort measure: 27 mm

The Belt outlet position does effect the belt shoulder position. Of the aspects tested it has the largest impact on the comfort measure.



Height seat max

Shoulder placement: 3
Comfort: 80 mm

Height seat min

Shoulder placement: 2
Comfort: 85 mm

Delta shoulder position: 1
Delta comfort measure: 5 mm

Seat height has an impact on the belt shoulder position as but low impact on the comfort measure.

Back recline max backward

Shoulder placement: 2
Comfort: 50 mm

Back recline max forward

Shoulder placement: 2
Comfort: 60 mm

Delta shoulder position: 0
Delta comfort measure: 10 mm

The backrest recline does only have a slight impact on the shoulder position. It also has a low impact on the comfort measure.

3.9 Choosing parameters

There are a lot of parameters that effect the area under investigation, the aim with this part was to organize these and find the most important to test in user study one. All of these parameters can be found in a compilation in appendix C were they are arranged in groups such as user anthropometrics, user mental ability, seat position and route etc. When planning the first user study on the area all parameters can't be investigated at the same time. The parameters that are most likely to have the largest effect should be chosen for investigation. In the last section some parameters effect were accounted for, in the following section the process for selecting the parameters for user test one will be described.

3.9.1 Method

To sort and select amongst the parameters each one was rated with a factor (1)-(3) of how much they would affect the four categories; lateral movement, belt- and head position, perceived comfort and perceived safety. These factors were then added which gave a value on maximum (12). Each factor was motivated by either engineering judgment, results from the pre-study (see chapter 3) or theory and terminology (see chapter 2). Each parameter that had a factor (3) in either of the four categories or had a total factor of (8) or above were chosen to be seen as the most important (see complete parameter list and factor ranking in appendix C). To look for relationships between the selected parameters hierarchy trees were created. Three hierarchy trees were created; one for belt- and head position, one for perceived safety and one for perceived comfort. The goal with the hierarchy trees were to identify which parameters that would be possible to alter during user test one. By combining these identified parameters with the information gained during the pre-study, the most important would be selected for further investigation.

3.9.2 Result

In this section the hierarchy trees will be presented. In figure 11-13 the hierarchy trees for belt- and head position, perceived comfort and perceived safety can be seen. The parameters at the end of the branches are marked with a lighter blue colour and are called variables, in this case meaning parameters that are not dependant on other parameters. Some of the variables appear on several places so for clarification all are listed once in the light blue box in the bottom. These are the variables that the selection should be made from.

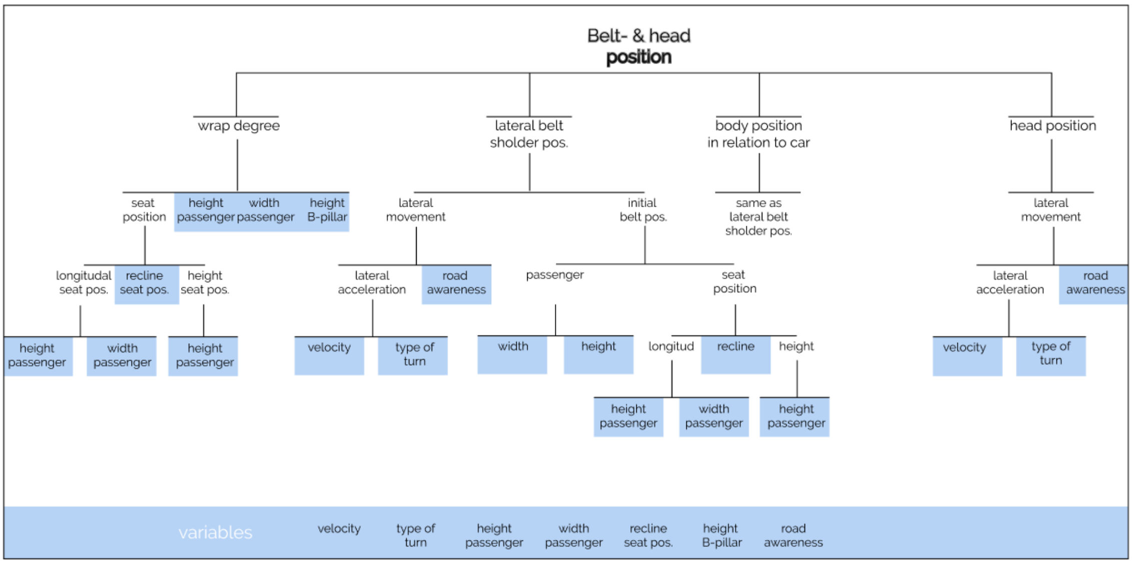


Figure 11. Vizualization of how the parameters effecting belt- and head position depends on each other, the blue box indicates the once that does not depend on another parameter.

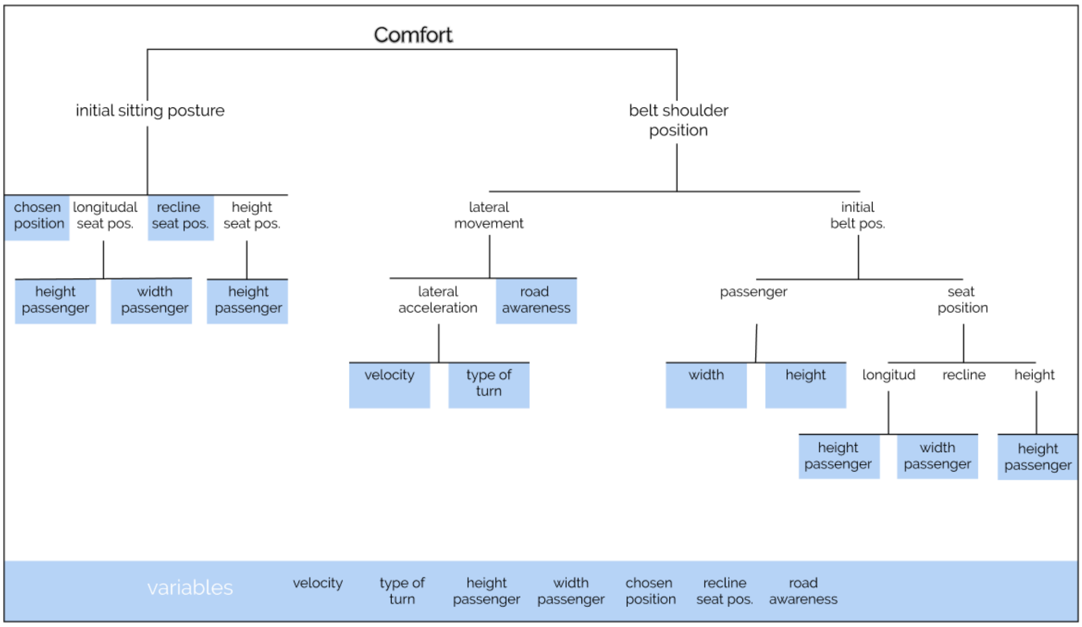


Figure 12 Vizualization of how the parameters effecting perceived comfort depends on each other, the blue box indicates the once that does not depend on another parameter.

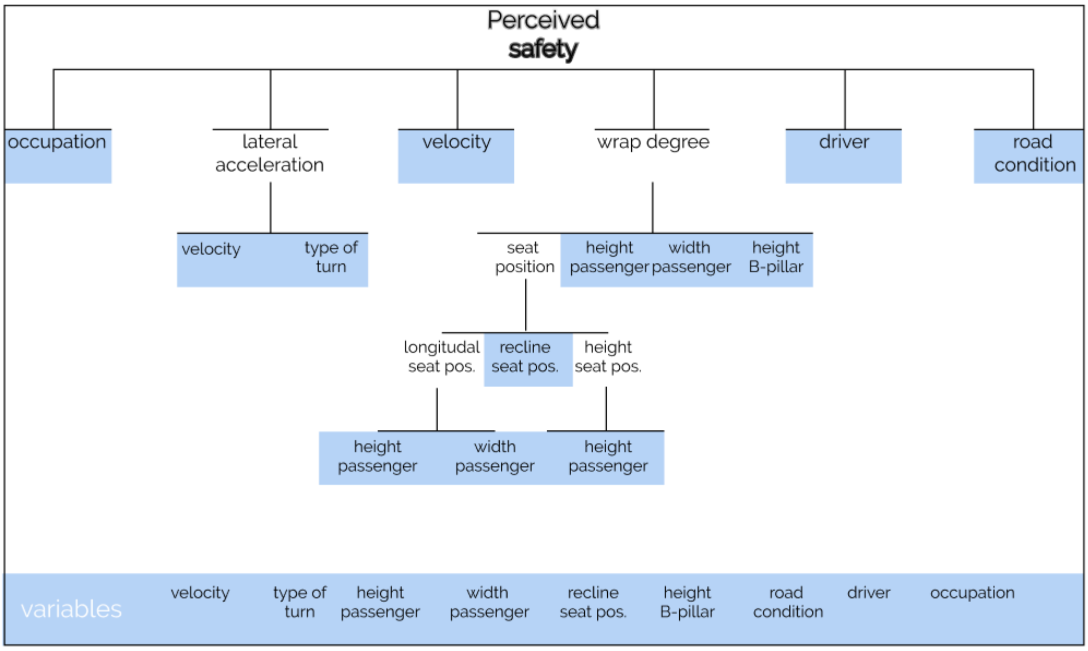


Figure 13 Vizualization of how the parameters effecting perceived safety depends on each other, the blue box indicates the once that does not depend on another parameter.

A decision was made weather each variable should be excluded or included in the first user test with the following motivations.

Velocity & type of turn

The parameters velocity and type of turn were investigated in an explorative manor during the pre-study (chapter 2). The result showed that these have high impact on the lateral movement of a front seat passenger and will therefore be investigated further in user test one.

Body height and BMI

After tests made on seat parameters effect on belt position in chapter two hypothesis were confirmed that the height of the seat and the longitudinal position of the seat would have high effect. Therefor passenger height and BMI are parameters worth investigating to see if the same relationships can be found. It is also of interest to identify if there is a group of people with certain anthropometrics that are exposed to a higher degree of lateral movement.

Height Belt outlet & recline seat position

The two parameters height Belt outlet and recline seat position together with the parameters longitudinal seat position and height seat position can be gathered in the term seat parameters. These parameters will effect initial lateral belt position as well as belt wrapping. They were tested separately in the pre-study. Method, results and analysis can be found in chapter two. Since they have already been tested they will not be investigated in user test one but the knowledge gained will be used in the analysis phase.

Road condition

The test will not be executed during slippery road conditions or during extreme weather situations.

Driver

Different drivers have different driving styles that might colour the perception of both comfort and safety. To eliminate driving style as a variable the same driver will be used throughout the test.

Occupation

A person's occupation might colour a person's perception. To avoid subjects with too much knowledge in the area Volvo employees working with ergonomics, safety or belt design departments will not be allowed to take part in the test. Instead a random selection of Volvo employees will be made to avoid a biased result. Eliminating this risk occupation is not believed to have a high impact on the results and will therefore not be used as a variable in user test one.

Road awareness

Road awareness is believed to have significant impact on the lateral movement since it likely has an impact on how prepared a passenger is in a turn. However, for this first test the awareness will be excluded to be able to focus on the essentials of lateral movement. When a knowledgebase is gathered, it might be of interest in another study to add assignments to vary the road attention. For this test the subjects will have full road awareness (no tasks, just ride along).

3.10 Conclusion

All the tests during the pre-study will be concluded separately in this section, followed by an overall conclusion from the pre-study on what to bring to the next phase.

3.10.1 Defining normal Drive

Velocities between 7.5 km/h and 110 km/h were measured and lateral accelerations between 0.5 and 3.5 m/s^2. The velocities that are most common are 73-110 km/h and 18-36 km/h when driving on regular roads. High lateral acceleration can be found driving within all velocity spans. The span that normally generates high lateral acceleration is 18-36 km/h generating accelerations between 1.5 and 2.5 m/s^2. In the delimitation section normal drive in this study has been described as following the speed limits on public roads, evasive manoeuvres not included. Together with the new information that definition can now be complemented with the speed interval 7.5-110 km/h and lateral acceleration interval 0.5-3.5 m/s^2.

3.10.2 Explorative driving

The aim with the explorative driving was to get a grasp of lateral movement on front seat passengers. One part of this was to determine whether it exists, does passengers move laterally? Furthermore the aim was to find the velocities, accelerations and types of turns that generate the most lateral movement to be able to determine a route for User study one that captures the most interesting situations.

All these questions got answered thanks the explorative expeditions. First of all, lateral movement on front seat passengers does exist but varies in size. This movement is not only in one direction, the passenger actually moves in several directions during each turn. During some of the movement the lateral acceleration is relatively low which means that the lateral movement is not directly proportional to the lateral acceleration. This is something that needs to be taken in to consideration when designing User study one. A decision needs to be made regarding what movement that should be measured for each turn.

The turns and velocities that generate the most lateral movement on the front seat passenger are roundabouts and t-crossings. The most lateral movement is achieved by driving through them in 18-36 km/h, more specifically 30 km/h. The highest lateral acceleration measured was 4.48 m/s^2 and did coincide with large lateral movement but as mentioned earlier lateral acceleration is not a prerequisite for lateral movement. Therefor the acceleration will not affect the choice of test route. The conclusion of this is that roundabouts and t-crosses are critical types of turns, and that the velocity 30 km/h is a critical velocity.

The route between Röra byväg and Björlandahallen includes the interesting turns and velocities and is thereby adequate as a route for User study one. The route ensures that the maximum lateral movement that can be obtained during normal drive will be included in this test.

3.10.3 Seat position and the belt

Thanks to these tests the different seat parameters effect on belt position, comfort measure and belt wrapping is investigated. Wrapping is mostly affected by the seat height while the belt outlet position has negligible effect. The further testing of the belt outlet confirmed that it has low effect, regardless of how it is combined with the other parameters.

Surprisingly the belt outlet positon affects the lateral shoulder belt position and comfort measure the most. The backrest recline has the lowest effect on the lateral belt position and the seat height has the lowest effect on the comfort measure. A parameter like seat height that has high effect on wrapping can thus have low effect on comfort measure. This means that no parameter is the most important for all aspects, but that they are all important in some way.

These insights needs to be thought of when analysing the results from User study one. For example a low belt outlet position increases the likelihood of shoulder belt on shoulder edge belt position (shoulder belt position 3). High seat position results in more wrapping which might be experienced as less comfortable.

As mentioned in the method, assumptions can be made on the effect of body height and BMI on wrapping, belt position and comfort measure based on the information about seat height and longitudinal seat positon. Since seat height turned out to have considerable effect on belt wrapping, the same should be true about body height. Thus, a tall person should have more wrapping than a short person. The longitudinal position turned out to have moderate effect on all three belt aspects, which implies that a person with high BMI should have the same effect. This being that high BMI results in more wrapping and belt closer to shoulder than low BMI. Important to note is that people of different sizes are likely to position their seats differently which means that the combination of anthropometric measures and chosen seat position needs to be considered.

3.10.4 Conclusion pre-study

The pre-study has given valuable insights to be used as a foundation when User study one is to be designed. The definition of normal drive in the whole study is now; driving on a public road in Sweden while following speed limits, evasive manoeuvres are not included, the velocities are 7.5-110 km/h and the lateral accelerations are 0.5-3.5 m/s^2.

Explorative driving showed that the most lateral movement occurs when driving in 30 km/h in a t-crossing or roundabout. The route between Röra byväg and Björlandahallen includes this type of turns and will be used for user study one.

Regarding the seat parameters, the seat height has the highest effect on wrapping while the belt outlet position has the lowest. The belt outlet does on the other have the highest effect on the belt position and comfort measure.

After considering all the variables from the hierarchy trees four final parameters were chosen to be investigated in user test one;

- Velocity
- Type of turn
- Body height passenger
- BMI

04. PHASE TWO

User study one; mapping lateral movement and identifying critical user group

In this chapter the method, results and conclusion from user test one will be presented. The aim of user study one is to identify critical user groups and map when passengers are exposed to the largest lateral movement

4.1 Hypotheses

The following hypothesis were formulated;

- When does the largest lateral movement occur?
- Which group is exposed to the largest lateral movement?
- How does lateral movement affect;
    - Body position?
    - Belt positon?
    - Perceived comfort?
    - Perceived safety?

4.2 Method

The following section contains the methodology that has been used during the second phase of this project. The data collection methods and the analysis methods will be presented separately.

4.2.1 Collection of data

Equipment

The car that was used during user test one was like in the pre-study a Volvo S90 T5 with comfort seat. The seats do not have massage functions or ventilation, but do have seat cushion adjustment. The cushion adjustment was locked during the test in a position that corresponds to a regular standard seat (elongation 1 cm). Again the results are mainly applicable on this type of car and seat. The car compartment was equipped with several technical devises (figure 14, figure 15).

- Two ordinary cameras
- Two 3D cameras (Real sense and Kinect)
- One distance sensor
- One screen
- One PC (Real sense)
- Centimetre tape
- Red electric tape
- Cardboard

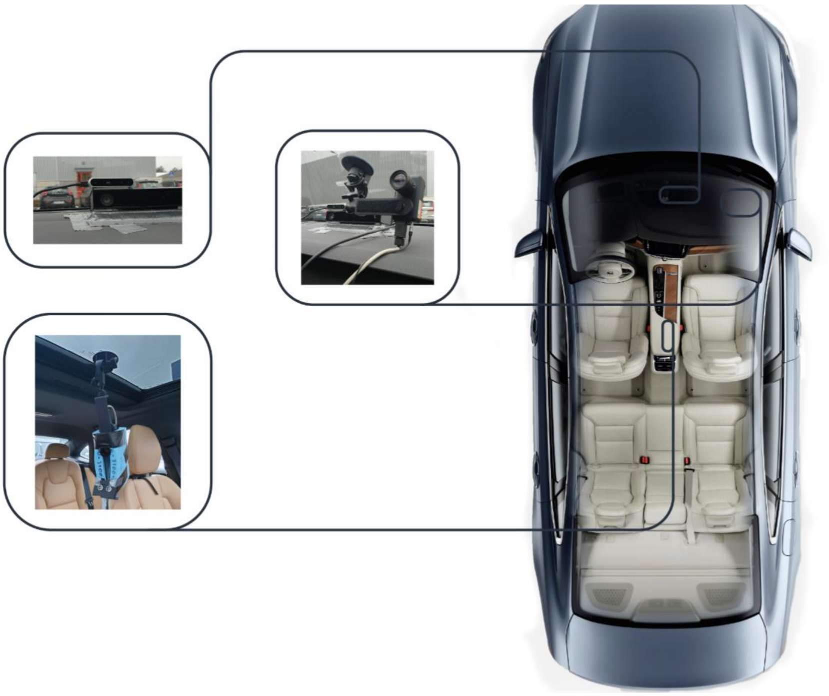


Figure 14 Cameras in the car, front camera, left rear camera, kinect camera, realsense camera

Figure 15 Other equipment one distance sensor, one screen, one PC (Real sense), Dewesoft computer

The ordinary cameras were mounted with goosenecks on windows in the compartment. One on the front window placed straight in front of the passenger seat and one on the roof window with a side view on the front passenger side. The 3D cameras were mounted on top of each other on the middle of the dashboard with duct tape. The distance sensor was mounted with duct tape underneath the camera mounted in the roof. The screen was mounted on the back of the driver seat with buckle straps. All of the cabling was drawn along the middle of the car and fixated with tape to prevent both driver and passenger to get tangled up. The PC was placed on the floor underneath the driver's seat.

Furthermore several markers were placed in the car compartment to enable calculation of seat position and measurement of passenger movement. The seat was marked on several places (figure 16); the bottom rail was provided with a centimetre tape along its side with a red marking to mark the starting position. The sliding part of the rail was also marked with red to indicate how much the chair had been moved. A point under the front part of the seat, a point under the rear part of the seat and a point on the top of the backrest was also indicated with red markings. The seat belt midline was marked with centimetre tape and the middle line of the seat was marked with a piece of cardboard and centimetre tape mounted on the back side of the neck rest on the passenger seat.

Figure 16 marking tape in the car

Other technical equipment found in the car (Figure 15);

- One Dewesoft computer
- One PC (Kinect)
- Cabling
- Two GPS sensors

The Dewesoft computer was fixated with buckle straps in the trunk, the PC was placed on the flooring in the trunk and the acceleration box was fixated with a hook under the floor mat in the trunk. The two GPS pucks were mounted and calibrated on the roof.

To administrate the tests, printed subject survey forms and pencils were at hand. One blue ball pen, and two crayons (green and red).

Subjects

The subjects were chosen among Volvo employees to theoretically represent variations in body height and width. There were 12 short people and 14 tall people and among them 13 had a low BMI and 13 had a high BMI. A tall person is defined by having a body height >175 cm and a person with high BMI has a BMI>25, 5. This amount was chosen since each group needs to consist of at least 12 persons to be able to look at variations between groups (see 3.3.1 subjects). This selection will ensure the possibility to identify statistical significant differences between the tall and short people and the people with low or high BMI. The subjects were not chosen based on age but since they are Volvo employees they are adults between 18 and 65. As a coincidence all short participants of the test were women and all tall participants were men, which led to a 50/50 representation of men and women.

Execution

The subjects were not told what the purpose of the test was, they only knew that it was a collaboration project between Volvo cars safety centre and ergonomics department and they would be front seat passengers during normal drive. In the invitation sent to the subjects they were asked not to wear dark or chunky clothing. They were also asked to wear long hair pulled back, to facilitate the analysis phase of the collected data. The test started in the PVE reception where the subjects were picked up. There they got to sign a GDPR agreement and their weights were collected with an ordinary bathroom scale. Jackets and phones were stored in the back of the car and the subjects were seated in the front seat and were told that they could adjust the seat if they wanted to. The seat was set in a predefined position when the subjects entered the vehicle (figure 17). This position was selected to be as favourable as possible for all subjects. The subjects were equipped with Patrick marks on the suprasternal notch and were then informed about the test procedure.

> *"We will go for a ride during 40 minutes. We will make two short stops for questions and then we will come back here. Your task is to just ride along, think of it as an ordinary shorter car trip with, for example, a colleague."*- Intro of manuscript, the full manuscript can be found in appendix D.

During all 26 tests the same driver was used to make sure that different driving styles would not have an effect on the results of the study. No professional test driver was used, but a regular person with seven years of driving experience. During the test the driver and the subjects take part in a normal conversation, talking about their work, a hobby or similar to simulate a setting as close to a normal car journey as possible.

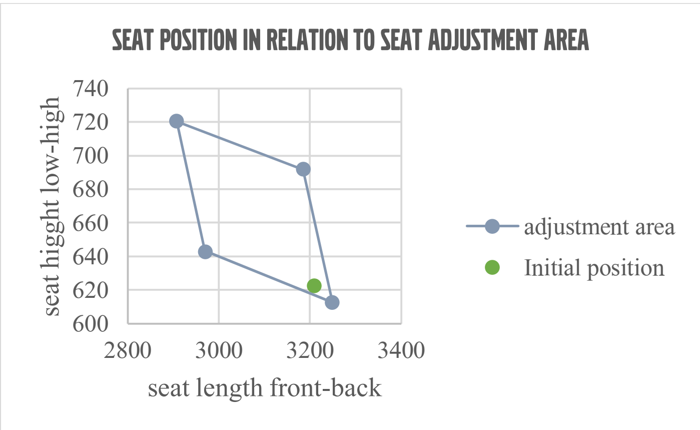


Figure 17 predefined seat position in relation to adjustment area

The selected route went between Volvo PVE and Björlandahallen via three different turns with varying velocities (figure 18). There was a country road with two obtuse turns that were driven in 70 km/h followed by two roundabouts on driven in 20 km/h and the other in 28 km/h both exited via the third exit. At Björlandahallen parking lot the car stopped for the first time. The passenger was asked to fill out a form while being probed by the driver in between each question. The interview consisted of four questions were the subjects were asked to mark with an 'X' on a 10 cm long line to specify how they perceive the overall ride-, seat-, and belt comfort as well as the perceived safety on a scale from "very bad" to "very good". During the interview a drawing of a human silhouette (front and back) was used as a mediating object and the subjects were asked to mark with a red pen areas where they experienced discomfort and a green pen on areas where they experienced comfort, *see appendix E for participant form User study one*. A semi structured interview method was selected to be able to have control over the collected subjective data but still be able to follow up on unpredictable leads that might emerge during the interview (see section 2.3.1). The interview generated both qualitative quotes and quantitative judgements on each of the questions.

Figure 18 Test route with turns in 70, 20 and 28 km/h

After that the car was driven to Tulsegårdsvägen and turns back to Björlandahallen. This means that the car passed through the two roundabouts two more times, first time through the first exit and second time through the third exit again. The second round was done to secure that there were two samples of each turn, in case the velocity was not kept correctly in the first turn. Since the test was performed on regular roads with surrounding traffic, deviations might occur due to other road users and vehicles. Back at Björlandahallen the car stopped for the second time. The subjects were asked to look at the previous form again to discuss their answers. Perhaps the first question round started new thoughts with the subject which need to be collected. Afterwards, the car was driven back to Volvo PVE again passing through the two roundabouts via the first exit and then via the country road with the two obtuse turns. When returning to Volvo PVE a side view picture was taken on the subjects shoulder from the passenger door, to document the belt wrapping.

4.2.2 Analysis

To analyse the collected data from user test one different analysis methods had to be used for the different types of data that was collected. This method section will therefore be divided after data type; quantitative- or qualitative data and whether it is subjective- or objective data.

4.2.2.1 Quantitative objective data analysis

The quantitative objective data was collected with two cameras, one with front view and one with side view. The data that was collected from the video footage included; lateral body movement, lateral head movement and position, belt position on shoulder (before and during turn) and distance from suprasternal notch to belt edge (before and during turn). Two pictures were selected for each of the 12 turns recorded. One picture was selected before entering the turn (an initial position, IP) and the other was selected when maximal movement (MM) was found during the turn. To facilitate the selection of pictures a map visualizing the GPS coordinates was used to identify the turns, the lateral acceleration was used to find the neutral position. A centre line and a marquee on the super sternal notch was used to identify the position with maximal lateral movement.

The selected pictures could then be measured. To convert the measurements from the pictures a scale was created and used for each frame. A known distance of 50mm on each frame was measured, this measurement was then divided by 50 to create the scale factor for that frame. A new scale was created for each frame to minimize errors that might occur due to subject movement.

Lateral body movement

To determine the lateral body movement in each turn the distance from the super sternal notch to the centre line was measured in each picture (figure 19). The notch to the right of the centre line gave a positive value and the marquee to the left of the centre line gave a negative value. The movement was calculated as follows;

Lateral body movement = ABS (MM-NP)

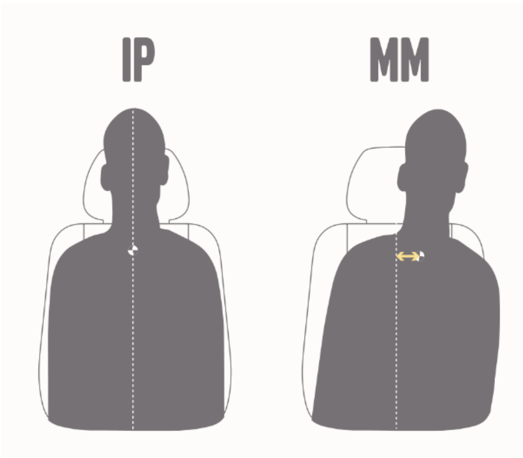


Figure 19 Measuring lateral movement, initial position and maximum movement

This means that lateral body movement equals the absolute of the difference between the maximum movement and the neutral position (figure 19). This procedure was performed on all 12 turns. The 12 turns were then reduced to 6 by selecting one of the two identical turns that had the most accurate velocity. This reduction was done to reduce the amount of measurements needed for the rest of the analysis of the quantitative objective data.

Lateral head movement

To investigate the lateral head movement an assessment was used to determine the head position. Three positions were decided and assigned a head position factor (HPF: 1-3); middle (1), neck rest edge (2) and off (3) (figure 20). HPF (3) is to be considered a non-optimal position. A judgement was made on the two pictures for each of the six turns. The movement was then calculated as follows;

Lateral head movement = ABS (HPF MM-HPF NP)

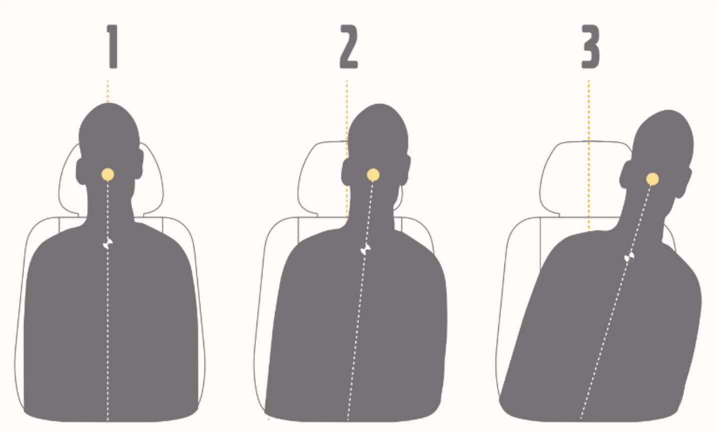


Figure 20 Assessment of head movement in the categories 1, 2 and 3

A compilation of the HPF NP was created visualizing the short vs the tall and the low BMI vs the high BMI in a bar chart. A separate analysis was also made looking for subjects who had HPF (3) in turn and not before turn. This analysis was made to search for anthropometrical patterns that could be the reason to why certain people get HPF (3).

