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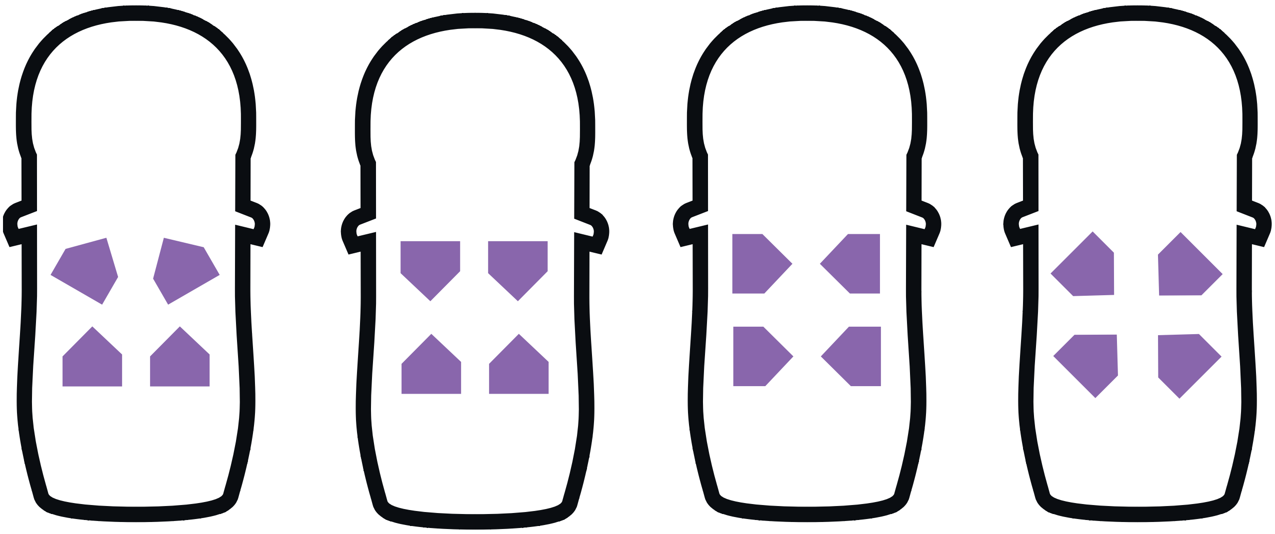

Defining and Evaluating New Load Cases in Autonomous Cars

Master's thesis in Applied Mechanics

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Department of Applied Mechanics
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2016

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New potential seating positions in autonomous cars.

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Abstract

Autonomous vehicles (AVs) are the focus for many research projects right now and are widely regarded as the most important next step for the automotive industry. AVs are anticipated to result in safer roads and with fully automated vehicles the driver does not need to be involved in the driving. This new situation opens up the possibility for new spatial orientations within the vehicle, which might be a challenge for today's passive safety systems. This master thesis is done in collaboration with Autoliv and aims to define new potential load cases in fully automated cars and to evaluate how today's passive safety systems handle these new load cases.

A literature review were complemented with a qualitative study to understand what activities occupants expect they will be engaged in when no one needs to focus on the driving, and how they will be seated. The qualitative study was performed at a local exhibition called *Vårgårdamässan* with a method called "Setting the Stage", developed specifically to explore user expectations. To evaluate the passive safety system, twelve sled tests with the THOR dummy were run in three of the newly defined load cases.

A position representing the extended living room, with the front seats rearward-facing, and a relaxing position, with the seatback reclined, were the most popular new seating positions both in the literature and in the qualitative study. These positions together with a conversation position, with the fronts seats rotated 30° inboard, were run in sled tests. The test matrix included rear-end impact, frontal impact and three different speeds (24 kph Euro NCAP rear-end pulse, 40 kph and 56 kph FMVSS 208 full frontal barrier pulse). The restraint parameters differed for each test and consisted of a driver airbag, an extra belt, an simulated knee airbag, a PRC (Pelvis Restraint Cushion), load limiting, pretensioning and modifications of belt geometry and seat adjustments.

The rearward-facing living room position generally performed well in frontal impact (rear-end impact for the dummy), with low injury risk values for HIC, BrIC and femur. The challenge for this position is to absorb the energy in the seat construction. The relaxing position was more challenging and got more focus in frontal impact; a beneficial kinematic for keeping the dummy in position, without high spinal loads, was an immediate forward motion or rotation of the upper body. The extra belt was the most important restraint system for the conversation position in frontal impact, but new solutions might be found that could handle this position. Only a few tests were performed for this load case, but much can be learned from small overlap/NHTSA oblique testing that resemble the test carried out in the conversation position.

The method "Setting the Stage", used in the qualitative study, resulted in detailed and realistic reflections from potential occupants and five new load cases were defined in total in the first part of the thesis. Some load cases were evaluated using sled tests, which limited the test matrix due to simplifications in the setup and limitations of the ATD; still, useful information was gained. Beneficial kinematics were identified and future potential challenges addressed for the two most popular load cases: the relaxing position and the living room position. This thesis was a first exploratory attempt to understand potential challenges within passive safety in autonomous vehicles, but more research and testing is needed to complete the results.

Keywords: autonomous vehicle, self-driving car, driverless, qualitative, sled testing, load case, seating positions, living room, sleeping, relaxing

Preface

In March, I stepped in to the now well-known building to begin my sixth round at Autoliv. Previous work had been done within passive safety, but now another topic was the hottest of them all – Autonomous Vehicles. As usual when working with Katarina, there was no time to be "start-up-confused". Already in my second week, the opportunity to perform a study at the exhibition *Vårgårdamässan* came up. Autonomous vehicle is a rather new subject and few articles have been published about it. Therefore, this was a perfect chance to gain knowledge that is currently locked into the researchers' chambers (or at least their companies...). The work has progressed with the same intensity, and is now starting to reach its end. The thesis work has resulted in a patent application, an article to the Enhanced Vehicle Safety Conference next year and a lot more work for my colleagues at Autoliv. Hopefully, this thesis contributes in any way to the development of autonomous vehicles.

I have done the first part of this thesis solely myself, but during the second part many people have been involved. During the preparations and the sled testing, I acted project leader. Colleagues have contributed with advice regarding the test matrix, supported with designing and building the test material and been responsible for conducting the sled tests. All data from the second part have been analysed by me, but with some discussions with colleagues at the research department.

Acknowledgements

First, I would like to thank my supervisor Katarina Bohman for many valuable advices and for always having time for our fruitful discussions. Then I would like to thank all my colleagues at Autoliv for always helping me answering my questions and for all the support during my sled testing; a special thanks to the colleagues at the prototype lab for the incredible work with the test material. Thanks to my examiner Johan Davidsson who has answered all my questions by mail in a minute.

Lastly, a thank to Gustav for taking care of our home and our lovely daughter during this time!

Sofia Jorlöv
August 5th 2016, Alingsås

Nomenclature

cN_{ij}	Cervical Osteoligamentous Spine Injury Criteria
N_{ij}	Neck Injury Criteria
AIS	Abbreviated Injury Scale
ATD	Anthropometric Test Devices
AV	Autonomous Vehicle
BrIC	Brain Injury Criteria
CFC	Channel Frequency Class
CLT	Crash Locking Tongue
CoG	Centre of Gravity
DARPA	US Defense Advanced Projects Agency
ESV	Enhanced Safety of Vehicles
Euro NCAP	European New Car Assessment Programme
HIC	Head Injury Criteria
NHTSA	National Highway Traffic Safety Administration
NIC	Neck Injury Criteria
PLP	Pre Lap Pretensioner
PRC	Pelvis Restraint Cushion
RP	Retractor Pretensioner
SAE	Society of Automotive Engineers
THOR	Test device for Human Occupant Restraint
WHIPS	Whiplash Protection System