Lateral shoulder belt position

To investigate the belt position on shoulder an assessment was used. Four positions were decided and assigned a belt position factor (BPF: 1-4); near neck (1), middle (2), shoulder edge (3) and off (4) (figure 21). BPF (3) and (4) are to be considered as non-optimal positions. To decide what position a belt had in a frame, help lines were drawn in each frame. One vertical line through the subject's armpit (vertical line-VL) and one line through the middle line of the belt (middle line-ML). If the ML does not cross the shoulder contour it is assigned a BPF (4). If the ML cross the shoulder contour to the left of the VL it is assigned a BPF (3). If the ML cross the shoulder contour to the right of the VL it is assigned a BPF (2). If the belt edge touches the subject's neck it is assigned a BPF (1). An assessment was made on the two pictures for each of the six turns. To indicate if the belt position was effected by lateral movement a delta was calculated as follows;

Delta belt position on shoulder = ABS (BPF MM-BPF NP)

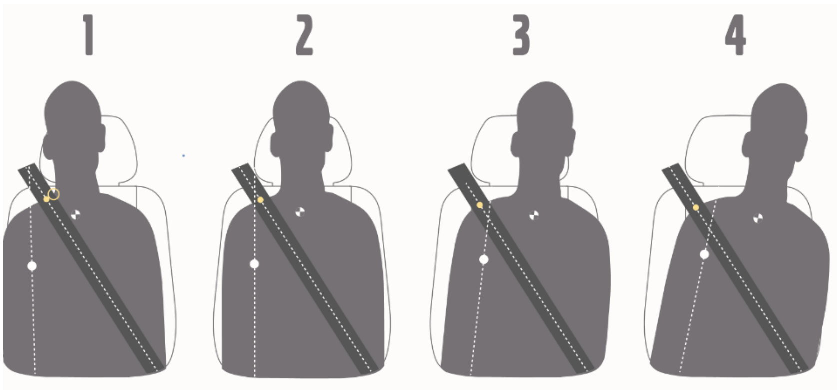


Figure 21 Assessment of shoulder belt position in the categories 1, 2, 3 and 4

To create an understanding of how the belt usually is positioned a bar chart was created that visualized the percentages of each BPF comparing the two sets of groups tall vs short and high BMI vs low BMI. This chart created an indication of which group of people that has the highest occurrence of the critical BPF. A specific analysis was also made on those subjects who had a BPS (3) or (4) in turn but not before. This analysis was made to be able to search for anthropometrical patterns that could be the reason to why certain people get BPF (3) or (4) in turn.

Comfort measure
Eliciting results regarding how the subjects perceive the belt comfort has to be done subjectively. But for this project it was decided to try and do it objectively as well. The hypothesis was made that having the belt edge close to neck would entail inferior belt comfort. To facilitate the measuring of how close the belt is to a subject neck it was decided that the shortest distance from a subject's suprasternal notch to the belt edge (a straight line normal to the belt edge) should be measured and collected.

For this data it is not of interest how the measurement differs depending on velocity and acceleration. Since it has to do with comfort, which is perceived over time (*see section 2.1*), it is of interest how the overall measurement is throughout the whole ride. Therefore the distance is collected in all six NP pictures, then an average was calculated as a representation of the measurement for the whole ride for each person. This measure was then compared with subjective comments, scale ratings, seat position and colour markings to find a connection between comfort measure and perceived comfort.

Seat position
As described earlier the seat was positioned in a predefined start position (figure 17). The subjects were allowed to change the seat position if they wanted to. To be able to document how the subjects sat, four measurement points were selected as described in *5.1.2 Equipment,* apart from the four belt outlet positions. The longitude position of the seat was measured with help of the cm markings on the bottom rail and the marking on the movable part of the rail (figure 22). Three other measures were collected, one from the marquee under the front part of the seat to the flooring of the car, one from the marquee under the rear part of the seat to the flooring and one from the marquee on the top of the backrest to the flooring of the car. These measurements were used to be able to identify the H-point (hip-point) for each test person. The measures were applied to a CATIA V5 model of a Volvo S90, placing the seat in the same position as the subjects. The coordinates for each subject's hip point could then be identified and collected. To be able to visualize how the subjects were seated the H-point for each subject was plotted in a point diagram that also displayed the nominal H-point, seating Reference Point SRP (a standard reference point for the vehicle industry). The adjustment area of the SPA seat was also represented in the diagram. The adjustment area is the area that represents all the possible coordinates for the H-point.

Figure 22 markings on the bottom rail to measure the longitude position

4.2.2.2 Quantitative subjective data analysis
To collect subjective data during user test one a semi structured interview was used. This means that the subjects had to answer both predefined questions and questions used in the moment to probe the user to explain deeper. See section *2.3.1.4* for further information about semi structured interviews. Different analysis methods had to be used to analyse quotes and judgements separately. The following methods were used.

Interview answers KJ

A KJ analysis was used to create an understanding of the subjective data collected during the semi structured interviews. A KJ analysis is performed by taking information form an interview and extract quotes and information that might be of interest. These quotes are then to be written on post-its or similar. The method was chosen since it is an acknowledged method to handle and make sense of subjective data.

To analyse the subjective material gathered during user test one all of the documented material from each test person was scanned. Important quotes and information from each interview was written down on separate post-it. These post-its represent the opinions of the tested population. To bring order in the cluster of information, the post-its' were grouped after relevance and inherence.

Scales

The subjects got to answer four questions with the help of scales as described in section *4.1.1.* To analyse the answers the distance between "very bad" and the subjects mark was measured. To visualise the judgement of the subjects the results were displayed in boxplots. Boxplots were selected since they provide a lot more information that a regular bar charts. A boxplot visualizes the distribution the mean and quartile one and three. Box plots were made comparing the judgement of tall versus short people as well as people with high BMI vs people with low BMI. The distribution visualized in the box plots provided a possibility to easily find values that did not concur with the rest of the population which needed further exploration. If a subject rates below 5 on the scale further investigation on that specific subject should be made.

Human silhouette sketch

The subjects were asked to mark with both green (comfort) and red (discomfort) but for the analysis phase only the red markings were analysed (figure 23). With this method only physical comfort was measured. The decision to only analyse the discomfort markings are based on the fact that comfort and discomfort can't be measured on the same scale as described in section 2.1. To analyse the collected material Adobe illustrator was used where a digital representation of the coloured areas could be created. A base layer of the human silhouette was created in the bottom and then locked. New layers for each subjects were created. On each layer the markings of that person was drawn with a red colour with a colour opacity of 70%. The layer structure provided the possibility to hide and show certain subjects so that the perceived discomfort of different groups (tall vs short and high BMI vs low BMI) could be visualized in different pictures. A colour scale was created to visualize how many subjects' judgements that was needed to reach a certain colour intensity.

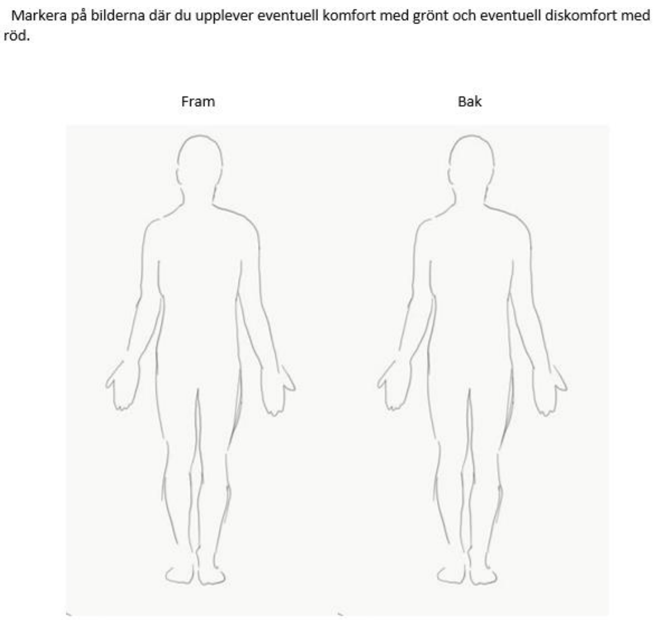


Figure 23 human silhouettes

Qualitative objective data analysis

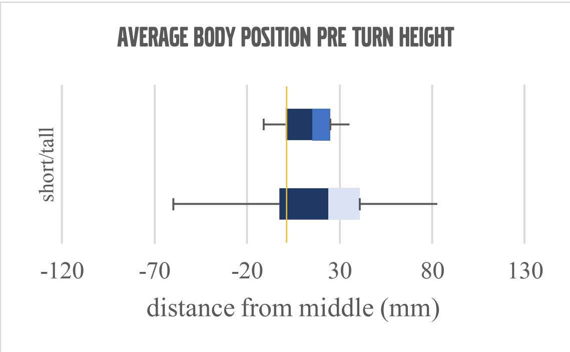
To collect data on the sitting posture direct observations in natural context was used. During the ride it was noted weather the passenger used any of the built in supports (middle section armrest or armrest on door) in the car to support themselves in a turn. Direct observations were used since the user could not be investigated from a far since a driver had to be present *(see section 2.3.1).*

4.3 Result

The results from user study one include both quantitative and qualitative data. The quantitative data constitutes the majority of the results and thus they will be divided in to several subgroups based on the research areas lateral movement, belt- and head position, comfort and perceived safety. Apart from the research areas, results regarding seat position, support and test validity will be presented. Some of the pictures from user study one can be found in appendix F.

4.3.1 Lateral movement

In figure 24 a-b the initial sitting positions of the subjects are visualized. What can bee seen is that tall people is the most homogenous group of subjects as they sit collectively in the middle in a span of 50 mm. Short people have a wider almost 150 mm. However there is no significan difference in initial sitting position between short and tal people. Looking at the subjects parted after BMI a tendecy can bee seen that people with high BMI lean towards the windows and people with low BMI lean towards the middle of the car. Although no significant difference can be found comparing the subjects based on BMI either.



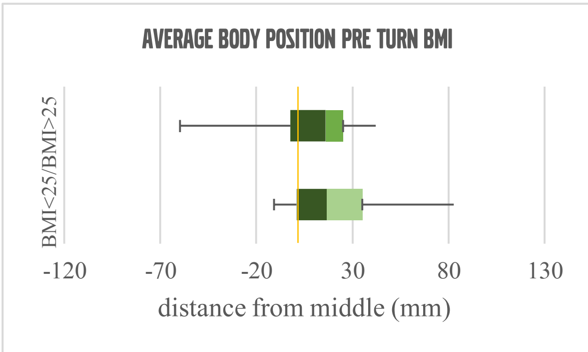


Figure 24 a-b; Boxplots visualizing the initial seat position of the subjects, meaning the distance in mm from suprasternal notch to the middle line of the seat. A negative value indicates a position towards the middle of the car and a positive value a position towards

From figure 25 it can be seen that that the median lateral movement in 20 km/h was 19, 2 mm, in 28 km/h was 28, 6 mm and in 70 km/h was 11.5 mm. The maximum lateral movement measured was around 138,5 mm while the 25th and 75th percentile of the movement was between 5, 3 mm and 44, 4 mm. Using a T-test it was conformed that people moved significantly more in 28 km/h than in 20 km/h and significantly more in 20 km/h than in 70 km/h. As a result of this the velocity with the most movement is 28 km/h.

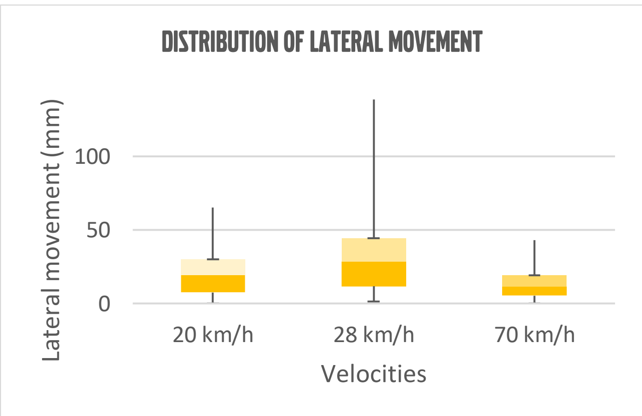


Figure 25. Distribution of lateral movement in different velocities

Figure 26-28 presents each velocity span separately and divides the subject groups after anthropometrical measures comparing short vs tall and people with low BMI vs people with high BMI. Starting with figure 13 that present the lateral movement while driving in 20 km/h there seems to be a clear difference in lateral movement. The median lateral movement for short people was 29 mm while for tall people it was 15 mm. The 25th to the 75th percentile of short people moved between 20 mm and 38 mm while that part of the tall people moved between 4 mm and 24 mm. A one-tailed T-test confirmed that short people move significantly more than tall people when riding in turns in 20 km/h.

In the same figure (figure 26) it can be seen that the difference between people with high/low BMI is not as clear. The median lateral movement among people with BMI<25 was 23 mm which is higher than for people with BMI>25 that was 20 mm. Looking at the 25th to 75th percentile though people with BMI>25 had a higher interval between 12 mm and 37 mm, than people with BMI<25 between 4 mm and 28 mm. This inconsistency was confirmed with a T-test which showed that there is no significant difference in lateral movement between people with BMI<25 and people with BMI>25 in 20 km/h.

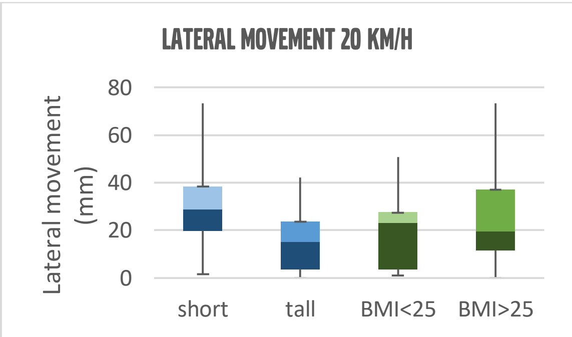


Figure 26 Lateral movement in 20 km/h

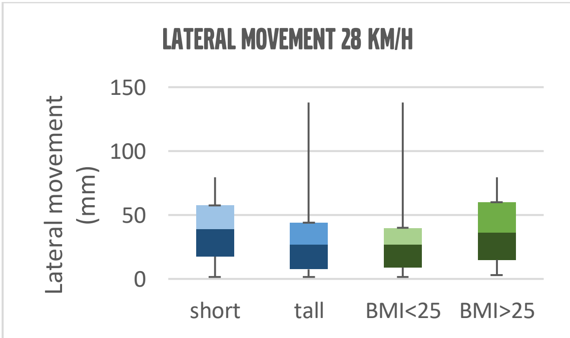


Figure 27 lateral movement in 28 km/h

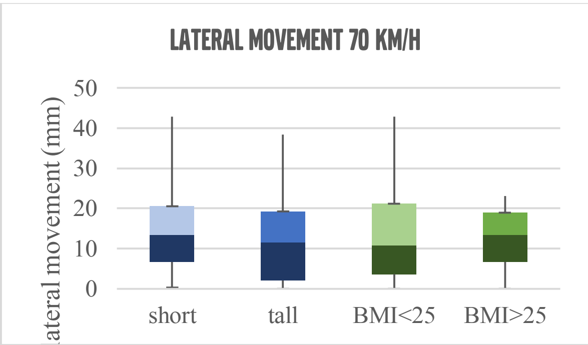


Figure 28 Lateral movement in 70 km/h

Similar results can be found from the turns driven in 28 km/h (figure 27). The t-test showed that short people move significantly more than tall people which can be seen in the boxplot. Just like in 20 km/h there was no significant difference in lateral movement when dividing the population after high/low BMI. A few tall people with BMI<25 stood out by moving a lot more than the rest of the group. The highest lateral movement measured during all the tests, at 139 mm, was thus a tall person with BMI<25 in a turn driven in 28 km/h. In 70 km/h there were no significant difference in lateral movement between the groups (figure 28).

Apart from velocity, the lateral acceleration was believed to have high impact on the lateral movement. In figure 29 the relation between lateral acceleration and lateral movement is investigated. A trend can be seen that an increase in lateral acceleration leads to an increase in lateral movement. The plotted data has an R value on 0.6 which would mean that there is a slight correlation that lateral movement increases with an increase in lateral acceleration.

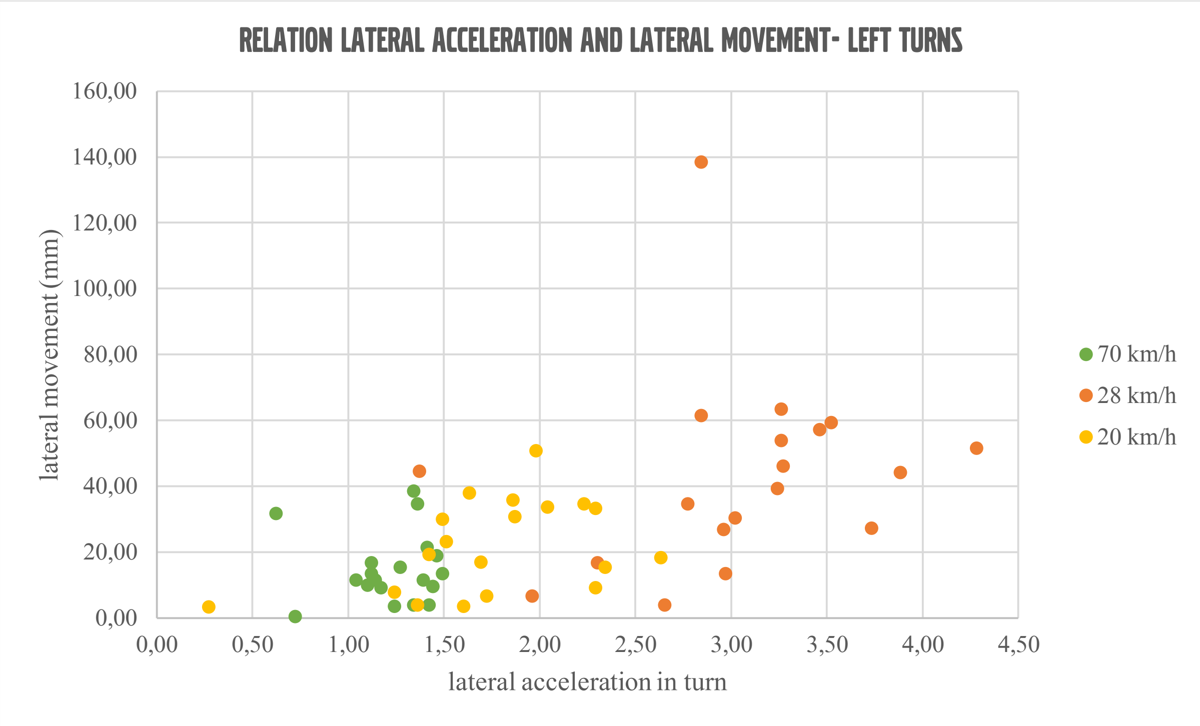


Figure 29. Lateral movement in relation to lateral acceleration in left turns; Each subject is represented with three dots, one for each speed.

4.3.2 Belt position and head position

As found in the theory chapter 2.2 about the cars restrain system, the belt shoulder position and head position are important aspects for the passive safety system to provide optimal protection. Below the subjects belt positions and head positions during the study will be presented in graphs (figure 30-32).

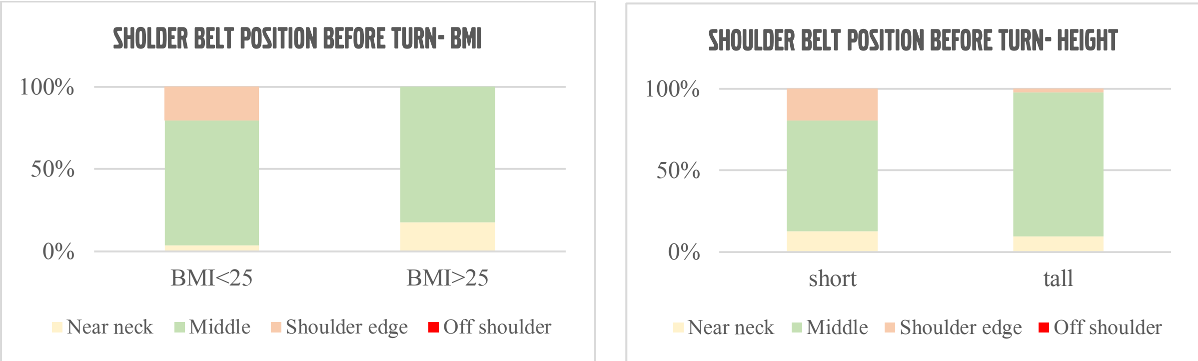


Figure 30 a-b. Distribution of belt positions before turn divided by a) BMI b) height.

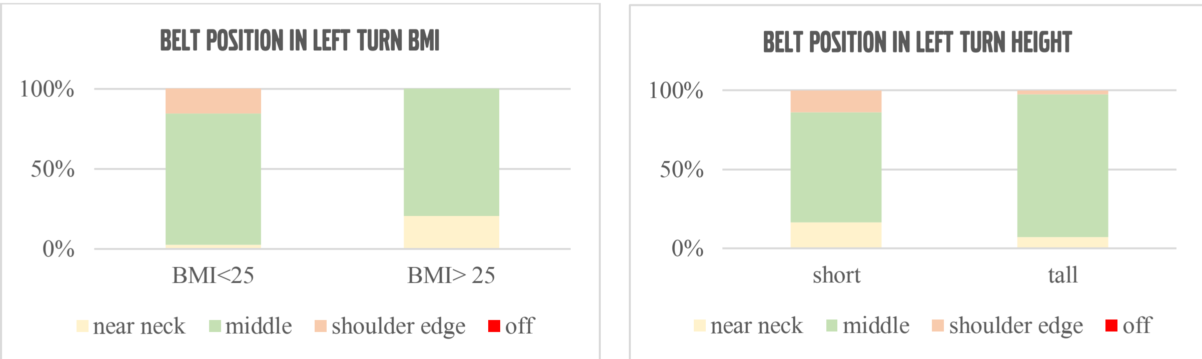


Figure 31 a-b Distribution of belt position during left turns divided by a) BMI b) height

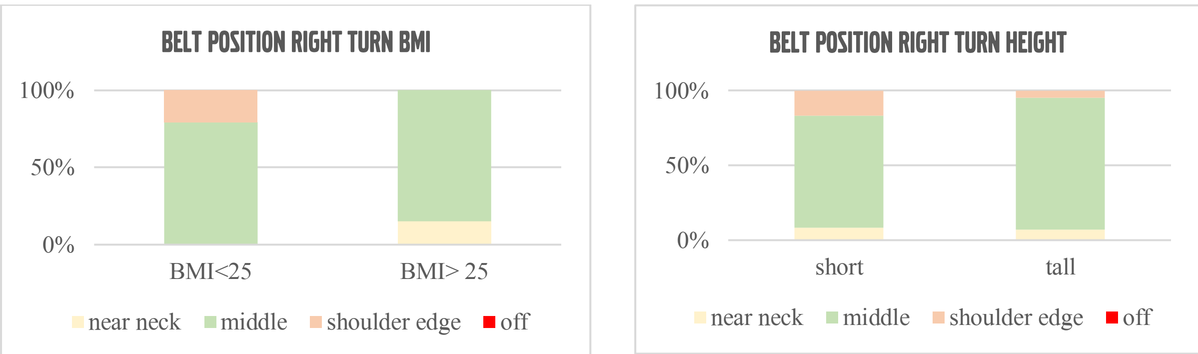


Figure 32 a-b Distribution of shoulder belt position in right turns divided by a) BMI b) height

The participants had a middle belt position during a majority of the ride (figure 30-32) Near neck belt position was more frequently occurring for people with BMI>25 than people with BMI<25 (figure 30-32 a)). This difference is not statistically confirmed either in initial position or during turn, no significance could be found. Looking at the occurrence of shoulder edge between people with BMI>25 and BMI<25 a significant difference could be found both before turn and during turn. The graph implies that there was higher occurrence of shoulder edge among people with BMI<25 than people with BMI>25 which was confirmed.

In figure 30-32 b) the same belt position distribution can be seen but instead divided on occupant height. The graph indicates that there would be a difference in occurrence of shoulder edge depending on height but there isn't. No significant difference could be found either before or during turn. The same goes for the near neck belt position.

5 subjects got shoulder edge from riding in a turn (table 10). That they got shoulder edge in turn means that they either had a near neck or middle shoulder belt position before turn. All of them had BMI<25, one of them was tall and 4 of them were short. This means that 36 % of the subjects with BMI<25 got shoulder edge belt position in a turn, 8 % of the tall subjects and 31 % of the short.

5 persons got shoulder edge due to lateral movement in turn

tall	short	bmi<25	bmi>25
1	4	5	0
8%	31%	36%	0%

Table 10. The amount of people who got shoulder edge due to turn

Moving on to the head position the partition during the ride for people with BMI<25 and people with BMI>25 is showed in figure 33 a) and 34 a). The most common position for both groups was the middle position while the off position almost never occurred (only in 6 % of all turns). Head edge position occurred more often for people with BMI<25 (35%) than for people with BMI>25 (27%). For people with BMI<25 the head off position occurred in 10% of the ride while for people with BMI>25 it occurred in 1% of the turns.

Figure 33 b) and 34 b) shows the distribution for the subjects divided on height. Here short people had a higher percentage of head edge position than tall people in turn 39% for short people and 24% for tall people. The head off percentage was a lot higher for short people 11% versus 1% for tall people.

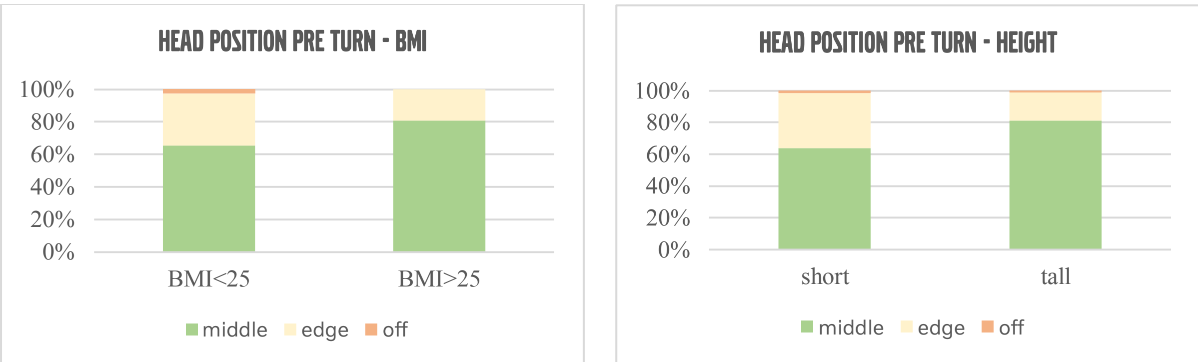


Figure 33 a-b. Distribution of head positions divided on a) BMI b) height.

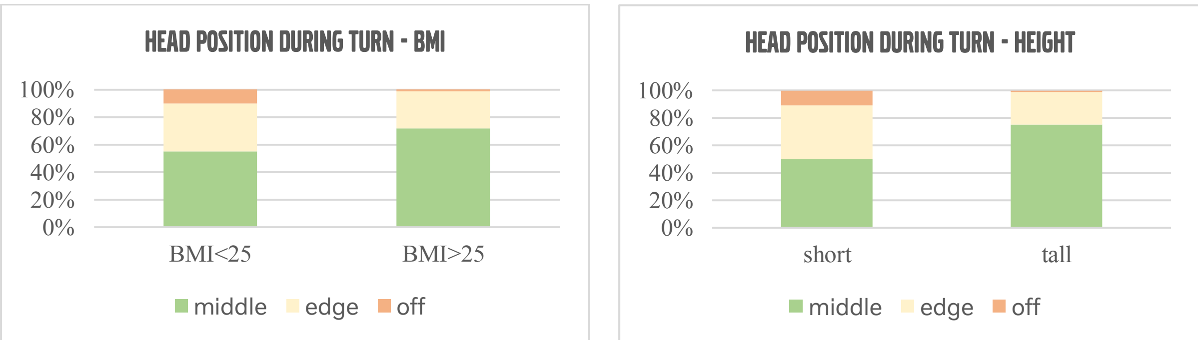
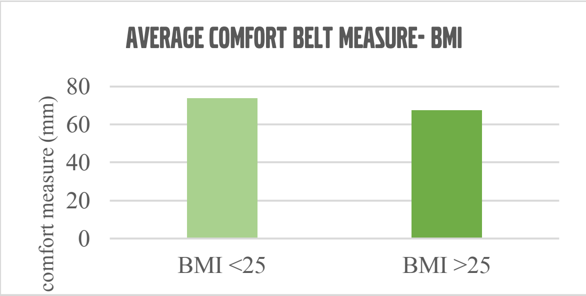


Figure 34 a-b. Distribution of head positions during divided on a) BMI and b) height.

4.3.3 Comfort

There was no significant difference in average comfort belt measure between neither tall and short people, nor people with BMI<25 and people with BMI>25. The slight differences that can be seen in figure 35 a) and b) are thus not a real difference. What can be said though, is that the average comfort belt measure for all participants was 71.4 mm.



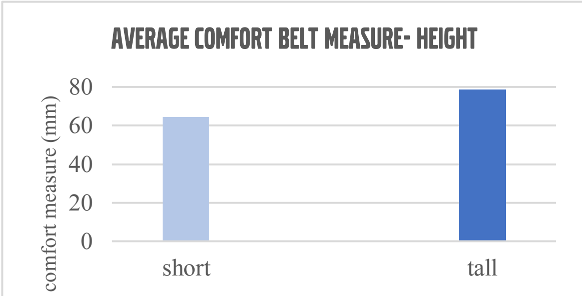


Figure 35a-b. Average comfort belt measure divided by a) BMI b) body height

The belt comfort was rated above 5 by almost all participants, only two people rated below 5 (figure 36). One of them rated belt comfort at 2.1 and the other one at 4.8. The comfort measures for these two persons can be seen in table 11.

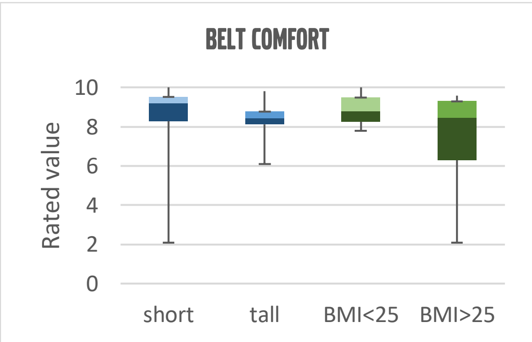


Figure 36 Rated belt comfort divided in body height and BMI

Table 11 Persons that rated belt comfort below five and their comfort measure.

Test person	Subject group	Rated comfort	Comfort measure
5	Short BMI >25	2,1	-3 mm
24	Short BMI >25	4,8	52 mm

People with BMI <25 rated the belt comfort significantly higher than people with BMI>25. There was though no significant difference in rated belt comfort between tall and short people.

Figure 37 visualizes the rated belt comfort depending on what rapping degree the subject had. No connection could be found between wrapping degree and how the subjects rated their comfort. The two participants who rated their belt comfort below 5 had wrapping degree 2.

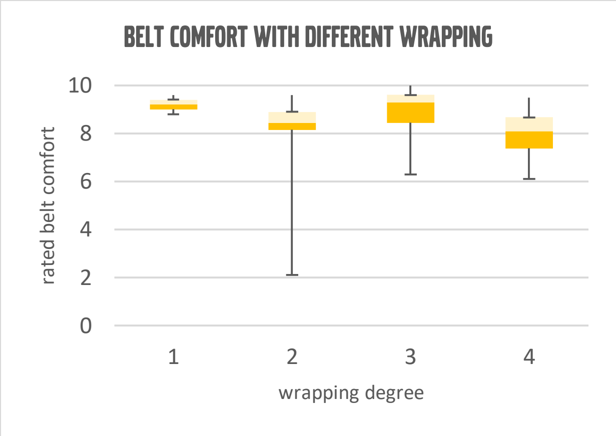


Figure 37 Belt comfort with wrapping degree 1, 2, 3 or 4.

Looking at figure 38 a), there was no clear difference in rated ride comfort between the different groups of people. No significant differences between short and tall people and no significant differences between people with BMI<25 and people with BMI>25. The results were rather coherent and no one rated the ride comfort below 5.

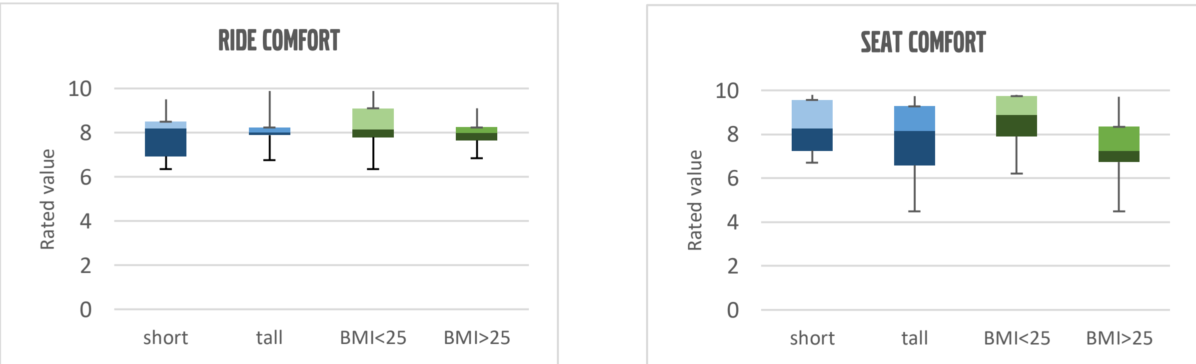


Figure 38 a-b. a) Rated overall ride comfort divided by body height and BMI b) Rated overall seat comfort divided by body height and BMI

No significant difference could be found between the different subjects groups on how they rated their perceived seat comfort (see figure 38 b)). There was only one person who rated seat comfort below 5.

As stated above the subjects in the study perceived their overall ride comfort and seat comfort as good. However as stated in the theory section comfort does not exclude discomfort. In figure 39-40 it is visualized where the subjects stated that they experienced discomfort. What can be seen is that no area has been marked as read in connection to discomfort by more than five subjects (figure 39). A tendency can be seen that people with high BMI experiences more discomfort on the back of their body than people with low BMI (figure 40 a) and b)). Discomfort of tall people is connected to the lower part of their body and shorter people have a more even spread of where they experience discomfort. Another tendency that can be seen is that only tall people and people with high BMI experience discomfort on their lower arms.

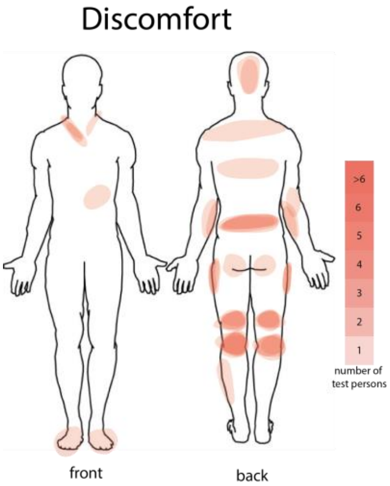


Figure 39 where all subjects marked discomfort

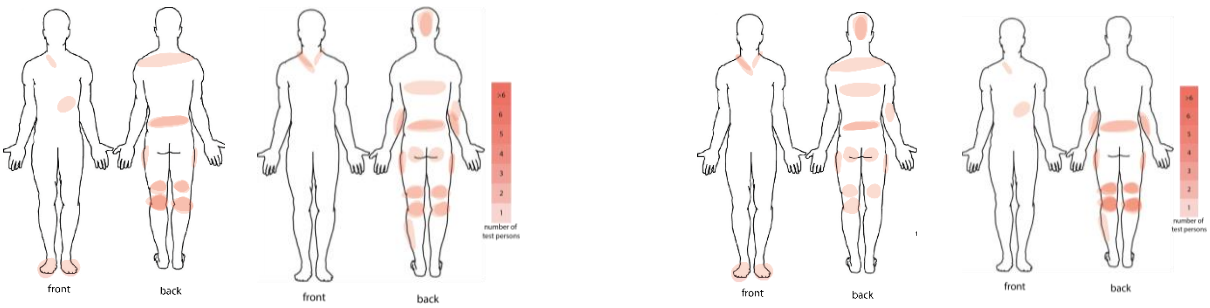


Figure 40a-d. Visualization of where subjects marked discomfort divided by BMI a) BMI<25 b) BMI> 25 and divided by height c) short d) tall

4.3.4 Perceived safety

Perceived safety was high for the participants during the test (Figure 41). No one rated below 5 and the results were similar between the subject groups. No connection between perceived safety and anthropometry was found.

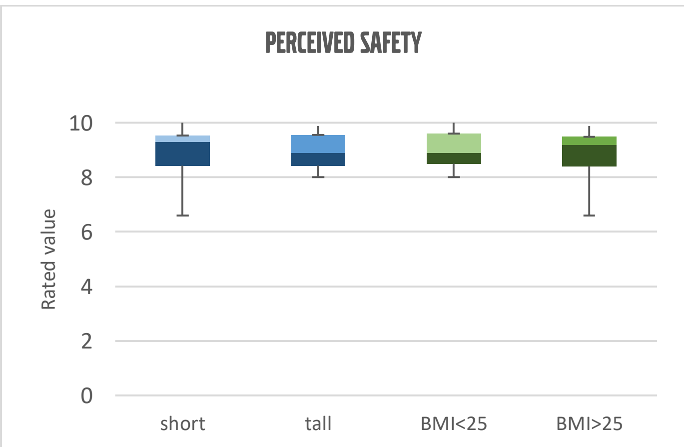


Figure 41 Rated perceived safety

4.3.5 Seat position

The chosen seat positions were all rearward in relation to the adjustment area (figure 42). Each dot symbolise one persons' hip point (H-point). What can be seen is that tall people tend to sit far back with a low seat height and short people tend to sit higher up. Most of the subjects chose to adjust their seat position however seven subjects chose not to make any changes. Of these people three were tall and four were short, two had low BMI and five had high BMI.

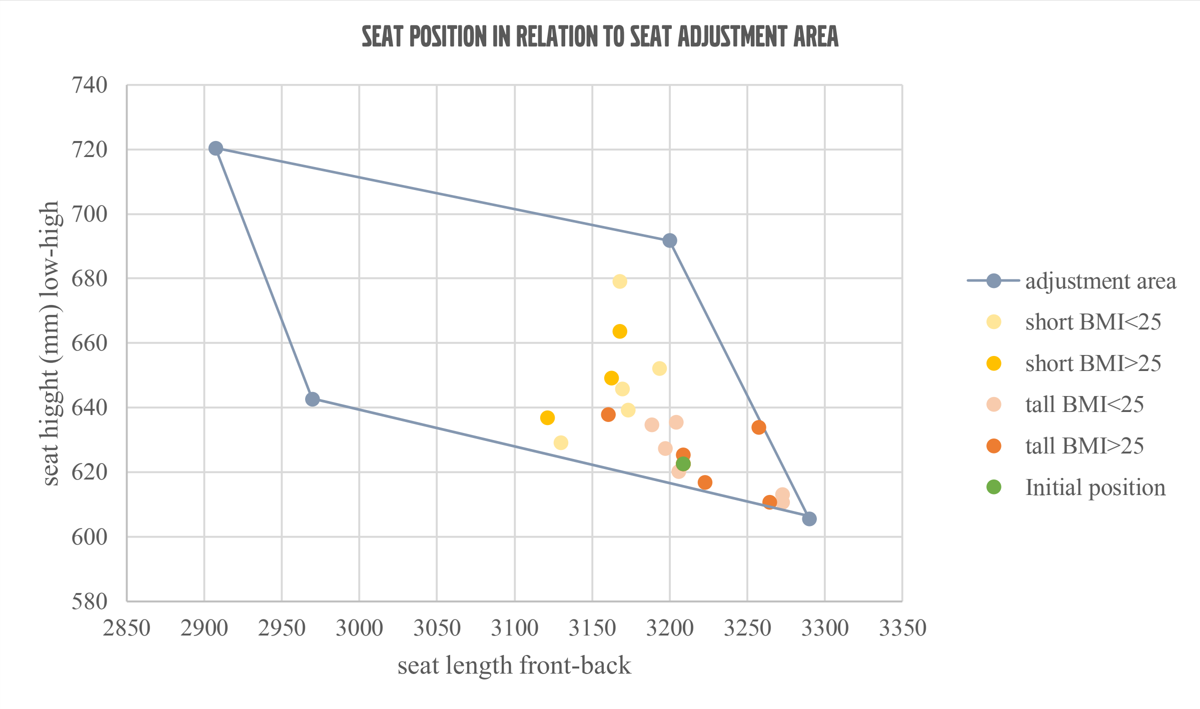


Figure 42 Hip point position during the test in relation to adjustment area.

The initial backrest angle was 25 degrees related to the vertical plane. Figure 43 visualizes how the subjects adjusted the backrest angle. Here we can see that the smallest angle was 20 degrees and the largest 31 degrees. Out of the 26 subjects 13 did not change the backrest angle and no pattern could be found for any of the groups. Short people changed to a more upright position and taller people changed to a more reclined. Looking at BMI most of the people with high BMI did not change the backrest angle while the once with low BMI changed to a more upright position.

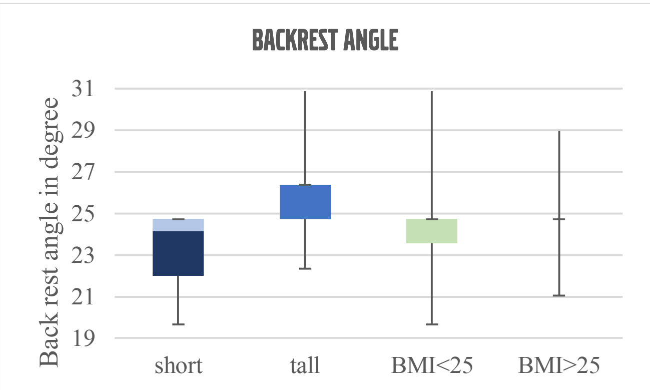


Figure 43 Backrest angle position visualized in a boxplot. For the tall people and the people with BMI<25 the median is displayed under the boxes.

4.3.6 Support

During the turns many of the subjects supported themselves on either "*the middle panel*", "*the middle panel and the door*" or "*no support at all*". The lateral movement was highest when the occupants did not support themselves (figure 44 a)). Support on the middle panel or on both the middle panel and the door on the other hand gave similar lateral movement. In figure 44 b) the backrest distribution is visualized depending of the amount of support that the subjects used. From that we can see the backrest angle did not affect how much support the subjects used.

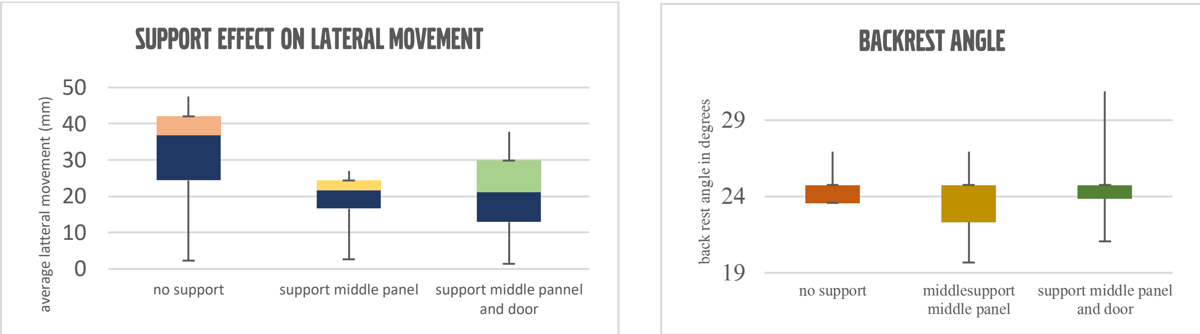


Figure 44 a-b. a) Lateral movement in relation to the amount of support used. b) Backrest angle in relation to the amount of support used. The median is displayed above the coloured boxes.

In figure 45 it can be seen that most of the people using both the door and middle panel to support themselves sat far back and with a low seat position, those using the middle panel for support sat higher up and those with no support in the middle. Looking at figure 46, all tall occupants used some sort of support, either only the middle panel or both the middle panel and the door. Among the short occupants some used support and some did not. The group that supported themselves the most were tall people with BMI>25.

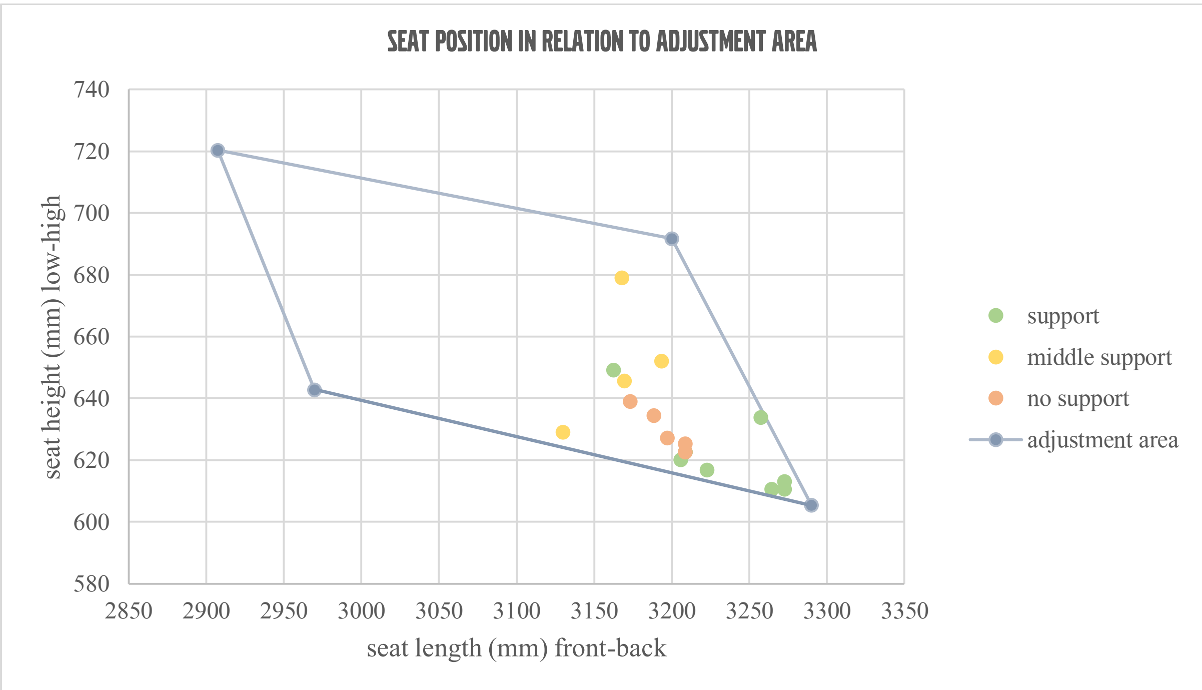


Figure 45 Seat position in relation to adjustment area. Each dot represents one person and how they supported themselves

user group	no support	support middle pannel	support middle pannel and door
SHORT	8	2	3
TALL	0	5	8
BMI<25	5	6	3
BMI>25	3	1	8

Figure 46 How the anthropometric groups supported themselves

4.3.7 Test validity

The measured velocities during the test had low deviation from the velocities aimed for, 20 km/h, 28 km/h and 70 km/h (Figure 47 a)). In the 20 km/h turns the median velocity was 19.8 km/h which only deviates 0.2 km/h from the aimed velocity. The median velocity in the 28 turns was even more accurate, it measured 28 km/h with 0 km/h deviation. In the 70 turns the median value was measured to 69.9, only 0.1 km/h from 70 Km/h.

Some more extreme deviations did though occur. The lowest velocity measured in a 28 km/h turn was as low as 18 km/h.

The lateral acceleration was highest in the turns driven in 28 km/h, the median value was 2.6 m/s^2 (Figure 47 b)). Between the 20 km/h turns and the 70 km/h turns the lateral acceleration was similar, 1.4 m/s^2 in 20 km/h and 1.3 m/s^2 in 70 km/h. The lowest lateral acceleration measured in a turn 0.24 m/s^2 and the highest 4.3 m/s^2.

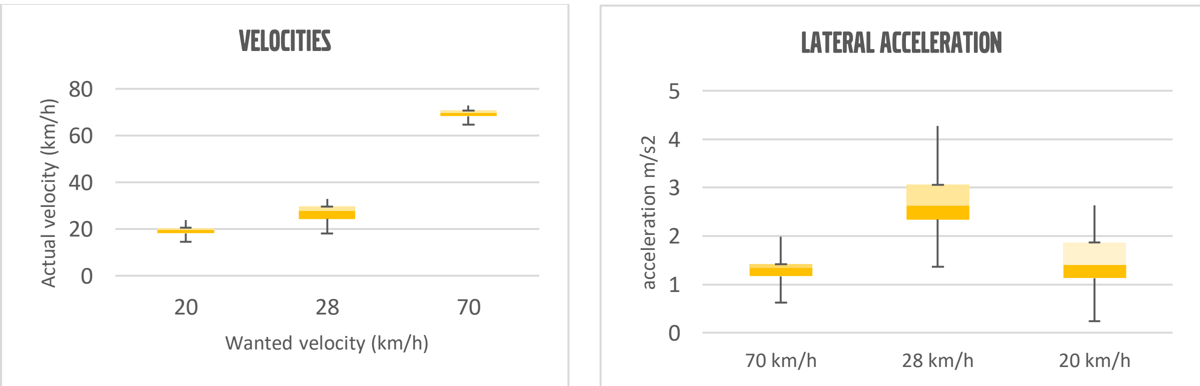


Figure 47 a-b a) measured velocities during the test b) Measured lateral accelerations during the test.

4.3.8 User insights from interview

In this section the result form the KJ analysis will be presented. The result will be presented for each group as a short summery of the quotes.

Why I feel safe

When talking about safety the participants did not express any concerns at all. There were three comments regarding not experiencing anything out of the ordinary and a lack of insecurity. They also described the traffic situation as calm/ordinary and expressed trust towards others moving in the prescribed traffic conditions. The main reason to why the investigated group of participants felt safe was car knowledge. Over 50% of the participants mentioned that they sat in a Volvo and that they knew a lot of the safety systems incorporated in the car which made them feel calm and safe. One person mentioned that they felt like they might procure worse injuries than others due to their size. This person was both tall and had a BMI>25, 5.

Route

50% of the participants mentioned that they perceived the route as smooth and pleasant while only 11% perceived it to be uneven and bumpy and the rest did not mention it at all. There was only one comment that was specifically directed towards roundabouts. This person perceived the speed in the 28 km/h roundabout as too high.

Movement

Four people specifically stated that they perceived the movement in the roundabouts as unpleasant. Two of them specifically talked about the 28 km/h roundabouts and the others talked about roundabouts in general. One person stated that they felt like they moved more as a passenger than what they do as a driver. There was also a comment regarding unpleasant head movement. However three people stated that they did not move around during the drive.

Belt comfort

Over 50% of the participants mentioned that they do not think of the belt during the drive. Around 20 % also mentioned that the belt did not irritate the neck as belts in other cars tend to do. Some of the participants also mentioned that they felt like the belt still allowed them to move while being belted. One person said "I am properly seated without feeling strapped". The participants also mentioned that the belt was easy to find and easy to reach.

Belt discomfort

Two persons mentioned that the belt edge was too close to the neck which created discomfort. Both of these participants were short and had BMI>25, 5. One woman also mentioned that the belt positioned itself over the bust which created discomfort and made the belt move around. Two critical quotes were "The belt never feels good" and "You just have to get used to the belt". Among the negative comments regarding the belt there is a tendency that short people and people with BMI>25 have inferior experiences of the belt.

Opinions of seat

60 % of the participants specifically stated that they perceived the seat to be comfortable. Other than that the opinions differed a lot according to personal preferences and anthropometrics. Tall people tended to feel like the seat cushion was too short and would have wanted to use the seat cushion adjustment. Three people mentioned that they would want better armrests.

Opinions of car compartment

Opinions regarding the car compartment were few and mostly good. Those who mentioned it said that the compartment was airy and comfortable with enough room for the legs. One person said that they perceived the compartment to be narrow and one person mentioned that they perceived the middle compartment to be too high and hard to be comfortable.

Error sources

Some people mentioned that they were disturbed by some of the equipment in the car. The tape marking on the belt was mentioned as disturbing as well as the cameras placed in front of and around the passenger. Someone even mentioned that the equipment made them feel uncomfortable.

4.4 Discussion

4.4.1 Lateral movement

The results on lateral movement in different velocities were clear and driving 28 km/ through a turn gave the most lateral movement. This aligns with the results from the pre-study since 30 km/h was the velocity believed to result in the highest lateral movement. The question is whether this can be explained by the increased lateral accelerations that occurs while driving in 28 km/h? There should be some connection since the most lateral movement was found in 28 km/h, the same velocity where the lateral acceleration was the highest. As seen in figure 32 a slight trend could be found with and R2 value of 0.3. However there is not a 100% correlation as seen in the results section.

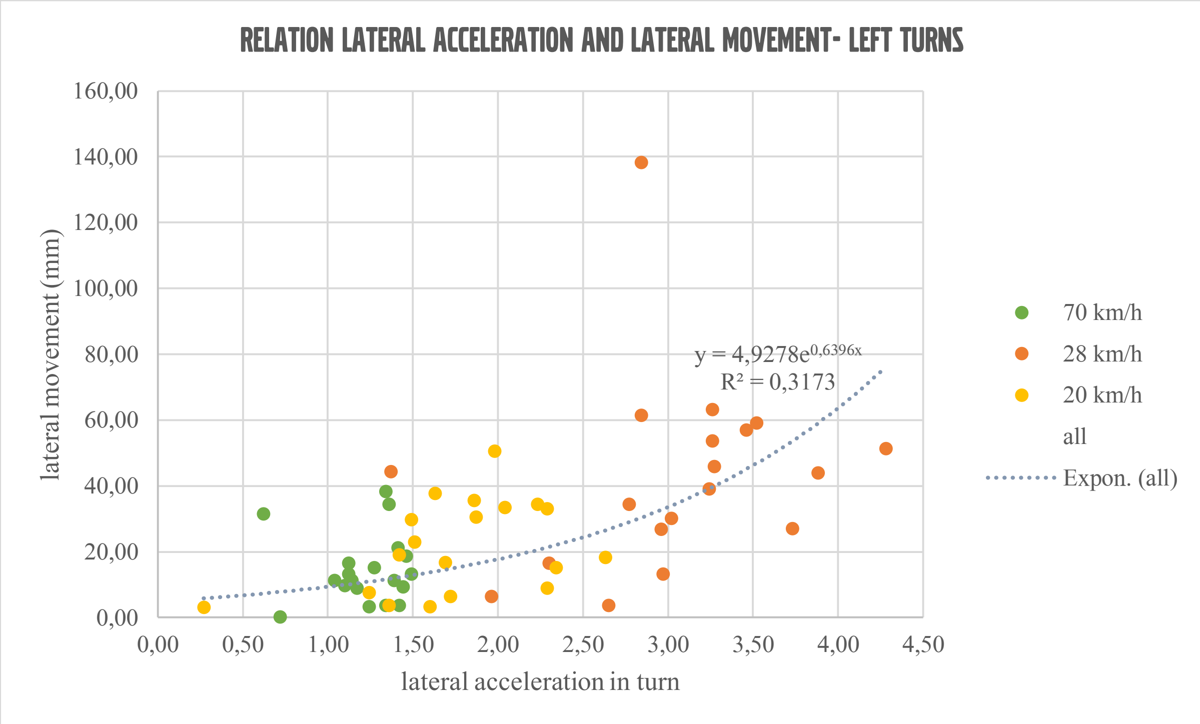


Figure 48 Lateral movement and lateral acceleration

Looking at figure 34 it can be stated that an increase in lateral acceleration is one of the reasons for the increase in lateral movement. The plotted trend line has an R2 value of 0.3 meaning that we have a slight increase in movement as the lateral acceleration increases. However there is not a 100% correlation as seen in the result section meaning that there are other parameters that effect the movement apart from the lateral acceleration.

Regarding the effect of the anthropometry on lateral movement the result showed that short people move more than tall people, but that there was no difference in lateral movement between people with BMI<25 and people with BMI>25. This makes short people an interesting group, since they are a critical group when it comes to lateral movement. One explanation to why people move more than tall people lies in how much people support themselves. Tall people support themselves more than short people and using support decreases lateral movement. Tall and short people also prefer different seat positions which could affect how much support that is used. Tall people sit further back and lower and short people the other way around which is not a surprising result since taller people have to do so the fit in the compartment and shorter people want to sit higher to see the road. The backrest angle did not have a clear connection to how much support that was used. So the seat position might affect which support that can be used in the compartment but since there is one person that has used both the door and the middle panel as support while being seated forward and upward the conclusion is drawn that it has more to do with body anthropometrics and reach.

Lateral movement did overall not cause discomfort for the participants in the study. The fact that the few people who experienced discomfort connected to lateral movement did so in the 28 km/h turn makes sense since those turns resulted in the most lateral movement. All in all lateral movement did for most people not decrease the ride comfort in the test situation, people have high acceptance. The participants were told to leave their phones in the back seat of the car and were told to just sit and ride along. Looking to the future when vehicles most likely are autonomous passengers will do more activities in the car which might make them less tolerant of lateral movement. Therefor a new test where the occupants are assigned with easy tasks that require slight precision could be of interest to see if the acceptance is decreased.

4.4.2 Belt position and head position

The non-optimal belt position, shoulder edge, occurred in 10 % of the turns due to lateral movement. This motivates that solutions to decrease lateral movement should be developed to strive for 100% optimal shoulder belt position in turn for all passengers.

Shoulder edge was more frequently occurring for people with BMI<25 than for people with BMI>25, in fact no person with BMI>25 got shoulder edge due to a turn. Since there was no significant difference in lateral movement due to BMI, the difference in shoulder edge occurrence between the groups cannot be explained by difference in lateral movement. A complementary graph was made to rule out this explanation (Figure 35). It seems as though people who got shoulder edge due to turn (1) moved slightly more than those who did not (0), but no t-test could be done to examine the significance since not enough subjects were exposed to shoulder edge belt position due to turn (there was not two large enough groups to compare). As a conclusion lateral movement cannot explain why people with BMI<25 have higher occurrence of shoulder edge. More plausible explanations are that people with BMI>25 either have wider shoulders or stop the belt due to their body composition.

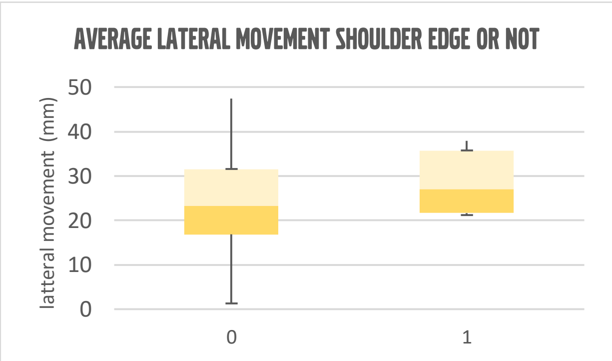


Figure 49. Lateral movement for those who got shoulder edge due to turn (1) and those who did not (0).

The non-optimal head position described as off only occurred 6 % of all turns which is a low percentage. The fact that short people had a higher occurrence of off head position makes sense, since they move more laterally.

4.4.3 Comfort

Belt comfort

The fact that no significant difference was found in comfort measure between people with different heights and BMI, might be explained by the seat position. The comfort measure should be dependent on the anthropometric measures, but adjusting the seat often compensates for the anthropometric differences. The average comfort belt measure 71.4 mm is relatively long which indicates that the occupants should not experience belt discomfort. Overall the rated belt comfort aligned with the comfort measure, since it was overall high and above 5. Only 2 persons rated their belt comfort below 5 and these people also had an average comfort measure below the average -3 mm and 52 mm. Where the limit goes for where discomfort is experienced, if there is such a limit, can't be decided since some subjects that rated their belt comfort above 5 had a shorter comfort measure than 52 mm. This does not seem to be dependent on wrapping degree, since high belt wrapping did not equal low belt comfort rating. Why these two persons experienced low belt comfort could perhaps be tied to their body anthropometrics as both of them were short and had a BMI>25 or in relation to how they sat. In fact they had some of the highest BMI within the group. Both subjects also had a large chest and were seated far forward in relation to the rest of the subject group (figure 36). So the reason to why they rated lower than the other subjects should be a combination of their body anthropometrics and where they sat. For future studies it might be of interest to see how the chest affects the perceived belt comfort.

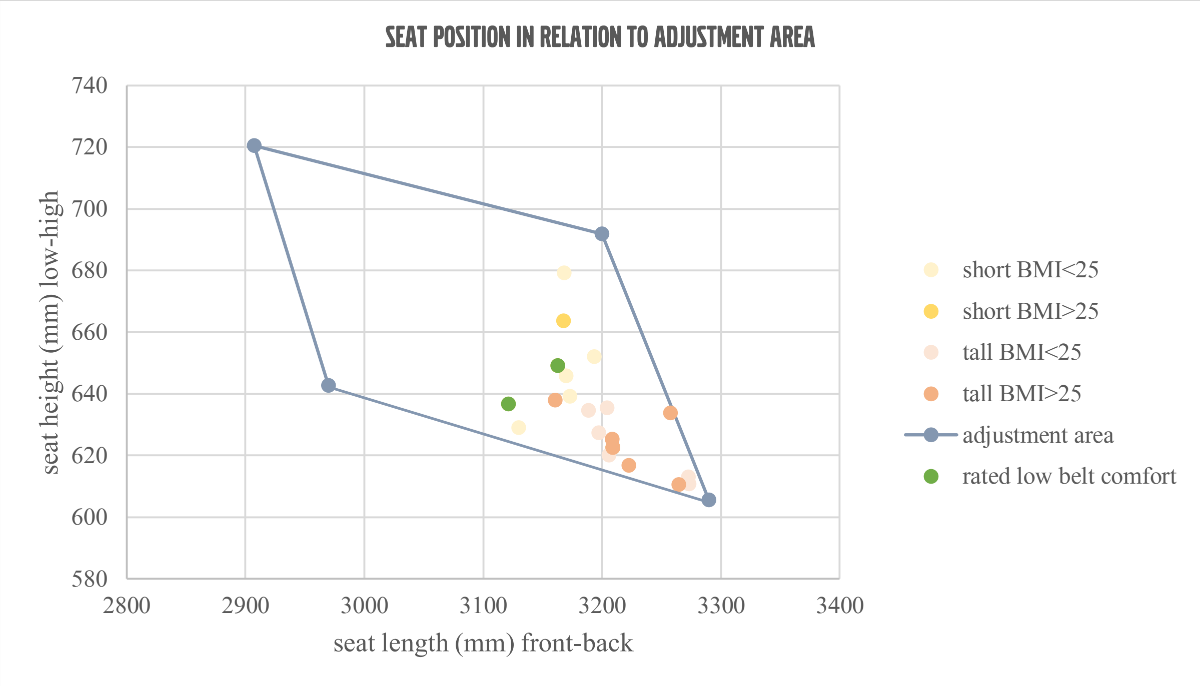


Figure 50 Seat position in relation to adjustment area with the subjects that rated below five marked in green.

Ride comfort

The fact that the rated ride comfort was not different for the different anthropometric groups makes sense since it more connected to the driving style and surrounding environment. Connecting this to lateral movement in turns, it shows that lateral movement does not result in a low overall ride comfort.

Seat comfort

The seat comfort was rated over all as good. The human silhouette result indicates that different group's experiences discomfort in different areas. In combination with the result of the overall good rated seat comfort and ride comfort it can be concluded that those areas of experienced discomfort did not affect the overall experience. Since comfort is time dependant the result might have been different if the test would have had a longer duration.

The one person who rated seat comfort below 5 was investigated further in order to understand why. This person was a male 197 cm tall (figure 37), with a BMI at 30 and the seat position almost at the initial seat position. The height stands out, he is the second tallest of all participants.

Table 12 A compilation of the tallest subjects that participated in the study and their seat comfort rating.

The tallest		
TP	*height (cm)*	*Seat comfort rating*
617	198	6,2
597	197	4,5
663	194	6,9
708	193	9,7
530	193	6,75
757	191	6,55
	average height	*average rating*
All TP	177	8,1
The tallest	194	6,8

Among the tallest there were people with the same height and BMI that rated seat comfort above 5, some just above 5 and some closer to 9 (table 12). Two people from the same group have similar seat position as the investigated participant, TP 757 and TP 617. No correlation with the seat position could though be found since one of them rated seat comfort 9.4 and one of them rated 6.5.

TP597 is one of the extremes in the group of tall subjects, this might have something to do with it. The tallest people commented on the lack of cushion-adjustment. TP597 rated low partly because he is one of the tallest and would like longer seat cushion for his long legs. He did though rate lower than rest of these tall people, which cannot be explained. Some of the others have similar seat position and so on.

4.4.4 Perceived safety

Lateral movement does not make the passenger perceive the ride as less safe, since they experienced lateral movement but rated perceived safety high. This is expected since normal driving should not make the passenger feel unsafe. Instead they felt safe thanks to the safe reputation of cars from the manufacturer Volvo cars and since many of them had knowledge about the safety system in the car. The fact that they were Volvo Cars employees probably affected the result and made them experience higher safety.

So what can be said is that lateral movement does not decrease perceived safety today, but a question that will be of interest to answer in the future is what happens with the perception of safety when the passenger will have to put the same amount if trust on technology instead of in humanity.

4.4.5 Test validity

The test was executed with the correct velocities, the deviation between the measured and aimed velocities was below 1 km/h. Due to other vehicles some of the roundabouts that should be driven in 28 km/h rather were driven in 20 km/h. The data from these turns were therefor moved to the 20 km/h turns. These deviating velocities is a direct consequence of driving in regular traffic among other cars. Driving in this environment did though give more realism to their perception of the ride, compared to a controlled environment like a test track. The measured lateral accelerations were within the limits of normal drive, even though some of the drives had velocities in the outskirt of what constitutes normal drive.

Moreover the fact that the ride comfort was rated above 5 by all participants and the lack of comments on the ride as unusual or weird, confirms that the ride was within normal drive, together with their high rating of the perceived safety. Something that affected some of the participants was though the camera equipment.

Since at least 12 tall people, short people, people with BMI<25 and people with BMI>25 were part of the study the results are reliable. The comparisons between tall and short people are thus reliable as well as the comparisons between people with BMI<25 and people with BMI>25. The fact that they were all Volvo Cars employees did probably affect the results. If other participants would have been used the perceived safety might have been experienced lower. The occupation of the participants have probably not affected the objective data, since that does not handle their opinions and experiences.

4.5 Conclusion user study one

The combination of a short passenger who does not support arms on the side panels or armrest riding in a roundabout in 28 km/h results in maximal lateral movement. People have high acceptance of lateral movement during normal drive and it does not affect the perceived safety. To decrease non-optimal belt position, lateral movement of the upper body should strive to be decreased. Further testing should therefor test concepts to decrease lateral movement, evaluate whether the acceptance of lateral movement decreases when doing activities in the car which will increase in the future since the driver will be left with more time at their hands as the car continues to be more and more autonomous. It should also evaluate if the lateral movement increases when support with side panels is not used. The results are reliable even though the fact that they were Volvo Cars employees might have increased their perceived comfort and safety.

4.6 Bring to user study 2

Shoulder edge due to lateral movement

Since some people got a shoulder edge belt position due to lateral movement, user study two will strive to test ways to decrease lateral movement There might be many ways to decrease lateral movement, but one plausible way to do so is s that the belt holds the passenger tighter during turns.

During user study two the test persons will be held by the belt during turns to see if this decreases lateral movement and is comfortable and experienced as positive.

Acceptance of lateral movement

So, the subjects did not experience any discomfort due to lateral movement in turns during the test. But what happens in the future when AD will be more common? When people will no longer be driving, it is plausible that they will want to use their time to do things. Will this decrease the acceptance for lateral movement?

To be able to test this, the participants in user study two will be given tasks during the test to see if they experience discomfort due to lateral movement.

Lateral movement without support

Since some of the passengers supported themselves during the ride, it would be interesting to see if they would move more if they do not support themselves. A natural way of ensuring that is to give them assignments making their hands occupied with something and see if that decreases lateral movement.

The task mentioned above will also function as restraining from supporting themselves and will show if lack of support leads to more lateral movement.

Participants and route

Since the goal will be to decrease lateral movement resulting in shoulder belt on shoulder edge and to see if passengers experience discomfort due to lateral movement, the passengers and turns that generate the most lateral movement will be of interest. If issues tied to lateral movement can't be found within the group with the most lateral movement, it will not be found in the other groups either. Furthermore if lateral movement is decreased for the group who moves the most, it will be decreased enough for other groups as well. Therefore, the second user study will focus on short people and roundabouts in 28 km/h, they will be this extreme group and route that will cover as many of the users' needs as possible.

The participants of User study two will be short and will be driven in roundabouts in 28 km/h.

4.7 Ways to decrease lateral movement

Since user study one showed that lateral movement should be decreased in order to maintain an optimal torso position, an early concept generation and evaluation was conducted. The method, result, discussion and conclusion will be presented as a mini report within the phase of user study one.

4.7.1 Method

The ideas were generated using the method brainstorming. As a prerequisite for the session the questions was asked: "In what different ways can lateral movement of front seat passengers be decreased?" "In what different was can be movement be hindered?"

4.7.2 Result

Side bolstering

- Bolsters on bottom seat
- Bolsters on back support
- Bolsters can tighten when entering a turn
    - By feeling the pressure
    - Based on the GPS position on a map
- Semi soft seat or back support that shapes after the body, bolsters are created from the shape of the passenger.

Strapped on place

- Double belt, like in a rally car
- Belt that is tight all the time
- Belt tension in turns
    - A sensor registers tension when the passenger starts moving in the turn and tightens the belt.
    - The belt tensions based on GPS position
- A belt that is more similar to a jacket, covers the whole upper body and is closed with a zipper.

Support for arms or hands

- Handles on the dash board in front of the passenger to grab on to.
- Hard hoop is wired down on the passenger after seated, like in a roller-coaster.
- Support surface for the bottom part of the arms are wired down on both sides after seated.
- Support that increases in size when the passenger is seated.
- Support that is adjustable depending on the size of the passenger.

The seat or car moves instead of passenger

- A seat that wardens of the passengers movement compensating movement.
- A car that does compensating movement.

4.7.3 Discussion

A more extensive ideating and concept evaluation should be done in future studies to ensure that an as good solution on decreasing lateral movement is found. The space of possible solutions is large and more information about lateral movement is needed to do a final concept evaluation. The design process is an iterative process and this constitutes the first iteration of concept generation (See 2.3.3 the design process).

Within the scope of this study the evaluation of concepts is a small part. Of the generated ideas only a few can be evaluated, preferably on a general level.

Looking at ideas where the car or the seat takes care of the movement by counter movements or similar would be a too extensive project. Adding support for arms would require an active action from the passenger's side and there for these ideas were also scraped for further evaluation.

Side bolsters were one of the themes of concepts generated, with different variations. If larger side bolsters are to be used to decrease lateral movement one challenge would be to make them fit all body proportions. During user study one some of the larger subjects experienced the existing side bolsters were to narrow. Seats with a variation of side bolsters can already be found on the market today and Volvo already has teams working on such which speaks for testing another solution.

Other car manufacturers are currently working with and experimenting what can be done with different belt alterations. Using different pre-pretensioning profiles to tighten the belt before drive is one example or to use it for nudging purposes. The belt pre-pretensioning profiles in Volvo cars today is activated during evasive manoeuvres and in pre-crash situations. There are no existing solutions using belt pre-pretensioning during drive. Therefore it would be of interest to try and test different belt pre-pretensioning profiles in turn to see if this could be used to minimize the lateral movement of passengers in the front seat. Testing this can be done without any bigger changes of the test car. The electrical belt roll in the car can be re-programmed with new pre-pretensioning profiles that can be triggered manually during drive. Using such profiles should increase the contact with the belt during turn which according to Backer et al. (2018) should decrease the lateral movement. Therefor it was selected to test the belt pre-pretensioning profiles idea.

4.7.4 Conclusion

Many of the concepts could be interesting to try out, but most of them require a lot of work in order to create a prototype that can be tested in a driving car. A prototype for a belt that tensions when entering a turn is relatively easy to create, simply by reprogramming the electrical belt that is already present in the car. This is also the solution that is deemed to have the highest effect on lateral movement with the lowest effort needed from the passenger. This should therefore be the first concept to test in user study two, and be the first step in the search for a solution on how to decrease lateral movement.

PHASE 3

User study two- investigating the effects of road awareness and supporting the occupant

User test two is a complementary study that builds on the findings form user test one, aiming to identify if the acceptance for lateral movement decreases if the passenger is occupied, weather lateral movement increases if the passenger is occupied, investigate if using different belt pre-pretensioning profiles can decrease lateral movement and see how the perceived comfort is affected.

Hypotheses

- Restraining the passenger with an electrical seat belt will decrease lateral movement.
- Restraining the passenger with an electrical seatbelt will decrease the occurrence of shoulder edge belt position.
- The acceptance of lateral movement will decrease if passenger are assigned with an assignment.
- Passengers will move more due to lateral movement if they are assigned with an assignment.
- Passengers will perceive higher safety due to the pre-pretensioning belt.
- The pre-pretensioning belt with the highest force will decrease the lateral movement the most but the belt comfort will be lower.
- The pre-pretensioning belt with the highest force will result in rated belt comfort below six.
- The pre-pretensioning belt with the lower force will decrease lateral movement and the perceived belt comfort will remain, not have a significant difference.

5.1 Method

5.1.1 Equipment

The same car with the same seat was used in user study two as in user study one. The seat was locked in one position optimized to give high shoulder belt wrapping for the subject group being investigated (figure 51) with the back rest angle 20˚. The selected position was based on the results of how the seat affects wrapping (see pre-study chapter 3) meaning that the longitudinal position was above middle, the height was high, the back seat was upright and the Belt output belt position was in its lowest position. As for the other study the car was equipped with the same tools and markings which were mounted in the same manner.

Furthermore administrational equipment was at hand in terms of participation fill in forms for the subjects (appendix G), fill in form for the observer (appendix H) and pencils.

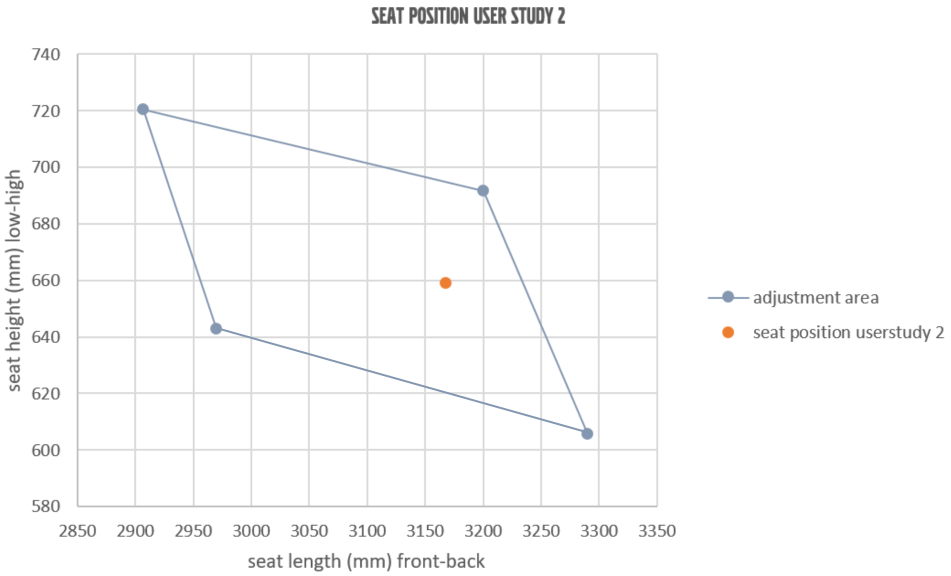


Figure 51 Hip point position for the seat position in user study two.

5.1.2 Electrical belt roll

Apart from the equipment used in user study one the electrical belt roll in the car on the front passengers side was provided with two new tension profiles that could be triggered with a computer form the rear seat of the car. To select the force of the tension a belt expert was consulted (Larsson, 2019) and different belt forces were tested in a belt rig. The rig consisted of a car seat and an electrical belt roll that could be provided different tension forces. After consulting the belt expert and testing different profiles the following were selected;

- Soft belt tension 40 N
- Firm belt tension 70 N

These were selected since they were deemed to produce an acceptable belt comfort experience while riding in normal drive. The force for each profile was measured with a belt sensor with a measuring range of 0-16 kN. The force was measured during 20 seconds twice per profile (see appendix I for full report). The max values on each profile had a variance on maximum 2 N and therefor the belt tension on the two profiles were considered repeatable.

To access the belt roll the interior on the Belt output had to be removed and a break-out cabling was used to be able to send triggering impulses to the belt role. The cabling was connected to a Vector device providing an interface for CAN signals form the car. The Vector device was then connected to a computer equipped with a program called CANoe. In CANoe a simple interface could be created that was used to work with the profiles. The interface consisted of four buttons and a drop down menu; start and stop buttons for accessing the electrical channel to the role, start and end buttons to activate and deactivate a belt profile and the drop down menu were the selection between soft and firm profile could be made. The computer was placed on the flooring in the rear seat.

5.1.3 Subjects

The subjects for user study two were all short, since user test one showed that they are the group most exposed to lateral movement. The limit was set at 1.75 m, only people shorter than 1.75 were chosen as subjects. The Selected group of 14 subjects were all women and they were all Volvo employees, either as consultants or with a permanent employment. Unfortunately they were all women but that came as a result for the selection of only investigating people with a body height below 1.75. 14 subjects were enough for this study since the aim of this study doesn't include comparing different user groups but instead investigating a critical group.

5.1.4 Route

User study one gave the result that the most lateral movement was found while driving through roundabouts in 28 km/h. Therefor this type of turn was further investigated in this study. Furthermore it was important to identify a turn that would generate an inboard movement (passenger moving away from the belt) of the passenger. This since it is of interest to see how the belt tension effect the occurrence of non-optimal shoulder belt position. It was also important to find a route with high repeatability in order to keep the route and type of turn as a consistent as possible while altering other variables. Based on these criteria the test track at Volvo Cars was selected (figure 52). The track has a speed limit of 90 km/h, has one sharp turn and can be sealed from other traffic with a gate. During the test each lap was driven in 40 km/h on the straight road parts and in a velocity of 32 km/h through the turn. It was chosen to drive in 32 km/h instead of 28 km/h in this study since the turn selected for this study was more flat than the once in user study one and a similar experience was sought.The turn was taken clockwise instead of counter clockwise to secure an inboard movement.

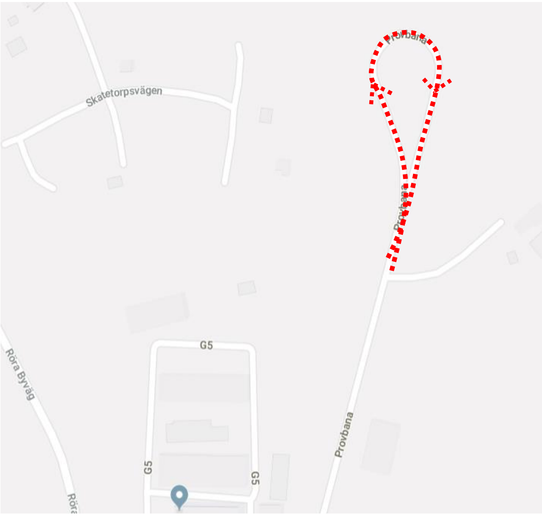


Figure 52 Test track

5.1.5 Execution

The same driver was used during all tests, who also acted as one of the test leaders. The other test leader took notes during the test and did observations. The subjects were told that the test aimed to investigate the comfort of a front seat passenger with focus on belt comfort during normal drive. They also knew that the study is a collaboration project between Volvo cars safety centre and ergonomics department and that the test would be held at a test track at Volvo Cars Torslanda. In the invitation sent to the subjects they were asked not to wear dark or chunky clothing. They were also asked to wear long hair pulled back, to facilitate the analysis phase of the collected data. Furthermore the subjects were asked to bring a mobile phone connected to their e-mail.

The test started in the entrance of the PV building at Volvo Cars Torslanda. The subjects were asked to fill in a GDPR agreement and their weight was collected with a bathroom scale. The weight was collected with cloths and shoes on, therefor 0, 5 kg were subtracted from the weight. When arriving at the car the subjects were asked to remove their jacket, any chunky clothing and leave their bag in the trunk of the car. One test leader was seated in the driver seat, the other in the rear seat behind the front passenger seat and the subject was seated in the front passenger seat. The subject was told to keep the phone accessible. While driving to the test track the subject was provided information about the test;

> "The test consists of four identical laps on a closed track. We will stop between each lap and ask questions regarding your experience of the scenario. Your will get different tasks for each lap and we will do some changes on the belt."

For full manuscript see appendix J. At the track the subject was asked to put a Patricks target on their suprasternal notch as a reference point for the video analysis later on. Before starting the test, the subject got to try the soft belt tension profile while the car wasn't moving. This was done to eliminate the surprise effect that otherwise might have occurred. Instructions for the rest of the test were then provided. The subjects were told that they would get three emails named scenario B, C and D and that they were to open and perform the task in the email when the test leader in the back told them to. They were also informed that they were not tested on how well they performed the task. The interesting part for the test was how they experienced it to perform the task.

Four laps were driven on the track, one scenario per lap. The order of the scenarios were randomly selected for each test. Two of the scenarios contained belt tension and three of the scenarios contained an assignment.

- Scenario A; No assignment and no belt tension
- Scenario B; Assignment and no belt tension
  - Assignment B
    Write an email to me with "breakfast" in the subject. In the mail I want you to tell me what you had for breakfast.
- Scenario C; Assignment and soft belt tension
  - Assignment C
    Reply to the email below;
    "Can you come to the meeting on Tuesday at nine? Was it you or me who was supposed to bring cookies? If you can't make it could you propose a new time?"
- Scenario D; Assignment and firm belt tension
  - Assignment D
    Open your calendar. Create a new appointment to drink coffee with a colleague of your own selection today at 15.30.

The assignments were chosen to be of similar character but different enough so the subjects would not experience improved performance due to practice. They were long enough to last through the whole turn. Between each lap the subjects were asked to fill in a semantic differential scale on how they perceived the belt during the turn. After the differential scale they were asked to mark their perception of how it was to ride through the turn, of the belt comfort and of how it was to execute the assignment in the turn on a 10 cm long line with the scale from "very bad" to "very good". While the subject answered, the test leader probed on why they perceived what they did. A semi structured interview method was selected to be able to have control over the collected subjective data but still be able to follow up on unpredictable leads that might emerge during an interview (see section 2.3.1). The interview generated both qualitative quotes and quantitative judgements on each of the questions.

When all four laps were conducted the subject was asked which of the four scenarios they preferred and why. A picture was taken on the subjects shoulder to be able to confirm that all subjects had good wrapping during the test.

Apart from the subjective data collected during the test, objective data was from the recorded video. This data was then used to find out how much the subjects moved during each scenario.

5.1.6 Analysis

Different analysis methods were used depending on the nature of the data collected. This method section will therefore be divided after data type; quantitative- or qualitative data and whether it is subjective- or objective data.

Quantitative objective data

The quantitative objective data was collected in the same manner as during user study one (see method chapter 4).

From the video footage analysis was made on lateral body movement, lateral head movement, belt position on shoulder and distance form suprasternal notch to belt edge. The methodology used for these analysis are the same as the once used in user study one. See method chapter 4.

Quantitative subjective data

Semantic differential scale

To elicit the subject's direct emotions towards the different scenarios, more specifically different belt experiences, they were asked to fill in a semantic differential. The scale consisted of five antonyms with six circles in between. Six circles were selected to force the subjects to make a statement and not provide them the possibility to be neutral in the question. See the scales in appendix G. To analyse the outcome of the scales all of the subjects ratings were compiled in an excel file. For each antonym couple four horizontal bar charts were created, one for each scenario. The bar charts visualized the percentage distribution of how the subjects had rated. The charts provided an indication of how the subjects perceived the belt tension in comparison to an ordinary belt.

Scales

The subjects got to answer three questions with the help of scales as described earlier. To analyse the answers the distance between "very bad" and the subjects mark was measured in mm. To visualise the judgement of the subjects the results were displayed in boxplots. Boxplots were selected since they provide a lot more information that a regular bar charts. A boxplot visualizes the distribution the mean and quartile one and three. Box plots were made comparing the judgement of the subjects' ratings for the four scenarios. The distribution visualized in the box plots provided a possibility to easily find values that did not concur with the rest of the population which needed further exploration.

Qualitative subjective data

KJ

To analyse the qualitative subjective material gathered during user study two a KJ analysis was performed. All of the documented material from each test person was scanned. Important quotes and information from each interview was written down on post-it and divided after which scenario it was connected to. The post-its represent the opinions of the tested population. To bring order in cluster of information the post-its' were grouped after relevance and inherence.

5.2 Results

The results from user study two include objective measurements as well as subjective results from the rating forms together with comments of the subject's experiences. Some of the pictures from user study two can be found in appendix K.

5.2.1 Lateral movement

No significant difference could be found between either of the four scenarios (see figure 53). Meaning that the subjects moved about the same distance no matter if they were to perform an assignment or if one of the belt tension profiles were used

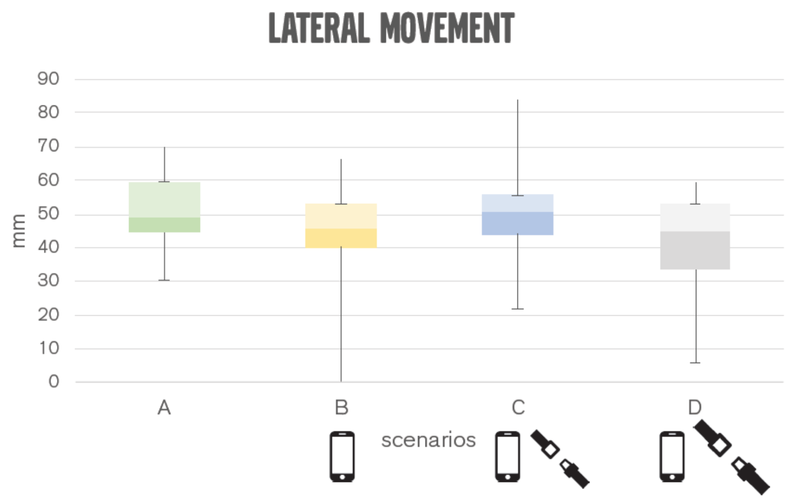


Figure 53 Lateral movement in scenario A, B, C and D

The lateral accelerations were about the same for all of the scenarios, with a mean value at 3.3 m/s^2 for all turns (figure 54). However the system measuring velocity did not function during the test. The driver was keeping track of the velocity and saw on the meter that it was 31, 32 or 33 km/h during all the turns. The measuring system afterwards showed totally different numbers at about 38 km/h. The velocity meter in the car and the velocity measuring matched during user study one, but in this test the measuring system somehow stopped working. Therefor the velocities will not presented, seeing as they are not true. The lateral accelerations during the test seamed more accurate but there might errors there as well.

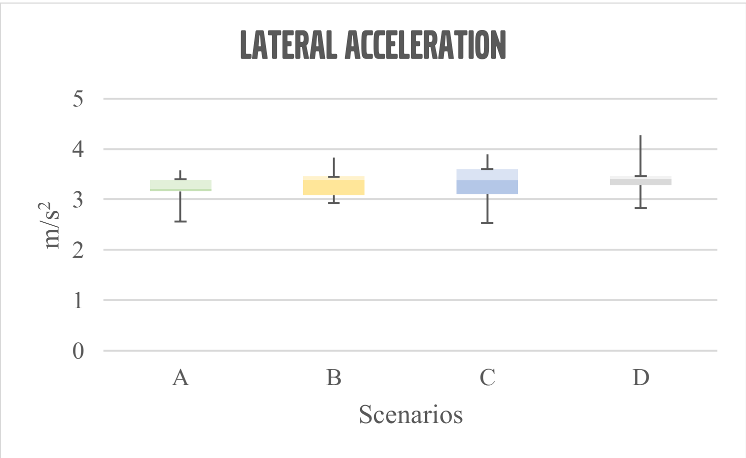


Figure 54 Lateral acceleration during turn in the scenarios

5.2.2 Head position and belt position

The distribution of head positons in the different scenarios are presented in figure 56 and figure 55. During the turn the amount of edge head positions has increased for all scenarios. In scenario B, C and D the amount of off head position has increased as well.

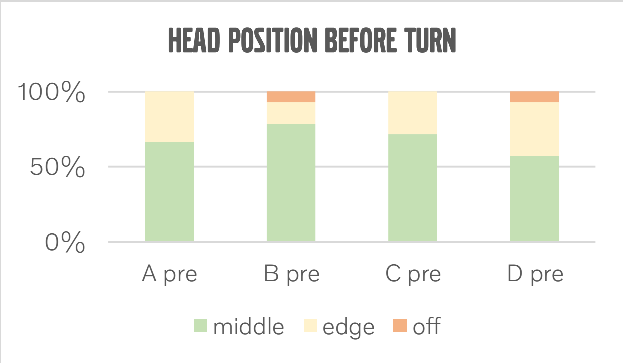


Figure 56 Head position before turn

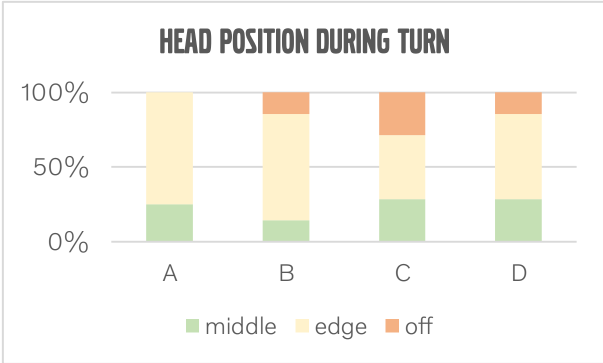


Figure 55 Head position during turn

No subject got a near neck belt position nor did anyone get off shoulder position (table 13). Number 3 is marked with grey in the table representing shoulder edge belt position. Some people had a lot of occasions of shoulder edge belt position while some had none. In table 14 the instances where there was not shoulder edge before the turn and the belt moved to shoulder edge during the turn. At the bottom the sum of shoulder edge due to turn for each scenario is presented, scenario A had 3, scenario B had 3, scenario C had 4 and scenario D had 2. There was no significant difference in shoulder edge due to turn between the scenarios.

Table 13 shoulder belt position pre turn and during turn. Edge= suboptimal shoulder belt position, middle= optimal shoulder belt position

	SHOULDER BELT POSITION							
test persons	A pre	A	B pre	B	C pre	C	D pre	D
1			middle	middle	middle	middle	middle	middle
2			middle	middle	middle	middle	middle	middle
3								
4	middle	middle	middle	middle	middle	middle	middle	middle
5	middle	middle	middle	middle	middle	middle	middle	middle
6	middle	middle	edge	edge	edge	edge	edge	middle
7	middle	middle	middle	middle	middle	middle	middle	middle
8	edge	edge	edge	edge	middle	edge	edge	edge
9	middle	middle	middle	middle	middle	middle	middle	middle
10	middle	edge	middle	edge	middle	edge	middle	edge
11	middle	edge	middle	edge	edge	edge	edge	edge
12	edge	edge	edge	edge	edge	edge	edge	edge
13	middle	middle	middle	middle	middle	edge	middle	middle
14	middle	middle	middle	edge	middle	edge	middle	edge
15	middle	edge	middle	edge	middle	middle	edge	edge

Table 14. Shoulder edge due to turn. Edge = shoulder edge belt position due to turn, middle= nu suboptimal belt position due to turn.

SHOULDER BELT POSITION

	People who got shoulder edge belt position due to turn			
test persons	A	B	C	D
1	middle	middle	middle	middle
2	middle	middle	middle	middle
3	middle	middle	middle	middle
4	middle	middle	middle	middle
5	middle	middle	middle	middle
6	middle	middle	middle	middle
7	middle	middle	middle	middle
8	middle	middle	edge	middle
9	middle	middle	middle	middle
10	edge	edge	edge	edge
11	edge	edge	middle	middle
12	middle	middle	middle	middle
13	middle	middle	edge	middle
14	middle	middle	edge	edge
15	edge	edge	middle	middle
sum	3	3	4	2

5.2.3 Semantic differential scale

In figure 57 – 61 the results from the semantic differential scale are presented. Scenario D, with assignment and the firm pre-pretensioning belt was rated as the safest belt (figure 57). Scenario D also got the highest rating on hugging – suffocating. Scenario A (no assignment, regular belt) and B (assignment, regular belt) were rated as softer than scenario C (assignment, soft pre-pretensioning belt) and D (assignment, firm pre-pretensioning belt) (figure 58). The ratings on uncomfortable – comfortable the ratings were similar among the scenarios although scenario A had ratings slightly more towards comfortable (figure 60). Scenario A and B were rated as the least aggressive (figure 61).

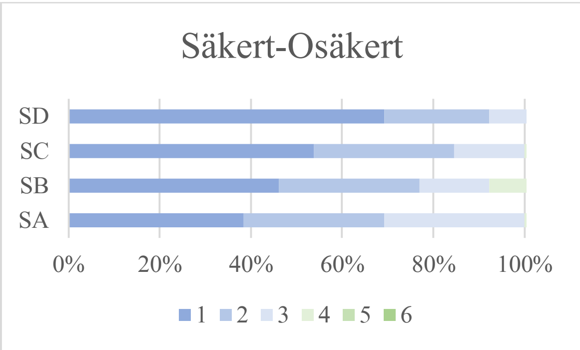


Figure 57 semantic differential scale safe - unsafe in percentage

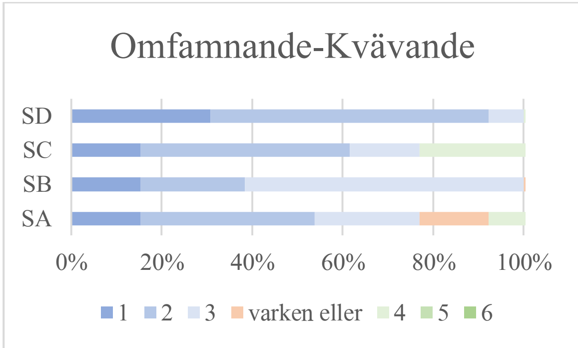


Figure 58 semantic differential scale "hugging - suffocating"

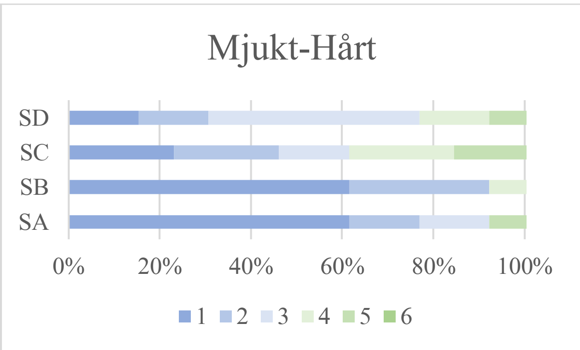


Figure 59 semantic differential scale soft - hard in percentage

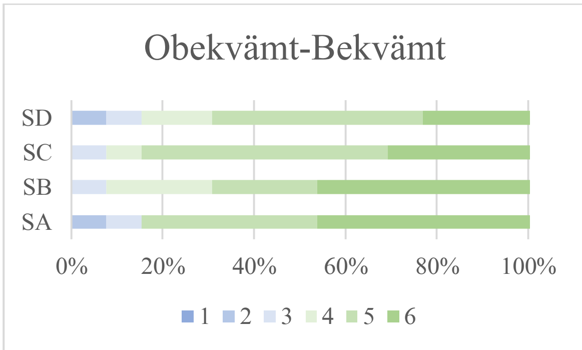


Figure 60 semantic differential scale "uncomfortable - comfortable" in percentage

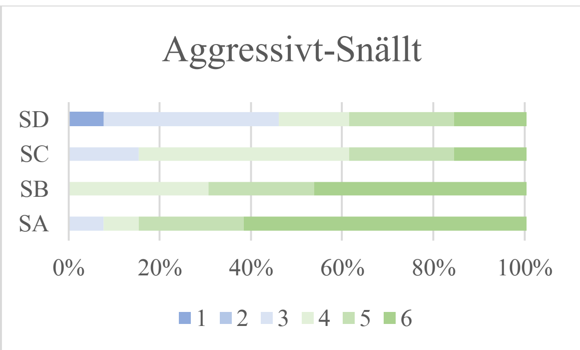


Figure 61 semantic differential scale "aggressive - kind" in percentage

5.2.4 Comfort

There was no significant difference in how the belt comfort was rated between the scenarios (figure 62). Most ratings were above 6 but some rated below, the lowest rating was 1.9 on scenario A. The average comfort measure was highest in scenario D (no assignment, firm pre-pretensioning belt) (figure 63).

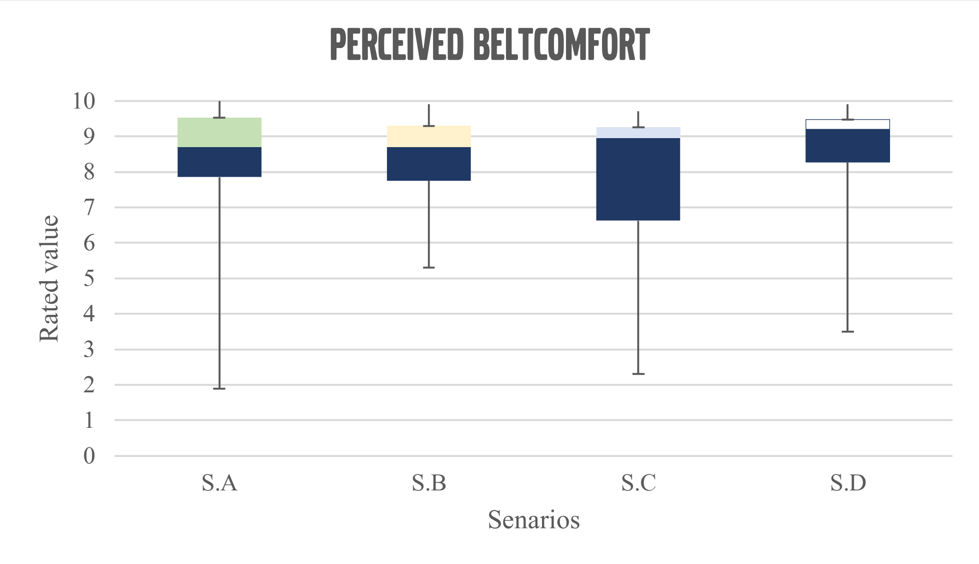


Figure 62. Rated belt comfort during turns

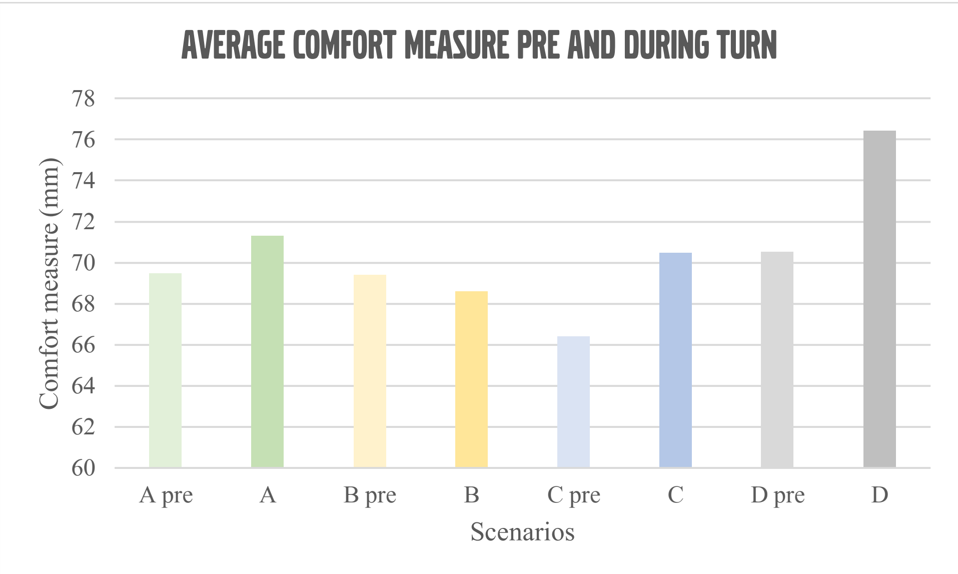


Figure 63 Average comfort measure for all 14 subjects in different scenarios before and during turn

There was no significant difference in how the different turns were rated to ride in (figure 64). The majority rated above 6, but in all of the turns some people rated below. One of the participants rated especially low, 1.9 on scenario A, 1.7 on scenario B, 5.2 on scenario C and 2.6 on scenario D.

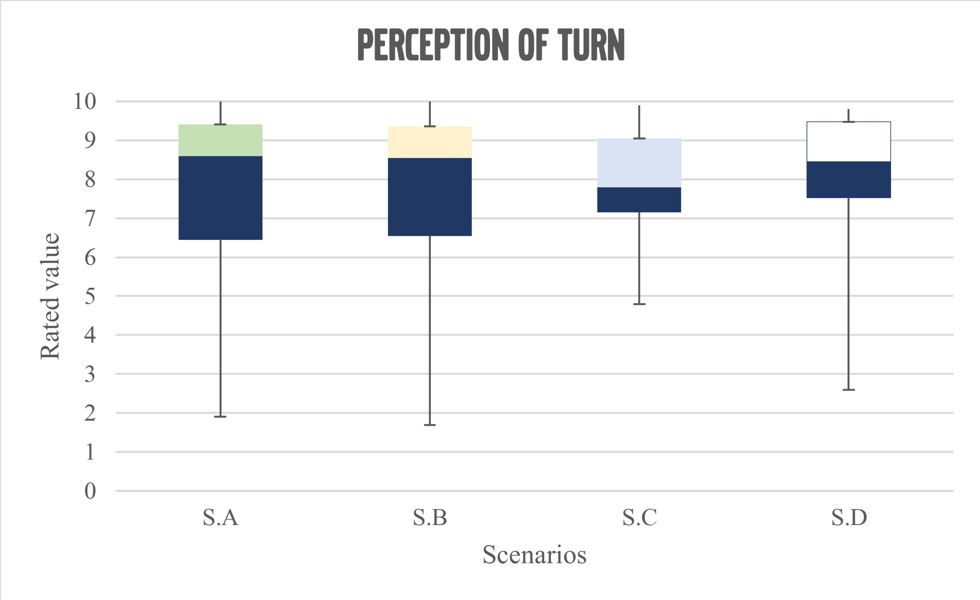


Figure 64 rated experience of riding in the turn

The experiences of performing the tasks were not significantly different among scenario B, C and D (Figure 65). The rating was overall high and above 6, the lowest rating was 1.7, in fact the same person who rated low on riding in the turn, also rated low on performing the task in the turn. The rating of this occupant was on scenario B 2.3, scenario C 1.6 and scenario D 1.4.

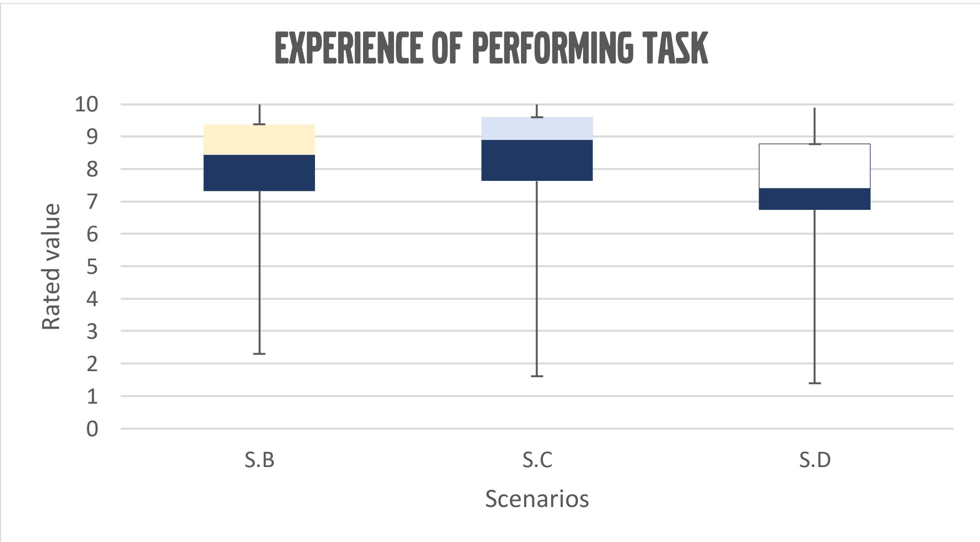


Figure 65. Rated experience of performing the task in the turn

Scenario C was preferred by the most subjects, 43 % (figure 66). Scenario D was preferred by 36 % of the subjects, scenario A by 21 % and scenario B was not preferred by any subjects.

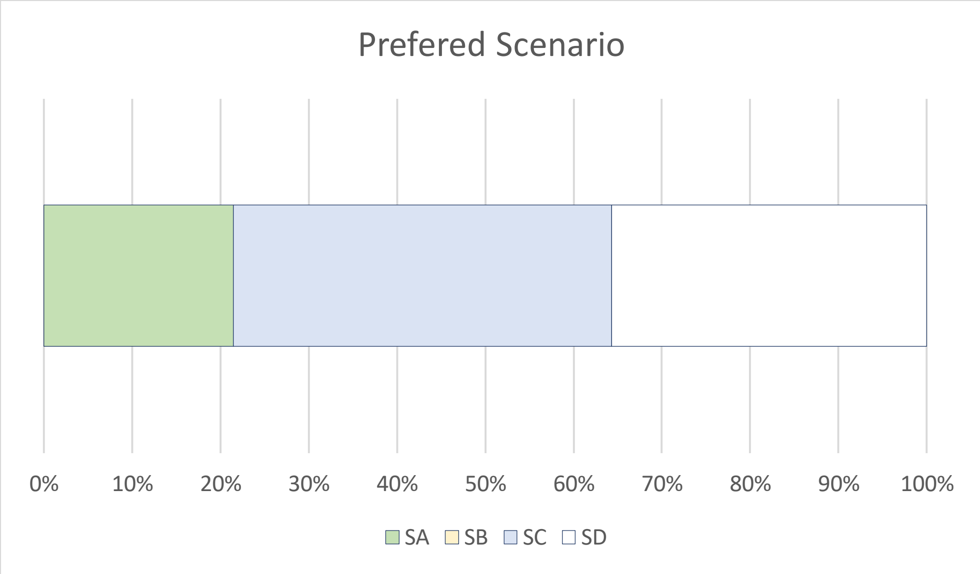


Figure 66. Percentage preferred scenario

5.2.4 KJ

Scenario A

Safety

The comments regarding safety for this scenario were subjects comparing this scenario with the others. Some subjects stated that they would have felt safer if there were some tension present.

> "I liked it more when the belt tightened so that I feel extra safe." Subject No 13

Belt

Most subjects did not mention the belt or said that they did not think about it.

> "Nothing weird with the belt, it was just as normal." Subject No 11

Comments that had a more negative tone were related to that the belt was perceived to be inferior in the turn or that it was too tight.

> "I almost lost contact with the belt during the turn" Test No 8

> "I slipped away more from the belt this time" Subject No 10

Movement

There was no assignment in this scenario so there were only comments regarding the perception of movement. Most subjects mentioned the movement, they stated that they felt it and that it might be good thing to feel that the car is turning.

> "I feel a movement, but that is probably good" Subject No 14

> "Automatically fend of movement but it is nothing that I need to focus on." Test No 4

However some subjects mention that they feel the movement but that they do not like it. They compare to other scenarios and state that they would prefer to be belted tighter.

> "I moved a lot and it is not comfortable" Subject No 8

> "I had to use my arms to avoid moving about" Subject No 11

Focus
Ones subject stated that they liked to see what was going on outside of the car. Another mentioned that they did not notice that the car was driving in the wrong direction before when they had an assignment.

Scenario B

Safety
One person stated that it would have felt safer if the belt would have pulled back as in some of the other scenarios. Another comment regarding safety was that they perceived that they could feel that the belt was working as it should as they felt it on their shoulder.

Belt
Most subjects mentioned that they did not think about the belt. They spoke about a habit of using a belt, that if feels natural and that they would not consider not to use it.

> "The belt does not move, it has a good position" Subject No 14

Some bad overall comments on the belt was that some don't want to feel the belt at all.

> "I just want the belt to work if something happens, otherwise I don't want to feel it." Subject No1

Some also talked about that they would have wanted the belt to restrain since they were comparing with other scenarios which they liked better.

> "Perhaps it would have been better if there was some tension in the belt" Subject No 7

Movement effect on assignment
There were some comments that could be tied to movement and the assignment. Those who had a hard time with the assignment mentioned that they needed to look up from the phone during the turn or that they would want to support themselves. Some also said that they never would do this type of assignment in a car, especially not in a turn.

> "I moved a lot and wanted to hold on to something" Subject No 8

> "I needed to choose if I wanted to do the assignment of look at the road, I took the road." Subject No 2

Otherwise the subjects mentioned that they did not think about the turn or that they were captured by the seat during the movement.

Focus on assignment
When it came to keeping focus on assignment there were no comments on that something would be disturbing. One person even said that it was easier to focus in this scenario compared to others since there was no belt tension.

Scenario C

Safety
Regarding safety, the subjects mentioned that they felt safer in this scenario than in the others. They also stated that it felt reassuring with the belt tension. There were no comments on that if felt unsafe.

Belt
The perception of the belt tension was varied without a clear trend. Some thought that it was good with the tension, liked that it was soft and some even wanted it to be harder. There were a lot of comments

on that the belt tension was nice since they did not have to fend off movement and that they felt like they moved less with the help of the belt.

> "Now I am not moving to the side, this was amazing." Subject No 2

> "The belt helps me not to slide in the chair" Subject No 14

There was also a group of indecisive people that acknowledged that there was a tension but could not decide if it was good or bad.

> "I did not think that the belt tension was bad, just that it was unnatural." Subject No 4

The subjects that did not like the tension talked about the tension as being too long and hard and that if they had a belt that did this all the time it would be annoying.

> "More choking this time, felt like someone was sitting in the back of the car pulling my belt" Subject No 4

Movement effect on assignment

There were different opinions if movement had an effect on the assignment or not for this scenario. Some subjects stated that they were able to sit still through the turn and therefore were able to perform the task.

> "I had a fixed position in the turn, otherwise I would have waited with the assignment" Subject No 1

> "Not as shaky this round, It was easier to do things at the same time." Subject No 11

However some subjects do not want to do an assignment at all as some just did not perform the task in the turn.

> "I prefer to ride on a straight road." Subject No 8

Focus on assignment

Split opinions if it was easy to stay focused on the assignment. Most did not experience decreased efficiency, but there were several comments on that the belt tension was disturbing as they tried to perform the assignment. They either mentioned the tension itself or the sound that the tension makes when it is triggered as reason for the disturbance.

Scenario D

Safety

Subjects that mentioned safety in regards to scenario D had nothing negative to say. They talked about an active protection and that it felt safe to be tightly belted to the chair. Two comments were;

> "Now the car is taking care of me" Subject No 13

> "Feels very safe, someone has been thinking" Subject No 1

Worth mentioning is that one person talked about a compromise between safety and comfort.

Belt

The positive comments regarding the belt can be divided into two major groups; belt in relation to the movement in the turn and belt in relation to body position. When it comes to belt and movement the subjects said that it was good that they sat properly even though it was such a sharp turn. They liked it since the turn was so sharp but expressed a regard on how often they would accept the belt to restrain them. When it came to body position they mentioned that the position of the belt was not to close nor too far away from the neck and also that if felt like the belt held them in a good position. Other comments were;

> "*The belt was cosy*" Subject No 11

> "*I like the belt, it was not too hard*" Subject 13

The indifferent subjects more or less just acknowledged the belt tension. They said things like;

> "*The belt is not uncomfortable just less comfortable"* Subject 15

> "*I feel that it is restraining me but it is not bad I think*" Subject 4

The negative comments were not many but some declared a concern for how children would handle the amount of force in the belt tension. They also talked about that you would learn to endure the tension for safety reasons if they would by a car with this feature. The most negative comment was;

> "*I don't like the tension, it scares me. It feels like something bad is about to happen.*" Subject No 5

Movement effect on assignment

There were not a lot of comments on how the movement effected the assignment execution. However some subjects stated that they did not think about that they were riding through a turn during the scenario. Other things that were mentioned had a more negative tone and talked about feeling nauseous while doing things in a car.

> "I would never do this assignment in a car if it wasn't a part of this test" Subject No 15

Focus on assignment

Most subjects mentioned that it was fine to perform the assignment during the scenario.

> "The assignment went good, I did not need to waste any focus on fending of unnecessary movement." Subject No 12

> "The belt does not disturb me now when I know that it might come" Subject No 5

However some subjects stated that they felt disturbed by the belt during the turn when they tried to perform the assignment. They said things like; I am losing my thought, I forgot what it was that I was supposed to do and the belt disturbed me.

Preferred scenario

No subjects mentioned scenario B to be their favourite. Most people preferred scenario C or D. the most common reason for preferring scenario C was that the subject felt that the belt tension was just enough. It was high enough to create a tension but loose enough to still be comfortable. One person stated;

> "*The tension in the belt caught me, I didn't think about that you were driving.*" Subject No.11

Worth mentioning is that one of the subjects that said that they preferred scenario C didn't perform the task in the turn but they still liked the belt tension even though they had full road awareness.

"*I moved less and the belt helped, but I did not do the assignment so I could see what happened on the road.*" Subject No 15

The most common reason for selecting scenario D as favourite was that the subjects felt like they did not feel the turn which was a good thing as they were doing an assignment. Two comments were;

"*I like the tension, it is just enough, perfect.*" Subject No 13

"*I like that the tension increases successively*" Subject No 8

Worth mentioning is that one person said that a reason to why they liked scenario D could be that they know what might happen in a crash if they would sit in a suboptimal seat position. The subjects preferring scenario A mentioned that it was nice to be able to look out and that it was nice to not have an assignment during the turn. Another opinion is that safety measures should not disturb.

5.3 Discussion

Here the results from user study two will be discussed in relation to the hypotheses formed before the study, found in each headline. In each following part the hypotheses are discussed and either confirmed or denied.

5.3.1 Restraining the passenger with an electrical seat belt will decrease lateral movement in turns

According to the results tension belt profiles does not decrease the lateral movement with the subjects. This means that the hypothesis was proved wrong which is a rather surprising result is. In user study one it could be seen that short people moved more and based on observations made, lack of support was deemed to be one of the reasons. Providing the shorter people with supporting belt tension in the turn should then reasonably decrease the movement. Some subjects mentioned that they felt like the need to fend of the movement decreased when the pre-pretension belts were used. This could indicate that the subjects stopped to fend of the movement when the pre-pretentioning belts were used and instead let the belt work. Perhaps this could have been one of the reasons to why no significant decrease of movement was found when using the pre-pretensioning belts. A relevant question is then if the belt pre-pretensioning profiles did not provide enough support to have an actual impact on the subjects. Perhaps it would have had a more effect if the profiles wold have had higher forces. Though some subjects perceived the pre-pretensioning belts as less comfortable than the regular ones so an increased force should not be the way to go since safety solutions should be comfortable under a longer period of time in order for passengers to use them correctly. However the scenarios with tension profiles were preferred to a higher extent than those without which means that the positive effects of the pre-pretensioning profiles should not be ruled out even though they did not decrease the movement and some found them to create discomfort. If higher pre-pretension belt forces could decrease the lateral movement it could be argued that the function should be added as a function that can be turned on and off.

Regarding the lateral movement of the head it is a clear result that the occurrence of edge positions has increased in all scenarios due to lateral movement. This result strengthens the result seen in user study one that lateral movement can lead to suboptimal head positions in some cases. Scenario A was the only scenario that did not have any occurrence of off head position. The reason for this probably has to do with the fact that the subjects were not assigned with any assignment in scenario A and could constantly look at the road. Looking at the scenarios with assignments, what is strange is that the occurrence of off head positions has increased drastically in scenario C compared to the other scenarios. This is strange since no significant difference in lateral movement was found between either of the scenarios. The reason for the increase of head off positions in scenario C can't be found in the collected data and further studies would have to be performed to answer this question.

5.3.2 Restraining the passenger with an electrical seatbelt will decrease the occurrence of shoulder edge belt position

Using belt pre-pretensioning profiles on the occupant does not decrease the occurrence of shoulder edge belt position. Scenario C and D did not have less occurrences of shoulder edge in turn than scenario A and B, no significant difference could be found. Since the subjects did not move significantly less in scenario C and D this is not a surprising outcome.

Looking at all the belt positions it seems as though some people have a lot of occurrences of shoulder edge belt positions while others never got shoulder edge belt position. When looking at the pictures, the subjects who got shoulder edge due to turn were near shoulder edge belt position during the whole ride. Their initial belt positions were close to or shoulder edge which indicates that the body parameters rather than the lateral movement in the difference scenarios have the highest affect.

By connecting the anthropometric measures with the initial shoulder belt position it seems as though sitting height is essential, which is often proportional to body height. The people who frequently had shoulder edge belt position were all above 1.70 m tall, those who never got shoulder edge belt position were below 1.70 m. Figure 65 and figure 66 are an example of a subject taller than 1.70 m who had an initial belt position near shoulder edge. She also had shoulder edge belt position in 6 of 8 pictures. Figure 68 and figure 67 show an example of a shorter subject who had an initial belt position at mid shoulder. She never got shoulder edge belt position.

Relating this to the result in the pre-study where the effects of the seat parameters were investigated, it was found that the belt outlet position has the highest effect on the initial lateral belt position. High belt outlet position results in initial belt position near the neck, while low belt outlet position results in initial belt position near shoulder edge. In this study it was seen that the relation between the belt outlet position and the sitting height decides the initial belt position. The same results are reached by having low belt outlet position as having high sitting height. Since all subjects had the same belt outlet position, the lowest, difference is only dependant on the sitting height. The goal with user test two was not to look at variants based on body height, only short subjects were chosen. Even so the height between them differed between 1.55 and 1.75 m. If the taller subjects within the short group would have had belt outlet position 2 it is likely that the occurrences of shoulder edge belt position would have decreased severely.

In user test one the participants were allowed to adjust their seat position themselves which made it impossible to draw this kind of conclusion since both the belt outlet position and body height affected the initial belt position together.

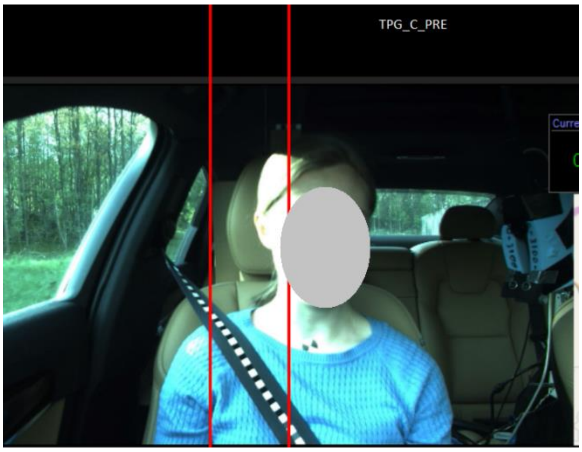


Figure 67 taller person with initial belt position near shoulder edge. Pre turn. Scenario C

Figure 68 taller person with initial belt position near shoulder edge during turn, scenario C

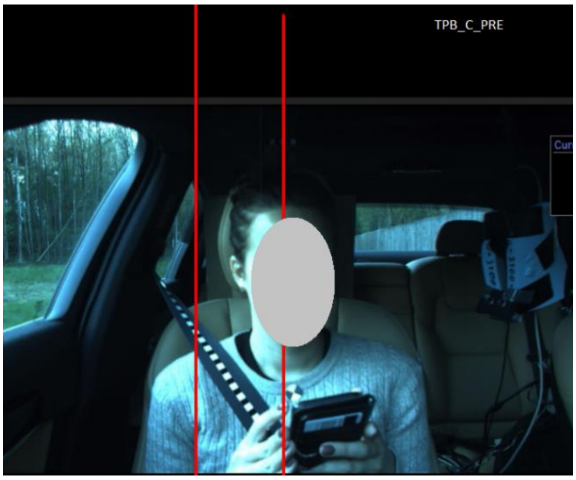


Figure 70 short subject with the initial belt position mid shoulder. pre turn, scenario C

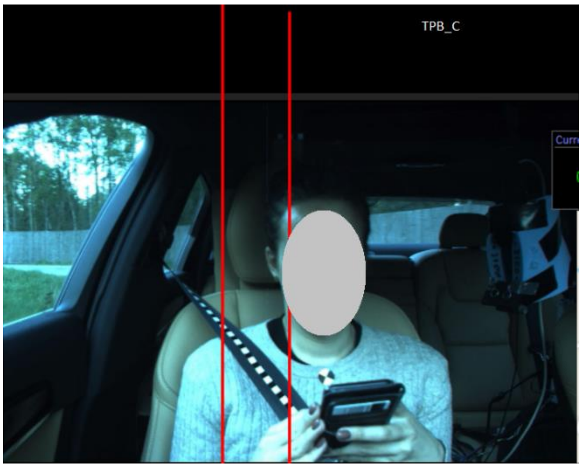


Figure 69 during turn, scenario C

5.3.3 The acceptance of lateral movement will decrease with passengers if they are assigned with an assignment

First of all there is no straightforward answer to weather the acceptance of lateral movement decreased when the subjects were assigned with tasks. When they did not have tasks some thought the turn and lateral movement was disturbing while some did not even notice the turn. Also when the subjects did have assignments some did not notice the turn while some thought it was uncomfortable. There were though slightly more negative comments when they had an assignment and they said that they had to look up during the turn, would have wanted support or did not like doing tasks in turns. This difference was evident when they were asked to choose which scenario they preferred. No one chose scenario B with the task, while some chose scenario A without the task. The motivation for choosing scenario A was that they appreciated that they could look up during the turn and that they did not have to do a task in the turn. Their dislike of doing tasks in the turn might not only be due to lateral movement, but also the feeling of lateral acceleration. Some commented on motion sickness when performing the task in the turn, which has to do with lateral acceleration. Lateral movement and lateral acceleration are closely connected and is difficult distinguish which of them they experience as the most uncomfortable.

Even though there was no difference in the rated experience of performing the task in the turn, the comments indicates a resistance towards performing an assignment in turn which speaks of a decrease in acceptance towards lateral movement. To be noted is that it is not known whether these subjects finds it comfortable to perform a task on a straight road either.

5.3.4 Passengers will move more laterally if they are assigned with an assignment

According to the results it can be stated that performing an assignment will not lead to an increase of lateral movement since there was no significant difference in amount of movement between scenario A and scenario B. This means that the hypothesis is discarded which is a surprising result. Performing an assignment reduces the support for the passenger since they have their hands occupied. Having an assignment also reduces their ability to follow the road and hence their ability to counteract movement. Due to these reasons it is odd that the movement did not increased as the subject got an assignment. A reason to why it did not increase could be that the test was performed on short people. In user study one it was seen that short people were the once that had the largest lateral movement, partly since they did not support themselves. This would mean that assigning them with an assignment would not remove any support and hence that the movement should be almost the same. It could then be questioned if the correct subject group was used for the test, but since the short people are the group that have the largest movements it is more interesting to explore solution possibilities for that group of people which supports the decision that was made.

5.3.5 Passengers will perceive higher safety due to the pre-pretensioning belt

Comparing the three scenarios with assignments, there was a trend that the two scenarios with pre-pretensioning belts were seen as more safe. Looking at the comments regarding the belt and perceived safety all subjects stated that the pre-pretensioning belt felt safer than a regular. When they had tried the pre-pretensioning belt and after that had a scenario without the pre-pretensioning belt they even commented that they did not feel as safe as with the pre-pretensioning belt. Someone rated the scenario without pre-pretensioning belt (B) as a bit more unsafe than safe. This means that the pre-pretensioning belt can make some passengers perceive a higher degree of safety, which seems to increase with higher force on the belt pre-pretensioning, since the stronger pre-pretensioning belt was rated higher than the weaker pre-pretensioning belt.

The fact that the subjects were Volvo Cars employees probably affected this result. Other people may have lower knowledge of the car safety system and the importance of the sitting posture which could lower their acceptance of the belt pre-pretensioning. One subject even made a remark on this as while rating the perceived safety of the pre-pretensioning belt. Using a more theoretical language when talking about perceived safety shows that the subject in question was clearly bias. However, judging all comments, they probably would have perceived high safety even without higher knowledge about the cars safety system. Also not all of the subjects had worked with safety, even though they probably had higher knowledge than the average person since Volvo Cars is a company with safety in their core.

To conclude this, the subjects did perceive higher safety due to the pre-pretensioning belt.

5.3.6 The pre-pretensioning belt with the highest force will decrease the lateral movement the most but the belt comfort will be lower

This hypothesis can be discarded, the higher force pre-pretensioning belt does not decrease lateral movement more than the belt tension profile with lower force. In fact as mentioned above no significant difference can be found in either of the four scenarios.

The results regarding belt comfort are not as unison. There was no difference in rated belt comfort between the scenarios, but in the semantic differential scale the lower force belt was rated as slightly more comfortable than the stronger tension profile. Since the semantic differential scale only shows indications on attitudes, no clear difference in belt comfort between the two tension profiles can be found. There is only an indication that the soft belt might be seen as more comfortable than the firm. Also the comments on belt comfort were scattered, some subjects experienced the soft belt profile as comfortable, while some did not, some experienced the stronger belt profile as comfortable and some did not. There were perhaps some more negative comments regarding the stronger belt profile, also more people chose the soft belt profile as their favourite than the stronger, with the motivation that it was the perfect balance between keeping the subject in place while still not being perceived as smothering. What is interesting here is that some subjects felt like they were held in place by the pre-pretensioning belt even though they moved just as much as when an ordinary belt without tension was used. Perhaps this could be the result of that the subjects did not have to compensate their movement but could rely on the belt instead. However such a conclusion can’t be stated at this stage, further test would have to be done using equipment to measure abdominal muscle tensioning on the subjects.

5.3.7 The pre-pretensioning belt with the highest force will result in rated belt comfort below 5

The higher force pre-pretensioning belt does not result in an overall rating of belt comfort below 5. The majority rated the belt comfort above 8 which is high rating. One person did though rate 3.5 on belt comfort and one at 5.3, but these people rated the belt comfort low in all scenarios. Thus, the stronger pre-pretensioning belt does not result in low rated belt comfort, even though two people rated below 6. The same thing can be seen in the comments, some liked the firm pre-pretensioning belt and described that it made them feel safe and in place, while some found it disturbing.

5.3.8 The soft pre-pretensioning belt will decrease lateral movement and the perceived belt comfort will remain, not have a significant difference

The soft pre-pretensioning belt did not decrease lateral movement, in fact lateral movement was the same in all scenarios. The rated belt comfort was the same for all scenarios so there was consequently no significant difference in rated belt comfort between not having a pre-pretensioning belt and having the lower force belt. The hypothesis can therefore be confirmed.

5.3.9 Test set-up reliability

Since the velocity measuring system did not work, the deviations cannot be shown. This could have been fixed if the pilot test would have been analysed. This was not done due to lack of time. The fact that the test was executed on a test road does though indicate that the deviation should be small. In user study one the deviation was small, with some exceptions due to disturbing traffic. In user study two there was no disturbing traffic so it is plausible that the deviation was even smaller. The observations of the test driver further confirms that the correct velocities were reached.

The malfunctioning measuring system might also have affected the measured lateral acceleration. These could not be observed on the car during the test and can therefore not be checked, even though the measured accelerations align with the lateral accelerations measured in the pre-study and user study one.

If the lateral accelerations are reliable they are needed to validate the choice of velocity. User study one showed that the most lateral movement is achieved riding in a roundabout in 28 km/h. Since User study two was performed on a test route with a wider turn, the choice was made to drive in 32 km/h to compensate. Since no comparisons can be made between user study one and two due to the fact that different routes were used, it is not vital that the lateral accelerations were the same. However it would mean that the results from user study two can be applicable in a roundabout on public roads. Comparing the lateral acceleration in 28 km/h in user study one with all the turns in user study two, the lateral accelerations were slightly higher in user study two. The lateral accelerations in user study two with mean value 3.3 m/s^2 were though within the definition of normal drive at 0.5-3.5 m/s^2 from the pre-study.

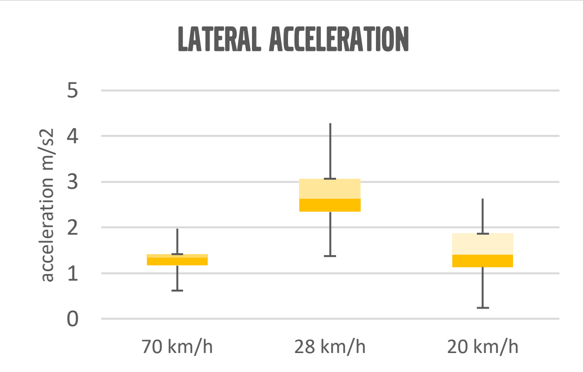


Figure 72 Lateral acceleration user study one

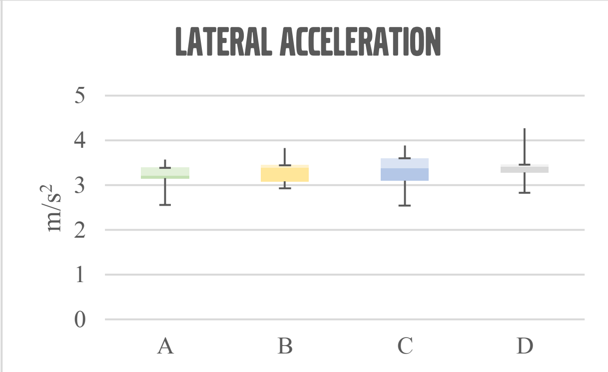


Figure 71 Lateral acceleration user study two

Performing the test on a test route might also have had negative effects. When the subjects rated their experiences their answers might have been affected by the fact that it was not a regular surrounding. This is always a consideration that has to be made, is it worth using a test route and possibly missing a part of the experience. In this case it was necessary to drive on a test course since the turn was to be driven in the opposite direction to investigate the occurrence of shoulder edge belt position and to have a high repeatability to compare the different scenarios.

5.4 Conclusion

When the subjects performed assignments in the turn lateral movement was not increased. This was a surprising result since they could not support themselves as much and did have less road awareness. There are some people who experience discomfort connected to lateral movement when doing assignments. This means that assignments does in some cases decrease the acceptance of lateral movement.

None of the pre-pretensioning belts decreased lateral movement. This was also surprising since the belts were believed to hold the passenger in place. The occurrence of shoulder edge did not decrease, it was found to be dependent on the initial belt position rather than the amount of lateral movement. The taller subjects, meaning the taller of the short subjects with heights between 1,7-1,75 cm, had a belt position near shoulder edge during the whole ride which increased the occurrence for them. Lateral movement sometimes results in a non-optimal belt position but who gets it is dependent on their body parameters, seat position and sitting posture.

The comfort experience of the pre-pretensioning belts is strongly personal. Some people find it comfortable and cosy while some find it disturbing and uncomfortable. This was true for both pre-pretensioning belts even though there were slightly more positive comments on the soft belt and more found it to be their favourite. The clearest difference from when they had a regular was that the opinions were much stronger. People either like pre-pretensioning belts or not.

DISCUSSION

In this chapter the result is discussed in relation to the research questions of the study. Also the selection of subjects and setting for the user studies are discussed.

6.1 How does lateral movement affect torso position, shoulder belt position and head position?

From user test one the conclusion was drawn that lateral movement should be decreased since some subjects did get non-optimal belt positions and head positions while riding in the turns. The off head position is tightly connected to when lateral movement occurs. The connection between lateral movement and non-optimal belt position was though unclear. The group who had the highest occurrence of the non-optimal belt position, people with BMI<25, did not move significantly more than people with BMI>25. From user test two the connection between lateral movement and the non-optimal belt position was retracted. Instead the occurrence of the non-optimal belt position was found to be dependent on sitting height (body height), seat position and sitting posture. Some people have an initial belt position near the shoulder edge which affects the occurrence of shoulder edge, not the amount of lateral movement. The lateral movement was equal for all scenarios but the amount of shoulder edge belt positon varied.

In the light of this the results from user test one does make more sense. The higher occurrence of the non-optimal belt position for people with BMI<25 can be explained with the similarity to a forward longitude seat position. The pre-study showed that the belt outlet position have the highest effect on the initial lateral belt position but also that the longitude position have high affect. It was more difficult to make this connection from user test one since the subjects got to choose their own seat position, which made both the seat position and body anthropometrics affect the initial belt position. Looking back it would perhaps have been more effective to evaluate the initial belt position together with both the seat position and the anthropometry more extensively.

The torso position on the other hand is naturally strongly connected to lateral movement. Both user studies showed that lateral movement in some cases leads to a non-optimal body position. Riding in turns, people have a body position further from the midline than on a straight road. This is of course more occurring when lateral movement is maximized and when the initial sitting posture is deviating from the midline. Sitting posture is complicated since it differs over time and is dependent on personal preferences. Lateral movement is maximized if the passenger is short, riding through a roundabout in around 28 km/h. In user study two the roundabout used was wider than in user study one, therefor the velocity used was higher, 32 km/h. Even though it is not exactly the same, the higher velocity compensates for the wider turn and the results can be applicable in smaller a roundabout on public roads in the velocity 28 km/h

Even though the occurrence of non-optimal belt position is more dependent on the initial belt position than the amount of lateral movement, lateral movement sometimes results in a non-optimal belt position. The fact lateral movement in some cases leads to non-optimal torso- belt- and head position motivates that lateral movement should be decreased.

6.2 How does lateral movement affect ride comfort, belt comfort and seat comfort?

The belt comfort is not strongly affected by lateral movement. This was an expected result since comfort is highly time dependent and a turn only corresponds to a small percentage of the turn. The subjects whom had a belt position near the neck had it during the whole ride which means that it is not affected by the turns. Also their experience of the belt comfort was based more on the whole journey than on the turns specifically. In user test one no differences were found in the comfort measure and perceived comfort based on height or BMI. This is probably due to that their adjustment of the seat position compensated for their anthropometric differences. It was found that seat position had the highest effect on belt comfort.

The comments from the subjects also entailed that the seat comfort was not based on the experience in the turns but rather during the whole ride. The seat comfort is thus not affected by lateral movement and was overall rated high.

The overall ride comfort is the kind of comfort most dependant on lateral movement. In the normal passenger ride setting tested in user test one, lateral movement did not decrease the overall ride comfort. The passenger is used to moving when riding in turns and has overall high acceptance for it. The acceptance decreases when they do activities, then lateral movement is by most people seen as disturbing. Most people do not want to do activities while riding in turns and some even experience that it decreases their ability to do activities. Something to consider is whether the ride comfort is mostly affected by lateral movement or lateral acceleration. Both can be noticed by the passenger and might affect them. The results from user study one showed that there is a slight correlation between lateral movement and lateral acceleration, which indicates that lateral movement is somewhat dependent on lateral acceleration. The comments from user test two show that lateral movement is at least a big part of the experience. Something interesting is the indication that the experience of the ride was more positive with the pre-pretensioning belts, while lateral movement was the same. Some even mentioned that they moved less or did not need to fend of the movement as much. Even though the belts did not decrease lateral movement, some of the subjects felt that they did. This means that the overall ride experience is mostly affected by how much lateral movement they experienced rather than the actual movement.

Since the wish of doing activities while riding cars is likely to increase with the increase of autonomous cars, this might be of greater concern in the future. Therefor a solution to decrease lateral movement and increase the acceptance of doing activities while riding in a turn is needed.

6.3 How does lateral movement affect perceived safety?

Lateral movement does not affect perceived safety, movement while riding in turns is seen as something normal and not something that decreases the perception of safety. Passengers perceive riding in a Volvo s90 as very safe and this perception is rather based on the car brand reputation, the trust towards the driver and/or surrounding traffic. Since the reputation of the brand and car is of high importance the high perception of safety cannot be directly translated to other cars or car manufacturers.

Passengers feels safe in a regular situation, however the belt with tension increased the ratings on perceived safety. This is though not due to decrease of lateral movement, the firm pre-pretensioning belt was perceived as safer than a regular belt but did not decrease lateral movement. This means that it was the belt itself that created an increase in perceived safety and not a decrease in lateral movement. The pre-pretensioning belts made the subjects feel taken care of and as though someone had put a lot of thought into making them as safe as possible.

6.4 What factors affect lateral movement and how?

Short passengers move significantly more laterally while riding in turns than tall people do. A part of the reason for this is that tall people to a higher extent support themselves on the mid panel and the side panel. Supporting the body while riding in turns decreases lateral movement, something that some people do during parts of the journey. It was found in user study one that when the passenger performs activities in the car their hands and arms are often occupied which eliminates their possibility to support themselves, which makes them move more laterally. While focusing on the activity, the road awareness decreases and the passenger cannot fend off movements created by turns ahead. This means that lack of road awareness also increases lateral movement. It was there for surprising that lateral movement did not increase in user study two when the subjects performed assignments.

The pre-pretensioning belts tested in user study two did not decrease lateral movement as predicted. It is difficult to understand why, some subjects even experienced a decrease lateral movement. It is possible that a pre-pretensioning belt with a higher force could decrease lateral movement but the risk is that the belt comfort would then be severely decreased.

Perhaps the most substantial aspect for lateral movement is the velocity and the sharpness of the turn. Riding on a public road in Sweden within the span of normal drive defined in the pre-study, the most lateral movement is achieved in 28 km/h through a roundabout. Maximizing both turn sharpness and velocity also maximizes lateral movement but on roads where the speed limit is higher, the turns are not as sharp. On the roads with roundabouts used in user test one the speed limit was 50 km/h but driving that fast through a roundabout would not be classified as normal drive. The lateral acceleration would be extremely high and it would neither be safe nor perceived as safe.

6.5 Are there any issues with lateral movement for front seat passengers?

One issue that was identified during the three phases of this study was that the perceived ride comfort decreases for some subjects when a passenger performs an assignment while riding in a turn. One of the positive aspects with autonomous cars is that they will create time from the driver who otherwise would have had to steer the car. This time many argues can be used for work, watching movies or similar. According to the results of this study, this would not be an option for many as they would be disturbed by the need to focus on what happens outside of the car in order to preserve an overall good ride comfort, on roads where these kinds of lateral accelerations are achieved.

From the results of user test one it seems as though lateral movement can be a reason to why some people are exposed to a belt position near the shoulder edge. Although user study two showed a contradicting result saying that there is no connection between the two. Instead the occurrence of shoulder edge could be connected to anthropometrical data of the subject and initial seat position. During user study two the initial seat position was locked for all subjects. This means that the belt outlet position was locked in the lowest position. Some of the subjects were rather tall to be in the "short" category and perhaps they should have had the belt outlet positon in the second position to have an optimal initial belt position. Having the belt outlet locked in the lowest position on these tall "short" people was probably a reason to why some subjects had an inferior initial belt position and therefor was more likely to be exposed to a belt position near shoulder edge during turn.

Even if lateral movement is not the largest reason to why some subjects were exposed to a belt position near the shoulder edge it did cause change in position of the subjects' torso. A skewed position means that the subject no longer sits in the intended optimal position in order for the cars restraining system to function optimally. This speaks for the need to develop solutions that would decrease the lateral movement of passengers.

6.6 How can identified issues be solved without compromising belt comfort, ride comfort and perceived safety

The most important issue that was found and that needs to be solved for the sake of the future autonomous cars is the fact that lateral movement might hinder passengers to perform tasks while the car is driving. Also that the passenger is exposed to a skewed torso position while the car is turning.

As discussed above lateral movement was not decreased with any of the pre-pretensioning belts, even though there is a possibility that a higher force would have affect. Therefore if this belt tension should be further developed the tension force should be tested trying to find the level that hinders the movement. It would also be necessary to investigate the duration of the tension. As mentioned earlier whether the tension is liked or not is highly personal. Some people like it while some do not. Some subjects described it as not uncomfortable, just less comfortable and that they think they would get used to it over time. It can be argued the regular seat belts also is something that users have gotten used to since it was introduced. The same thing might happen if the pre-pretensioning belt in turn was introduced. The risk with forcing the use of a pre-pretentioning belt is miss use to eliminate discomfort. If the passenger thinks the belt is too uncomfortable it is likely that they will place it in another way. Then the pre-pretensioning belt would be contra productive and could in fact result in a less optimal belt or body position than without it. Therefor if the function is to be added it is of importance that it is optional.

The movement can also be decreased if the passenger has full road awareness but then opportunity to do activities instead of driving disappears. Further studies should investigate what activities people will engage in while riding in autonomous cars as well as the behaviour when riding through turns. Do people pause their activities while riding in turns or continue doing them? Some of the subjects in user study two solved their discomfort by simply not performing the assignment while the car was turning. Perhaps the car could provide alerts to the passenger when approaching a road section that will generate a lot of lateral movement. In that way the passenger would be able to have full road awareness when needed. However this would create disturbances and hinder the passenger from a continuous work flow which would be sub optimal.

Another way to decrease lateral movement is to simply reduce the velocity when turning. Having autonomous cars driving slower in turns with other “ordinary” cars during a transition period would however be problematic. The AD cars would act as hinders in the ordinary traffic flow creating irritation amongst other vehicles moving in traffic. Another con with this solution would be that more time would have to be spent in the car. If a solution could be created that decreases the lateral movement instead that would be a better way to go.

This study has investigated one possible solution, the pre-pretensioning belt, which was found to not solve the issue, at least not with the selected tensioning forces. It is crucial to recognise that this solution only is one solution within a vast solution space. There can be many other solutions worth investigating. For example there could be several possibilities working with the side cushioning in the seat of the car. An extensive ideation should therefore be performed and evaluation of more concepts to find a solution that is appreciated by more passengers and that also ensures to be comfortable during a long period of time.

6.7 Selection of subjects

To understand the behaviour and needs of people with different ages, car knowledge and impairments further studies should be carried out. Since this is an early investigation of the phenomenon of lateral movement, specific user needs within the user group will have to be part of further studies. All people that might drive in a car from young children to elderly is a wide user group that requires several studies in order to find all user needs.

The fact that all the subjects were Volvo Cars employees probably affected the results, especially the subjective data. Based on the comments from some of the participants it was clear that the fact that they were Volvo Cars employees did affect their perceived comfort. Some of the subjects had even been part of developing the seat. It is plausible that some of the subjects liked the seats a little bit extra because they felt partly responsible for making them. Even the subjects who worked with a totally different thing on Volvo Cars were probably a bit extra positive to their brand. With that said, Volvo Cars employees are people like anyone else and their experience of the belt comfort, seat comfort and overall ride comfort should be similar to other people, only slightly more positive.

Some of subjects had high knowledge about the cars safety system which partly coloured their perceived safety. People with less car knowledge and less knowledge about this particular car model might have rated perceived safety a bit lower. Taking away the participants who had the most safety system knowledge, the comments imply that subjects with less knowledge would still rate perceived safety high. Also among people who are not employed at Volvo Cars, the brand has reputation of producing safe cars. The situation itself also has high effect on perceived safety, many of the subject commented on that there were no disturbances in the surroundings or no disturbing vehicles. In the end the fact that all subjects were Volvo Cars employees increased the perceived safety, but with other subjects it still would have been high.

Another aspect of the subjects is age. For this study only adults between 18 and 65 were included, leaving children and elderly out. However the results from the studies carried out on children in the back seat during evasive manoeuvres showed similar results, that the sitting height and initial belt position have high effect on belt position and lateral movement. This study showed that for adults the height is of high importance, short passengers are exposed to more lateral movement than tall people. The belt position was found to be dependent on the initial belt position rather than the amount of lateral movement. Adults and children seem to be exposed to lateral movement in a similar way despite anthropometric differences. In the study made on children they sat on different cushions which can be seen as compensating for one of the body differences between children and adults, the height. Since there are many other differences between children and adults, further studies need to be carried out to know how children are exposed to lateral movement during normal drive in the passenger seat, this study can only be seen as an indication.

Comparing the results from this study with the study on adults in the front seat during crash avoidance manoeuvres, both studies found that the stature has effect on lateral movement. The study conducted by Reed et al. (2018) also found that BMI has effect on the lateral movement, which was not found in this study. It is possible that the differences in BMI between the subjects were too small in this study to show a difference. The study by Reed et al. (2018) was conducted in Michigan, USA where people might have bigger differences in BMI than in Sweden. This might explain the different results. Of course the difference might also be due to that the studies investigated different kinds of driving situations, normal driving and crash avoidance manoeuvres.

6.8 Selection of setting

Further studies need to be carried out to make sure that the results are applicable in other car environments. As mentioned earlier, the relation between the subjects and the car have effect on their perceived comfort and safety. Other car brands and models have different reputations and deliver different experiences. The seats can be different the colours can be different, the look of the car both outside and inside can be different and so on. Therefor these subjective experiences are only applicable in a Volvo S90 with a comfort seat. The results can give indications for similar car types and seats, but for some cars the subjective results are not applicable at all. The same thing is true for the surrounding setting. Executing the test in another country would probably have changed the results totally, especially the overall ride comfort and perceived safety.

The objective data on the other hand is more applicable in other cars and environments. The lateral movement will not be exactly the same in different cars and countries, but since it is affected by basic mechanics such as velocity, sharpness of turn and lateral acceleration, the results are expected to be highly comparable. However if results are to be compared with the tests performed in this study it is essential that a seat is used with approximately the same amount of cushioning in the seat and the backrest. This since the cushioning supports the passenger and hinders movement.

The same thing can be said about the position in the car. The rear seat and driver seat are different from the front passenger seat. The rear seats are flatter and provided with less cushioning and the driver's seat provides other types of support such as the steering wheel. Similarities in the lateral movement patterns are though expected to be found. This is confirmed by the study performed on children in the rear seat that got similar results that the amount of movement is dependent on initial belt position and sitting height. However it is important to note that lateral movement was found to be affected by whether the passengers supported themselves during the ride or not. The ability to do so varies in different positions of the car.

The perceived safety and comfort is also different being a driver, a front seat passenger or a rear seat passenger. These differences are part of the reason why this study was needed, there was an information gap regarding the front seat passenger that needed to be filled.

CONCLUSION

In this section of the report the overall conclusions from the three phases of the project will be presented.

The effects of lateral movement on front seat passengers have been investigated, a lot of insights have been gained, while some areas still need further research. First of all non-optimal belt position and head position can occur due to lateral movement but is more dependent on the initial sitting posture, seat position and seated body height. Lateral movement does influence the upper body position, and can in some situations lead to a non-optimal body position. Due to this lateral movement should be decreased.

The belt comfort and seat comfort are rather dependant on the whole ride than the experience of certain turns. The overall ride experience on the other hand can be affected by lateral movement in turns. When the passenger was not occupied with an assignment and had high road awareness, lateral movement did not cause discomfort. When the assignment was introduced lateral movement was not increased but some subjects did experience discomfort and some mentioned that they found it harder to perform an assignment in turn than on a straight road section. This is something that will be important to solve in future autonomous cars when the possibility to do activities in the car will be demanded.

Lateral movement is not mentioned when people are talking about their perception of safety. This was the same both when the subjects had full road awareness and when the awareness was limited. Therefore it can be stated that lateral movement does not affect the perception of safety but is rather seen as a natural phenomenon.

Lateral movement itself is affected by a lot of parameters, the height of the passenger and the velocity were found to be the most important aspects. The most movement was generated in roundabouts in 28 km/h on short passengers who was not using the tunnel armrest or door armrest for support.

To assure an optimal body position during the whole ride and high comfort and efficiency in future autonomous cars without decreasing the velocity, lateral movement should be decreased. There are many ways to do so, this study tested only one solution within the vast space of possible solutions. None of the pre-pretensioning belts decreased lateral movement and the attitude towards them is personal. If it is to be implemented further investigations on the force and duration needs to be done, but one thing is certain, it needs to be optional. Other ideas within the space of solutions should be investigated to assure that the passenger always stays in an optimal position and has a comfortable ride.

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9 Appendix

A Form Explorative driving one

Table 15. Form Explorative driving one

Velocity km/h Seat position	7,2 - 18	18 - 36	36 - 54	54 - 72	72 - 108
Forward					
Backward					

B Form Explorative driving two

Table 16 Form Explorative driving two

identify interesting turns			
Type of turn	Velocity km/h	Yaw rate degrees	Lateral acceleration m/s2
T cross			
roundabout			
T cross left turn			
turny road			
roundabout third exit			
roundabout third exit			
T cross right turn			

C List of all parameters

Table 17 List of all parameters, they are rated on how much they affect the research areas from 1 to 3 where 1 is low affect and 3 is high affect.

Important parameters

Type	Parameter	Latteral movement	factor 1-3	Safety (safety distance belt+head position)	factor 1-3	Perceived safety	factor 1-3	Comfort (belt comfort, seating comfort, overall ride comfort)	factor 1-3	Total factor
	Age		*		*	older more carefull?	1	Old person lower overall ride comfort?	1	2
	Gender		*	since F9	2		*			2
Posture (body)	Initial sitting posture	sitting with slouch--> less movement lower center of mass, sitting awry--> more movement less suport from seat, sitting "propperly"--> less movement more support from seat	2	starting position will effect outcome	2		*	How you sit affect overall ride comfort, seating comfort and belt comfort	3	7
antropro methrics	Body height	longer persons should move more lateraly due to pendulum effect	1	Longer person will sitt longer back due to legs, and therefore have less wrapping. Not as safe.	3	D4, F4, Less wrapping - less percieved safety	1	D4, F4, Less wrapping - higher belt comfort	1	6
	Sitting height	longer persons should move more, due too more momentum or pendulum effect	1	Most common high body height - high sitting height. If only legs are long the wrapping will be worst. If low body height and high sitting height - better wrapping.	3	see D5 and F5, if high rapping - high percieved safety	1	D5, F5. high wrapping - low belt comfort		5
	Shoulder width		*	broad sholders--> better lateral belt position	2	People with narrow shoulders feel like the belt is going to fall off - low percieved safety	2		*	4
	Waist	low center of mass--> less movement	*	Effect the initial lateral belt shoulder position, as well as wrapping degree. High torso deapth - belt closer to neck - high safety. Also more wrapping - more safe	2	F9 More wrapping, high perceived safety	2	thick waist - Belt closer to neck - low belt comfort. More fat more seating comfort	2	6
	BMI	High BMI less movement	2	High BMI usually means high body volume. See F7. Lowest safety are people with low BMI since tall and thin. F4, F7	2	High BMI usually high body width - high percieved safety	*	low BMI - low belt comfort. More fat more seating comfort	2	6
	Torso depth, fat upper body or breast		*	Broad torso deapth - belt closer to neck - high safety. Also more wrapping - more safe	3	F9 More wrapping, high perceived safety	2	Belt closer to neck - low belt comfort	2	7
	Muscle distribution	Strong obleque stomach muscles --> less movement	2	Since D13 less muscles larger safety risk	1		*		*	3
										0
Users mer	Car experience		*		*	a lot of car experience--> feel safe, experienced prior car accident--> feel less safe	2		*	2
	Gender		*		*		*		*	0
	Occupation		*	Working with ergonomics / safety can effect your inital sitting position, seat position and belt positon	1	working within the car industry --> high risk awareness, specially if working within safety department	3		*	4
										0
										0
Car enviro	Sound		*		*	lound sounds that can be assosiated with car failiure--> feel unsafe	1	Uncomfortable sound - bad overall ride experience	1	2
	Temperature		*		*		*	Comfortable temperature vital for overall ride comfort	2	2
	Light		*		*	dark outside of car--> decreased sight--> feel unsafe	1		*	1
	Cameras		*		*		*	Feeling watched might lead lower overall ride comfort	1	1
	Driver		*		*	drivers state affect perception of safety	3	The drivers state of mind affect mental comfort - overall ride comfort	1	4
	Backseat passenger		*	If talking to backseat passenger--> bad seatblt positon	2	mental state/verbal communication can affect both driver and fron seat passenger	2	If talking to backseat passenger--> bad seatblt positon,bad belt comfort	1	5
	road awareness	If follow road--> predict movement and move less	3	since D28--> bad sight larger safety risk	3	can't see what is going on	2		*	8
										0

Table 18List of all parameters, they are rated on how much they affect the research areas from 1 to 3 where 1 is low affect and 3 is high affect.

Seat positi	Longitudal position	possible more movement farther back (think rollercoaster)	1	seat position far back--> worse seatbelt positon (less contact with seatbelt)	3		*	Seat position far back more comfortable due to less contact with seatbelt and more leg space. Belt comfort and overall ride comfort.	2	6
	Backrest recline		*	seat position far back--> worse seatbelt positon (less contact with seatbelt)	2		*	High seating comfort with a lot of backrest recline	2	4
	Height	move center of mass, higher seat perhaps more movement	1	higher up--> better wrap degree--> better belt positon	3		*	Only affect if the person hit the head in the cieling - overall ride comfort	1	5
	Seat recline	more recline--> more friction--> less movement	1	backward recline leads to less wrapping - less safety.	1	backward - less wrapping - less percieved safety	*	Backward - less wrapping - higher belt comfort	2	4
	Seat cushioning	More side cushioning provides more support--> less movement	2	since D34	1		1	A lot of cushioning higher seating comfort	2	6
	Seat material	Different materials --> different friction, more friction --> less movement	1	sicne D35	1		*	Material against skin affect seating comfort	1	3
										0
Car seatbe	Wrap degree		*	High wrap degree - high safety	3	hugging feel-->safe	3	High wrap degree, less belt comfort	3	9
	Height on B-pillar		*	since it effects C35. High B-pillar - low wrap degree - low safety.	2	F36 high wrap - high percieved safety	2	High wrap degree, less belt comfort		4
	Chosen belt position, in relation to upper body or breasts		*	See torso depth. Also belt above breast - belt closer the sholder - less safe.	2	See torso depth	*	See torso depth, also belt above breast, belt closer to shoulder - higher belt comfort	2	4
	Lateral belt sholder position		*	Inside armpitt measure - positive safety, outside armpitt measure - negative safety	3	possibly feel less safe if beltposition is negative	2	Near neck low belt comfort	3	8
										0
Route	Speed limit	High speed limit--> smooth roadsection-->less movement	2	See lateral movement	2	if driver drives faster than permitted--> unsafe	2		*	6
	Turn degree	Sharp rurn--> latteral movement and latteral acceleration, seen during explorative drive	3	See lateral movement	3	See lateral movement - less percieved safety	2	Sharp rurn--> latteral movement and latteral acceleration, seen during explorative drive. Lower overall ride comfort. Can also affect belt comfort, but depends if the motion is towards neck or from	2	10
	Road condition	Affects possible velocity. Slippery conditions--> lower velocity	1	See lateral movement	1	slippery road, less percieved safety	3		*	5
	Route length	Longer route--> tired passenger and more prone to do other activities in car--> more movement	2	See lateral movement	2	unsafe feeling decrease with time	1	Lower overall ride comfort after long time	2	7
	Traffic situation	alot of traffic --> uneven and slower driving	1	See lateral movement	1	alot of traffic --> uneven and slower driving	2	Uneven driving -> less overall ride comfort	1	5
	Setting		*		*	think cliff	1	Affect overall ride comfort	2	3
										0
Driving sty	Velocity	high velocity in turn--> more latetral acceleration+movement, seen during explorative drive	3	See lateral movement, more dangerous if crash	3	high velocity (driver less controll? More can happen if accident	3	D49, more lateral movement leads to less overall ride comfort	2	11
	Latteral acceleration	High latteral acceleration--> alot of latteral movement, but low lateral acceleration in one point does not always mean low lateral movement, can be large movement due to earlier lateral acceleration.	3	See lateral movement	3	less percieved safety - experienced during explorative drive	3	See lateral acceleration, more lateral movement leads to less overall comfort	2	11
	Smoothnes	smooth driving--> less movement, seen from explorative drive	2	See lateral movement	2	beliefe in drive- jumpy does not feel safe, experienced explorative drive	2	Smooth driving - overall ride comfort	2	8

D manuscript User study one

Hämta person i PVE entré, säga hej tack för att kom. Avhandla trevligheter. Nu står ju du på ergonomis lista så det finns ju ett muntligt avtal över hur sekretessen ska hanteras men på grund av GDPR så behöver det avtalet säkras upp med en namnteckning så vi har med det här så du kan få läsa igenom det och skriva på nu så ser vi till att det hamnar rätt.

Vi ska även väga alla för att säkerställa att vikten stämmer. Be dem ta av sig jackan.

Gå till bil

Testet kommer gå till så att Anna här kommer att köra bilen och du kommer att få sitta i framsätet av bilen och bara åka med. Vi kommer att åka en liten bit i området runt Volvo och stanna två gånger då du kommer få svara på frågor.

Kommer till bilen

Här är bilen, det är en Volvo S90. Du kan **lägga jackan, mobiltelefonen på ljudlöst** och annan utrustning som skulle kunna störa under testet där bak sedan är det bara att hoppa in i bilen. Tänk dig som en **vanlig kortare tur du åker med en kollega** eller familjemedlem.

Det sitter **tre kameror** som vi använder för att samla in data. Testet pågår under **hela tiden** vi kör. Innan vi kör iväg kommer vi att behöva fästa en **referenspunkt** på dig, hoppas att det går bra.

Ger tid att ställa in stol om de vill det. Noterar ifall de gör justeringar på stolen i formulär samt fyller i säkerhetsdelen.

Visa **linjal** framför passagerare till kameran. Vi kommer nu **att åka till Björlandahallen** och där kommer du att få svara på lite frågor. Du får gärna tänkta att du åker på en kortare utflykt.

Kör iväg

Stannar vid Björlanda skola

De fyller i formulär, anna probar

Av vilka anledningar upplevde du… ?

Förändrades … under någon del av rutten?

Nu kommer vi köra en kort bit och komma tillbaka hit då du ska få svara på frågor igen.

Kör till traktorservice och tillbaka till björlandahallen.

Vi tar upp formuläret igen och frågor

Har upplevelsen av… förändrats?

Var det vid någon speciell del av rutten?

Nu ska vi åka tillbaka till Volvo och avsluta testet.

Parkera

Be personen sitta kvar. Ta en bild på bältesomslutningen, lämna tillbaka jackan och mobil.

Tack för att du har varit med i vår studie.

E Participant form User study one

User study one

TP:______________________________

Frågerunda 1

Markera din upplevelse med ett kryss på linjen

Hur upplever du åk-komforten i sin helhet?

Väldigt dåligt väldigt bra

Hur upplever du säteskomforten?

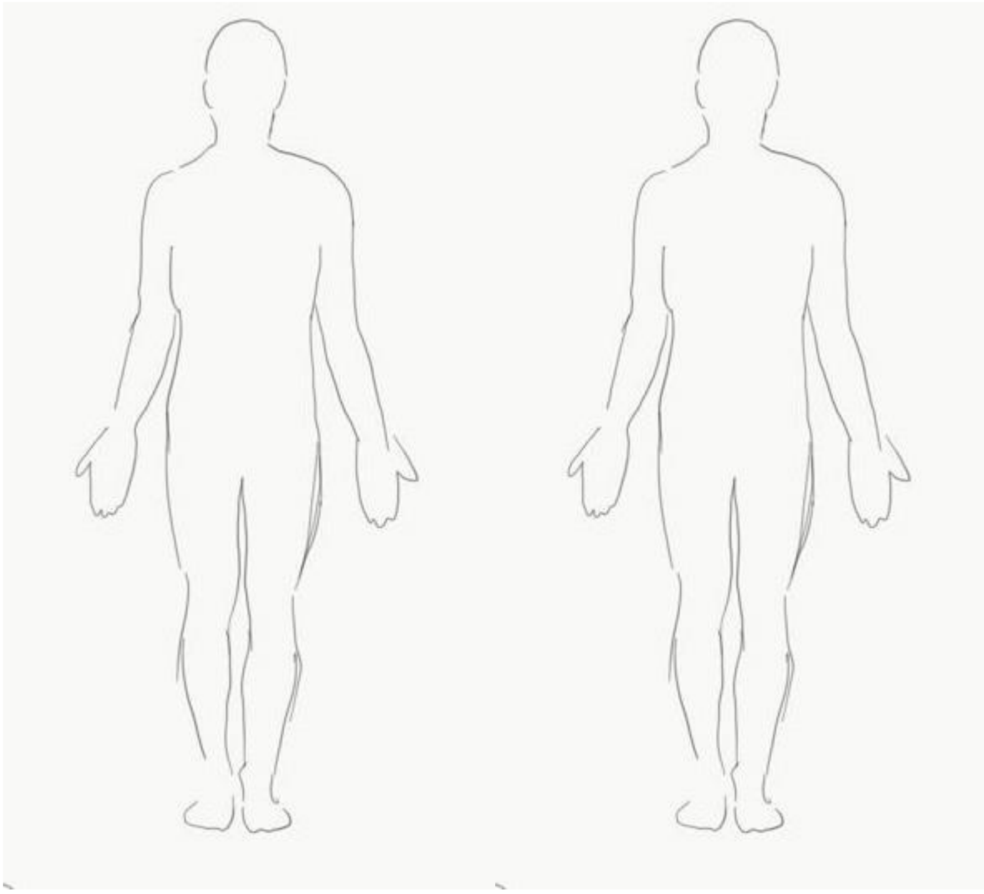
Väldigt dåligt väldigt bra

Hur upplever du bälteskomforten?

Väldigt dåligt väldigt bra

Markera på bilderna där du upplever eventuell komfort med grönt och eventuell diskomfort med röd.

Fram Bak



Hur upplever du säkerheten?

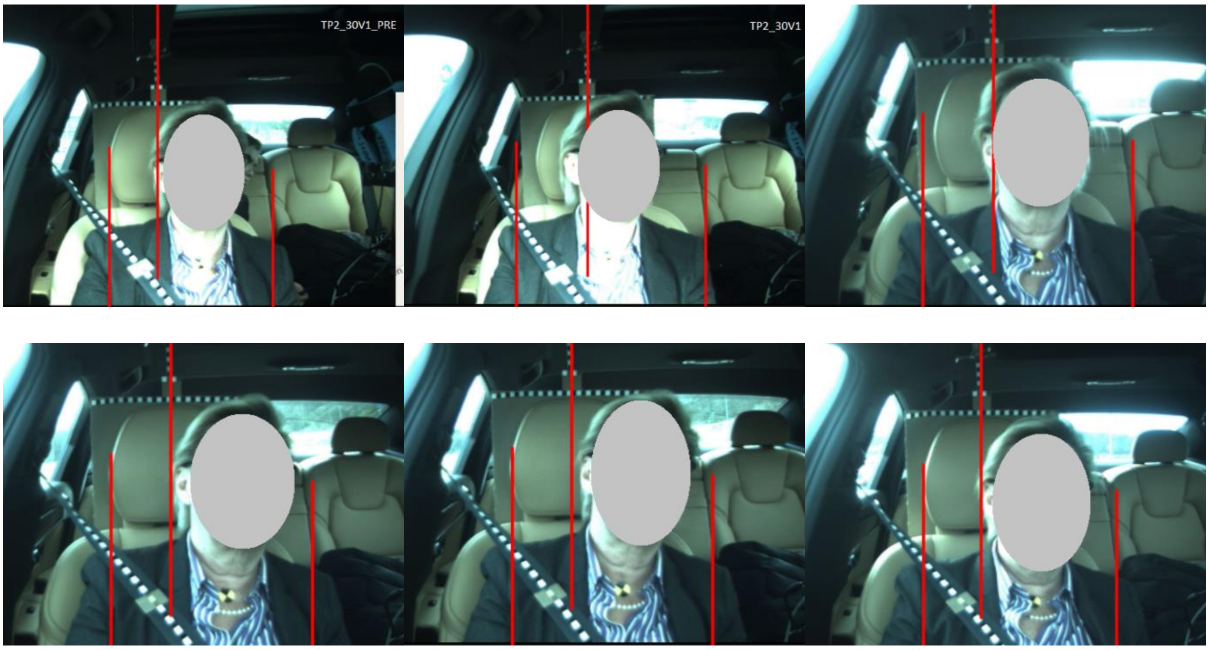
____

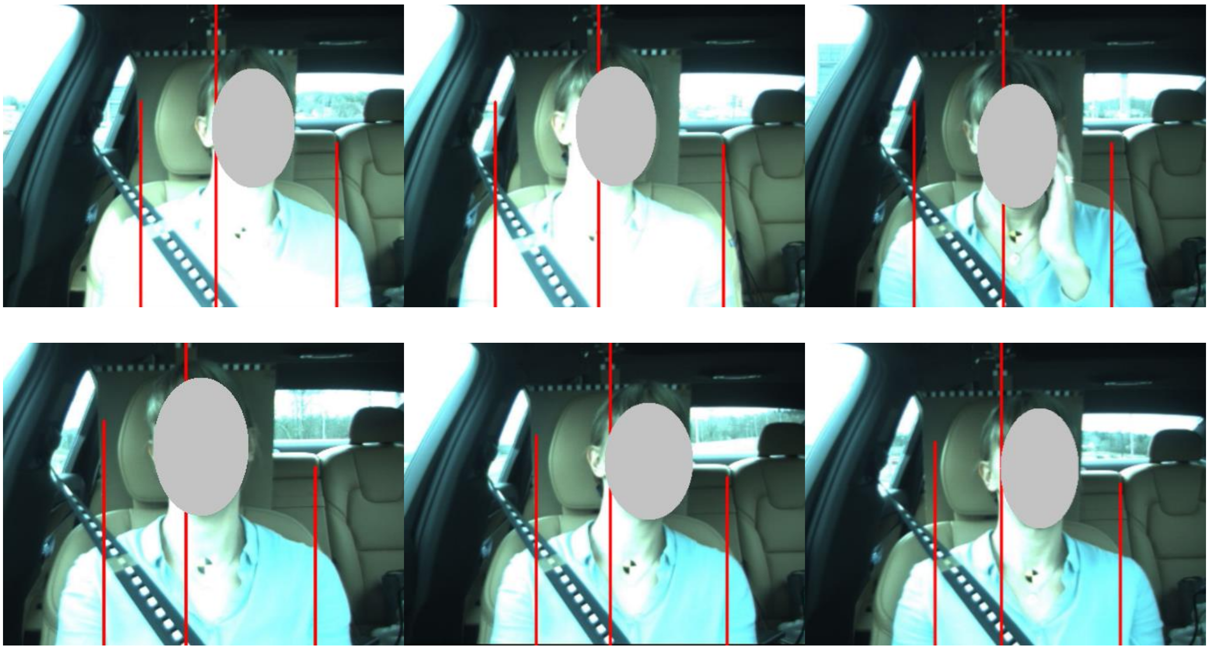
Väldigt dåligt väldigt bra

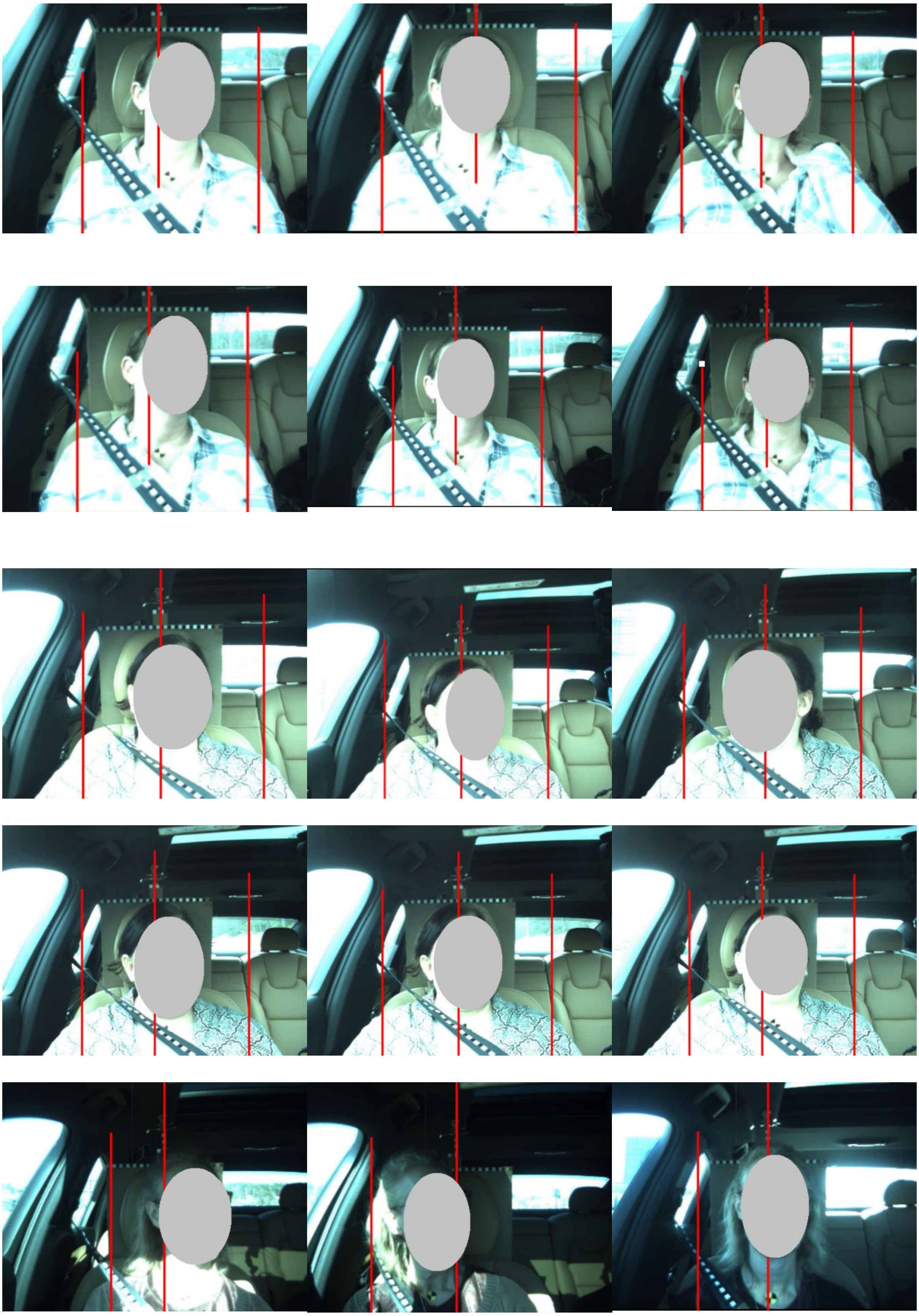
F Pictures from user study one

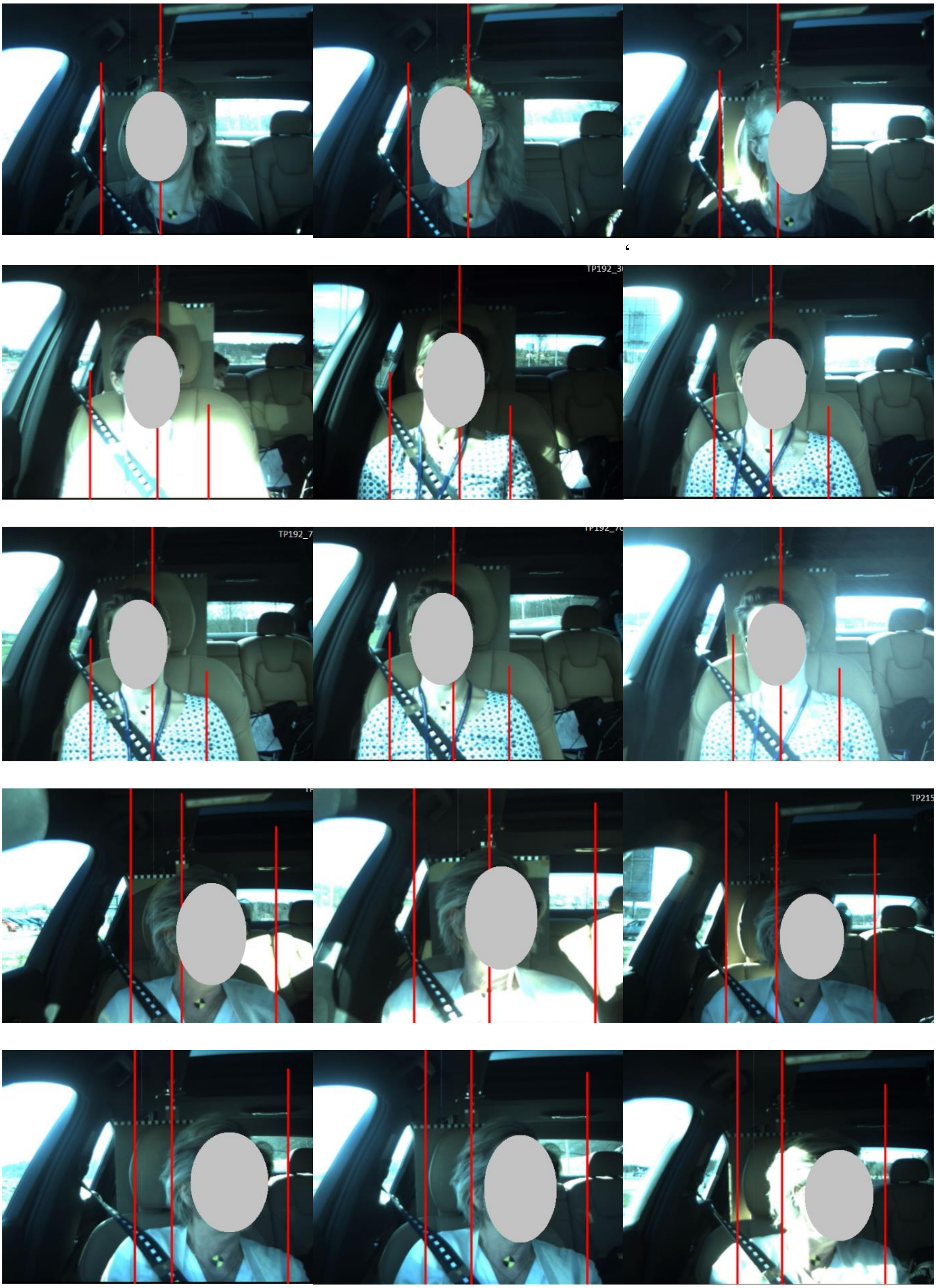
Below some of the pictures used for analysing are presented. For each of the subjects six pictures are shown of the total 12 per subject. The left turns in 28 km/h, right turn in 20 km/h and left turn 70 km/h are presented, while right turn in 28 km/h, left turn in 20 km/h and right turn in 70 km/h is not shown. The ride lines were used for analysing, the right one was used to find the frame in the turn where the most lateral movement was found. The middle line was used to measure their lateral position and the left line was used to determine the belt position. If the belt midline crossed the shoulder inside the red line, it was mid shoulder and if it crossed on the outside it was shoulder edge.

28 pre left	**28 left**	**20 pre right**
70 pre left	70 left	20 right









User study two

TP:______________________________

Scenario 1 ☐

Markera mellan motsats orden med ett kryss hur du upplever bälte tunder svängen

Säkert	O	O	O	O	O	O	Osäkert
Aggressivt	O	O	O	O	O	O	Snällt
Omfamnande	O	O	O	O	O	O	Kvävande
Mjukt	O	O	O	O	O	O	Hårt
Obekvämt	O	O	O	O	O	O	Bekvämt

Scenario 1 ☐

Markera din upplevelse med ett kryss på linjen

Hur upplever du att det är att åka i svängen?

____

Väldigt dåligt väldigt bra

Hur upplever du bälteskomforten?

____

Väldigt dåligt väldigt bra

Hur upplever du att det var att utföra uppgiften i svängen?

____

Väldigt dåligt väldigt bra

Scenario 2 ☐

Markera mellan motsats orden med ett kryss hur du upplever bältet under svängen

Säkert	O	O	O	O	O	O	Osäkert
Aggressivt	O	O	O	O	O	O	Snällt
Omfamnande	O	O	O	O	O	O	Kvävande
Mjukt	O	O	O	O	O	O	Hårt
Obekvämt	O	O	O	O	O	O	Bekvämt

Scenario 2 ☐

Markera din upplevelse med ett kryss på linjen

Hur upplever du att det är att åka i svängen?

Väldigt dåligt väldigt bra

Hur upplever du bälteskomforten?

Väldigt dåligt väldigt bra

Hur upplever du att det var att utföra uppgiften i svängen?

Väldigt dåligt väldigt bra

Scenario 3 ☐

Markera mellan motsats orden med ett kryss hur du upplever bältet under svängen

Säkert	O	O	O	O	O	O	Osäkert
Aggressivt	O	O	O	O	O	O	Snällt
Omfamnande	O	O	O	O	O	O	Kvävande
Mjukt	O	O	O	O	O	O	Hårt
Obekvämt	O	O	O	O	O	O	Bekvämt

Scenario 3 ☐

Markera din upplevelse med ett kryss på linjen

Hur upplever du att det är att åka i svängen?

Väldigt dåligt väldigt bra

Hur upplever du bälteskomforten?

Väldigt dåligt väldigt bra

Hur upplever du att det var att utföra uppgiften i svängen?

Väldigt dåligt väldigt bra

Scenario 4 ☐

Markera mellan motsats orden med ett kryss hur du upplever bältet under svängen

Säkert	O	O	O	O	O	O	Osäkert
Aggressivt	O	O	O	O	O	O	Snällt
Omfamnande	O	O	O	O	O	O	Kvävande
Mjukt	O	O	O	O	O	O	Hårt
Obekvämt	O	O	O	O	O	O	Bekvämt

Scenario 4 ☐

Markera din upplevelse med ett kryss på linjen

Hur upplever du att det är att åka i svängen?

____

Väldigt dåligt väldigt bra

Hur upplever du bälteskomforten?

____

Väldigt dåligt väldigt bra

Hur upplever du att det var att utföra uppgiften i svängen?

____

Väldigt dåligt väldigt bra

User study two

Car: Volvo S90

Observer: Agnes Andersson   Print name: ______________   Datum:____________ _

Test nr:__________   TP nr:_________   GDPR:____   Weight:____________ _

Scenario order

S1__________ _   S2______ _   S3__________ _   S4_____ _

Questions Senario 1

Av vilka anledningar upplevde svängen som du gjorde?

Svarskategori	inget speciellt	rörde mig mycket	röde mig lite pga bälte	jobbigt med uppgift

	det gick fort	det gick långsamt	skarp sväng

övrigt

Av vilka anledningar upplevde du bälteskomforten som du gjorde?

Svars kategori	tänkte inte på bältet	drog åt mycket		nära halsen
		positiv	negativ	

övrigt

Vad påverkade ditt utförande av uppgiften?

Svarskategori	rörelse i svängen	åtdragning av bälte	brist fokus	fokus	vana

	åksjuka

övrigt

Questions Senario 2

Av vilka anledningar upplevde svängen som du gjorde?

Svarskategori	inget speciellt	rörde mig mycket	röde mig lite pga bälte	jobbigt med uppgift	personliga preferenser

	det gick fort	det gick långsamt	skarp sväng	samma som scenario

övrigt

Av vilka anledningar upplevde du bälteskomforten som du gjorde?

Svars kategori	tänkte inte på bältet	drog åt mycket positiv	negativ	nära halsen	samma som scenario

övrigt

Vad påverkade ditt utförande av uppgiften?

Svarskategori	rörelse i svängen	åtdragning av bälte	brist fokus	fokus	vana

	åksjuka	samma som scenario

övrigt

Questions Senario 3

Av vilka anledningar upplevde svängen som du gjorde?

Svarskategori	inget speciellt	rörde mig mycket	röde mig lite pga bälte	jobbigt med uppgift	personliga preferenser
	det gick fort	det gick långsamt	skarp sväng	samma som scenario	

övrigt

Av vilka anledningar upplevde du bälteskomforten som du gjorde?

Svars kategori	tänkte inte på bältet	drog åt mycket positiv	negativ	nära halsen	samma som scenario

övrigt

Vad påverkade ditt utförande av uppgiften?

Svarskategori	rörelse i svängen	åtdragning av bälte	brist fokus	fokus	vana
	åksjuka	samma som scenario			

övrigt

Questions Senario 4

Av vilka anledningar upplevde svängen som du gjorde?

Svarskategori	inget speciellt	rörde mig mycket	röde mig lite pga bälte	jobbigt med uppgift	personliga preferenser
	det gick fort	det gick långsamt	skarp sväng	samma som scenario	

övrigt

Av vilka anledningar upplevde du bälteskomforten som du gjorde?

Svars kategori	tänkte inte på bältet	drog åt mycket		nära halsen	samma som scenario
		positiv	negativ		

övrigt

Vad påverkade ditt utförande av uppgiften?

Svarskategori	rörelse i svängen	åtdragning av bälte	brist fokus	fokus	vana

åksjuka	samma som scenario

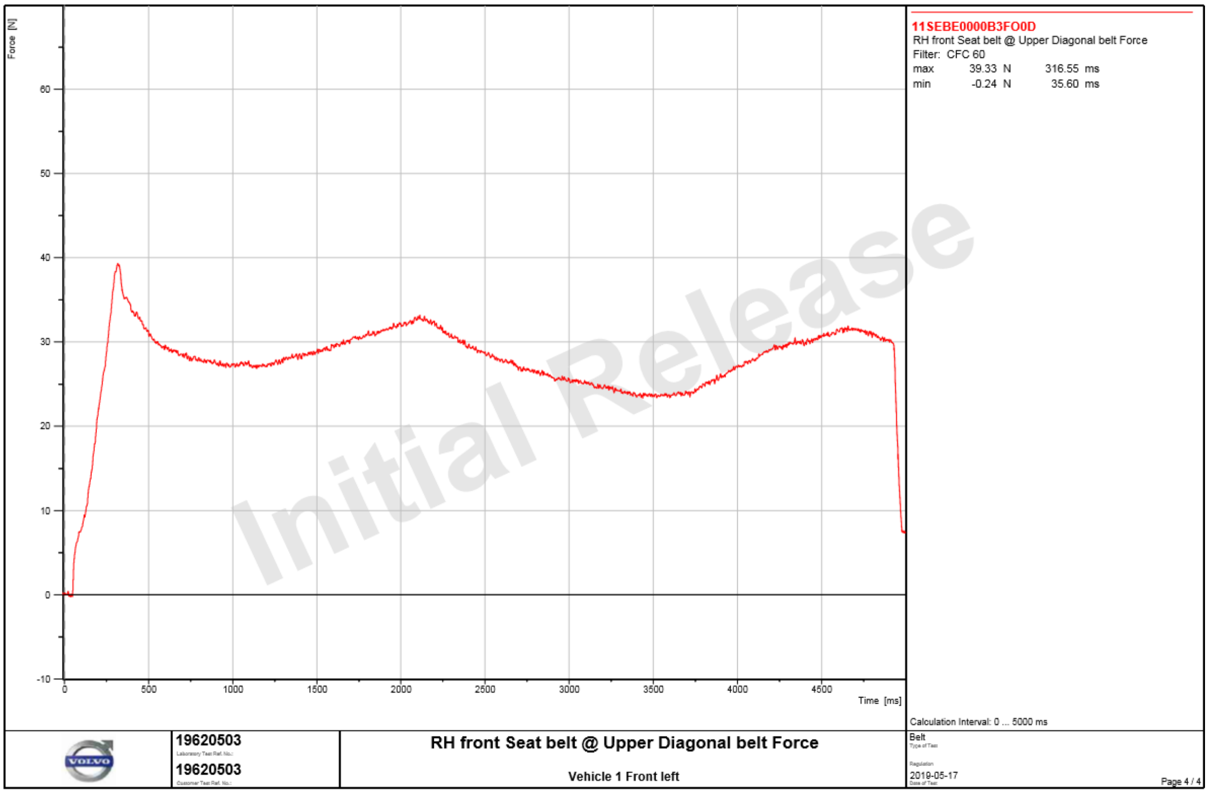
övrigt

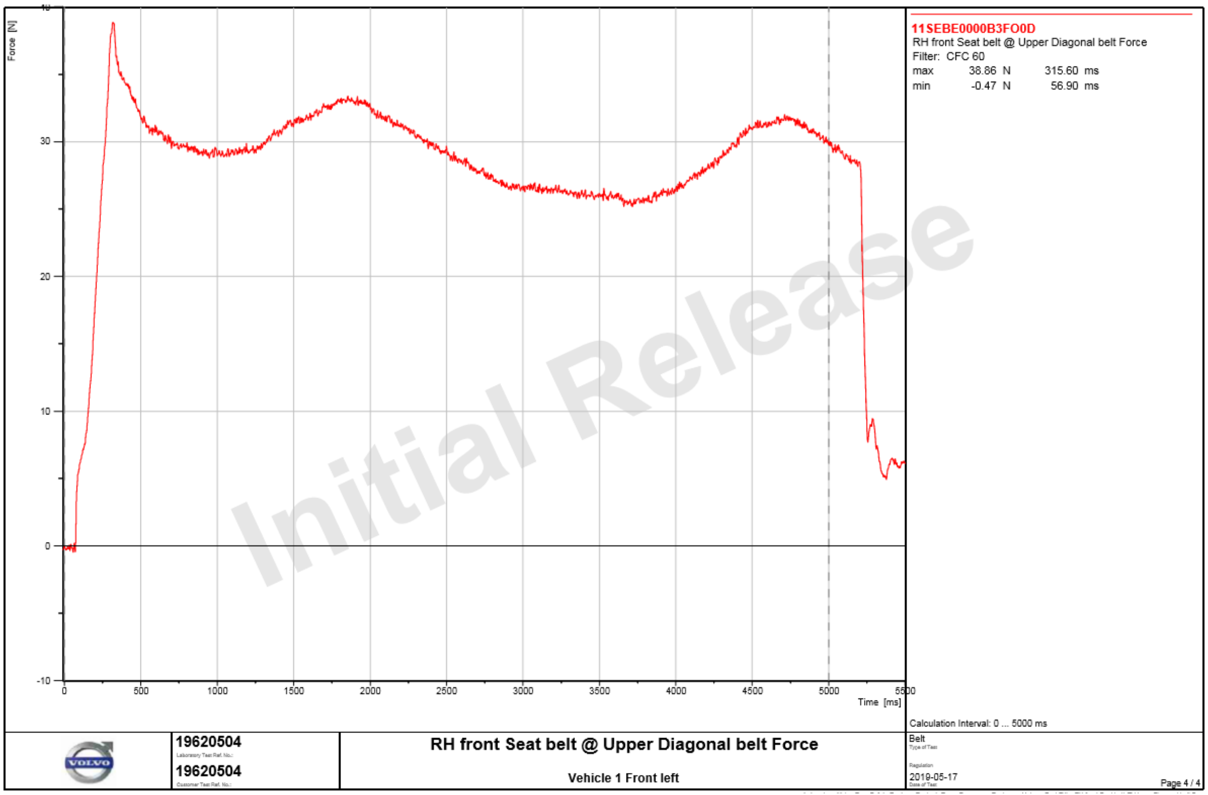
Vilket scenario föredrar du?

övrigt

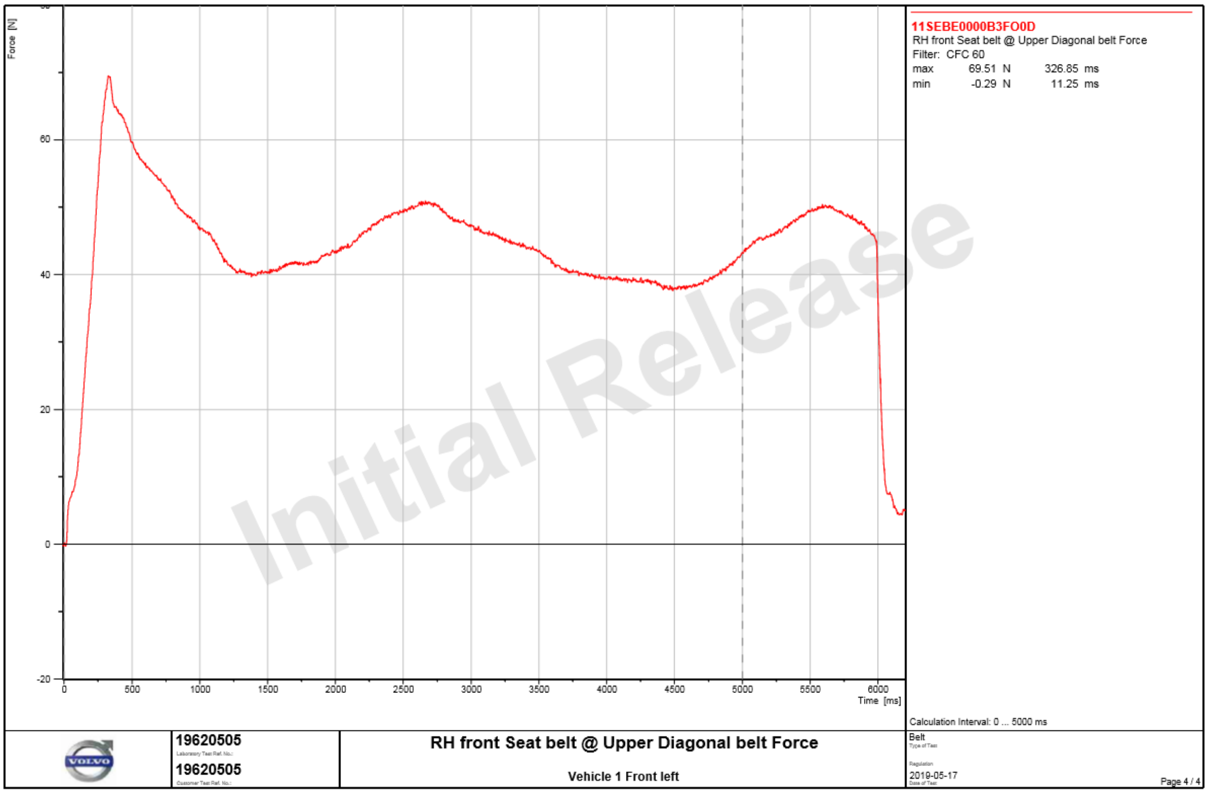
I Forces pre-pretension belts

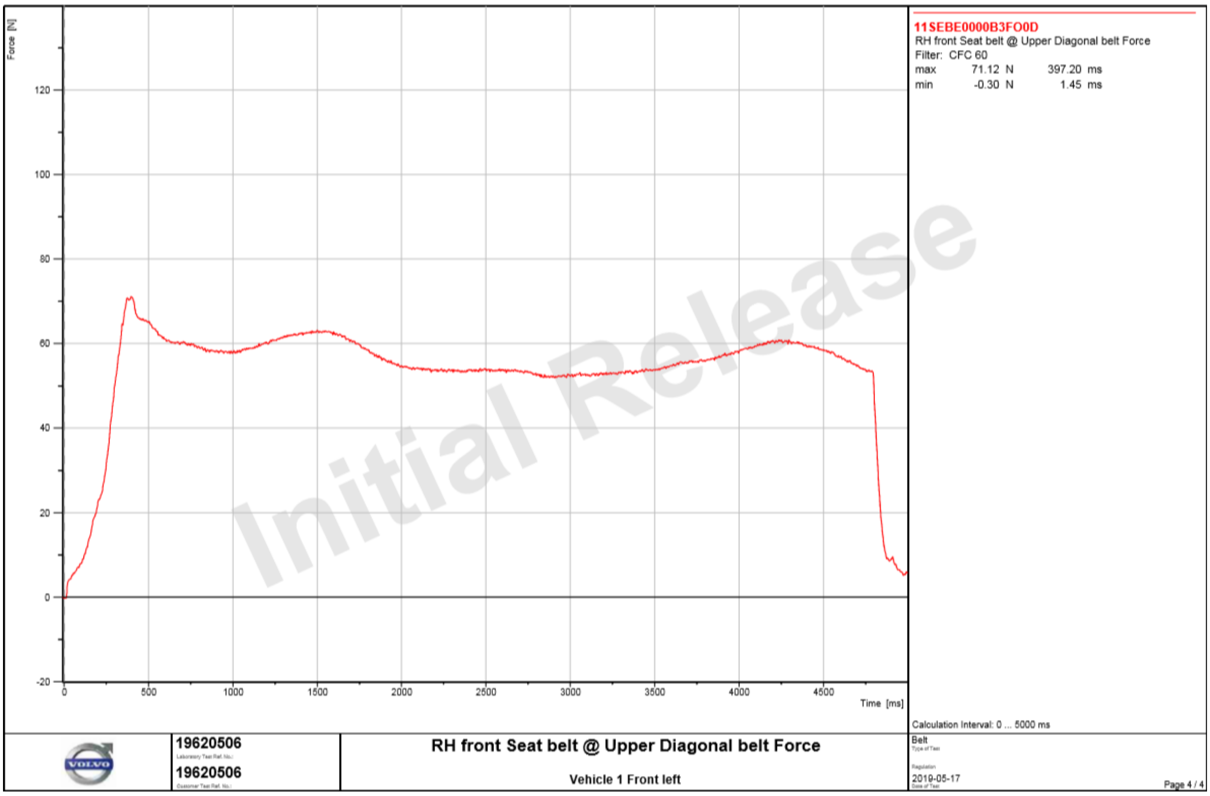
Soft pre-pretension belts





Firm pre-pretension belts





J Manuscript User study two

MANUS USER STUDY TWO

UTANFÖR HIVE

- Möter upp TP
- Consent form
- Vägning
- Gå till bilen

MOT BILEN

- Förklara testupplägg
  - Kommer köra 4 varv
  - Efter varje varv får du fylla i ett formulär svara på frågor om din upplevelse
  - Vissa av varven kommer du få en uppgift att utföra under turen, vissa av turerna kommer bältet att dras åt i svängarna
  - Jag kan ta din jacka och lägga i baksätet
  - Vill inte att du ändrar sätet

I BILEN

- Provdra låga bältesåtdragning
- Fäster punkt på suprasternal notch
- Nu ska vi åka den första rundan
- Kom ihåg att vi inte testar dig

KÖRNING

- Scenario 1
- Stanna och fyll i formulär, proba
- Scenario 2
- Stanna och fyll i formulär, proba
- Scenario 3
- Stanna och fyll i formulär, proba
- Scenario 4
- Stanna och fyll i formulär, proba

Efter körning

- Vilket scenario föredrog du?
  - Varför?
- Ta kort på wrapping (dubbelkollnings syfte)

Tack så mycket för att du ville vara med!

SCENARION

A

- Ingen uppgift
- Ingen bältsträckning
- Kör genom rondellen i 26 km/h

B

- Uppgift
  - Under turen kommer vi be dig skicka mail till olika personer
  - Kom ihåg att vi inte testar dig
  - Öppna outlook
  - Leta fram Agnes Andersson
  - Skriv frukost i ämnesraden
  - Skriv ett mail och berätta vad du åt till frukost imorse.
- Ingen bältstreckning
- Kör genom rondellen i 26 km/h

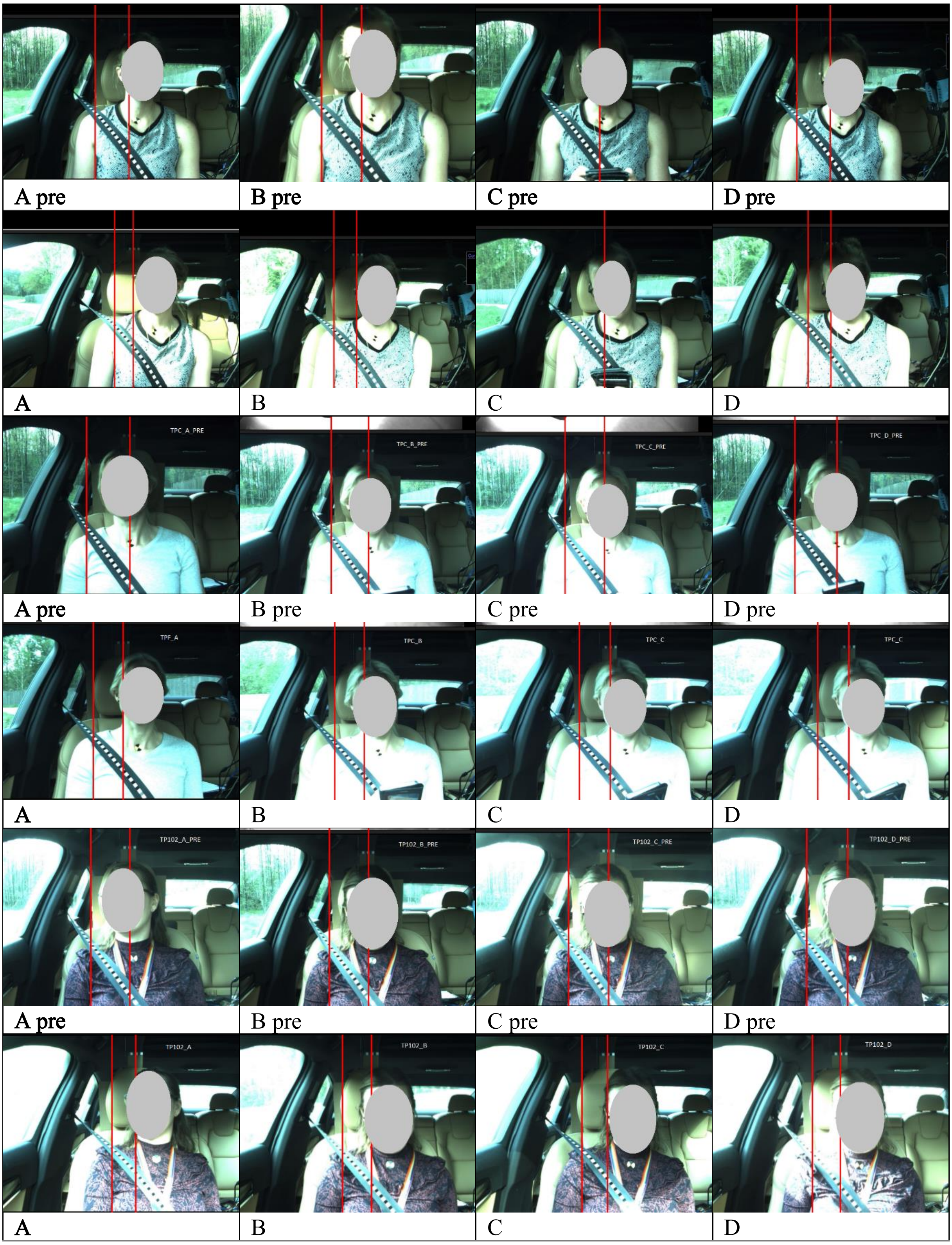
C

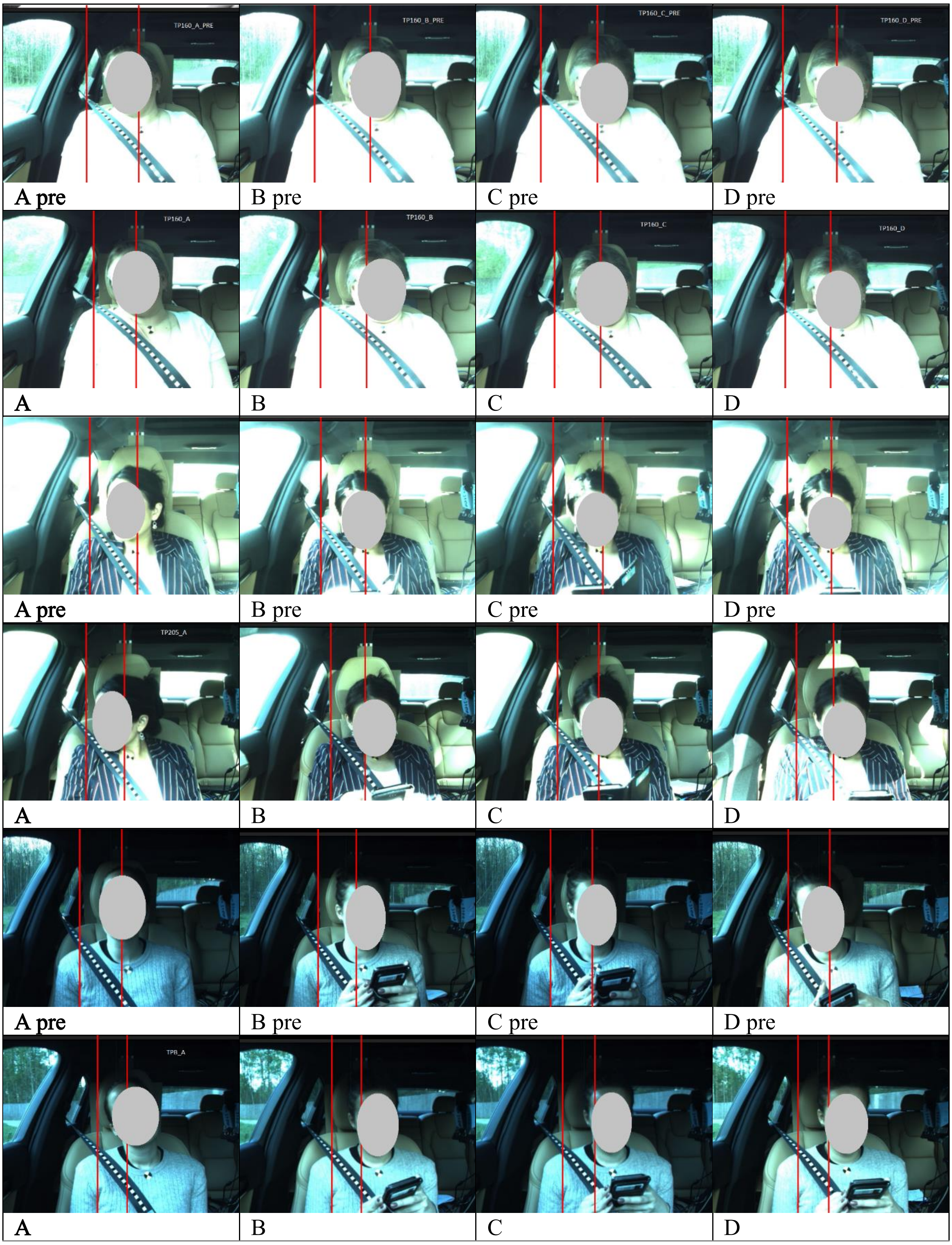
- Uppgift
  - Under turen kommer vi be dig skicka mail till olika personer
  - Kom ihåg att vi inte testar dig
  - Svara på mail
    - ”Kan du komma på mötet på tisdag kl 9? Jag räknar med dig och har för mig att vi sa att du skulle ta med bullar.
    - Om du inte kan, kan du väl föreslå en ny tid?
- Bältsträckning svag
- Kör genom rondellen i 26 km/h

D

- Uppgift
  - Under turen kommer vi be dig skicka mail till olika personer
  - Kom ihåg att vi inte testar dig
  - Svara på mail
    - Öppna din kalender
    - Skapa en påminnelse för att dricka kaffe med valfri kollega idag klockan 15.
- Bältsträckning stark
- Kör genom rondellen i 26 km/h

K Pictures from User study two




A pre
B pre
C pre
D pre
A
B
C
D
A pre
B pre
C pre
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A
B
C
D
A pre
B pre
C pre
D pre
A
B
C
D