Contents

1 Introduction

Autonomous vehicles (AVs) have gone from science fiction to reality. The AV technology has undergone rapid development the last decade, boosted since 2004 by the US Defense Advanced Projects Agency (DARPA) challenges [Pettersson and Karlsson 2015]. It anticipates to offer benefits for the society and the individual, and change the way we live and work [Ekchian et al. 2016], but a number of issues must be solved before large-scale use of AVs become reality. Today's legal framework is not suitable for autonomous vehicles and some technical challenges require more research [Eugensson et al. 2013].

One new challenge in AV concerns the passive safety system. In the future, AV is anticipated to not be involved in crashes, but in the early phase and during a transformation time to full autonomy crashes will occur [Eugensson et al. 2013]. AV freeing time for the driver and this new situation leads to questions about how the driver and the other car occupants will sit and what activities they will be engage in. [Ive et al. 2015] New spatial orientations will be possible, which will be a challenge for today's passive safety systems. This master thesis consists of two parts; the first part will focus on the new load cases in the autonomous car and the second part will evaluate how today's passive safety system handle these new load cases.

1.1 Why Automation?

Automation is regarded as the most important next step for the automotive industry due to its many potential benefits [Wallace and Sillberg 2012]. Enhanced safety, reduced need for infrastructure investments, improved fuel economy and lower emissions, reduced congestion, more efficient use of the urban landscape, more time for the individuals and mobility for physically impaired people are advantages frequently mentioned in the literature [Eugensson et al. 2013; Ekchian et al. 2016; Pettersson and Karlsson 2015].

Enhanced Safety: Various sources recognize that up to 93% of all crashes today are fully or partially caused by human error, which induce that many lives could be saved with AV [Sings 1979; Tumbas et al. 2015]. Eliminating human error is the largest potential in reaching the Vision Zero that has been adopted by many governments. Enhanced safety is also positive for a society's economy. [Eugensson et al. 2013]

Infrastructure Investments and the Urban Landscape: AV will affect how the infrastructure is built. The parking areas can be much smaller and the roads narrower when there is no need for a human driver. [Eugensson et al. 2013]

More time: The AV will free a lot of time for the driver and time is today a critical factor in the society. Time is strongly connected to wellbeing, as well as money. [Eugensson et al. 2013; Ekchian et al. 2016] One estimate claims that autonomous vehicles globally can save $5.6 trillion per year. This includes fuel savings from congestion avoidance and more efficient driving and savings from accident avoidance, as well as productivity gains. With autonomous vehicles, people will spend less time in the vehicle since congestions are anticipated to decrease and the time in the car could be spent working. [Shanker et al. 2013]

1.2 What is Automation?

The first automated system was electronic stability control, which was released in the late 1990th. Since then, a number of systems, which partially or fully take over the control of the vehicle in a safety critical situation, have been developed in order to avoid or mitigate crashes. [Eugensson et al. 2013] These systems can control steering, braking and acceleration without direct input from a driver.

There are different levels of automation, and National Highway Traffic Safety Administration (NHTSA) has developed a classification that is commonly used. The first level is level 0, which means that the driver completely control the vehicle at all times. At level 1, one or more specific functions are automated, e.g. electronic stability control and pre-charged brakes, and at level 2 two or more functions work together to relieve the driver. An example on level 2 is adaptive cruise control combined with lane keeping assistance. At level 3 and 4 the car performs all safety critical functions, but at level 3 the driver needs to be in control during certain conditions and in level 4 the driver is no longer needed more than to provide the destination. [NHTSA 2013]

1.3 Where is Automation Today?

The most famous self-driving car is the Google car, which has level 3 of automation according to the definition. Until today the Google car has completed more than 2.4 billion kilometers in self-driving mode. [Google 2016] Tesla is leading in autonomous vehicles for ordinary people, and provides today an automation of level 2 or in low speed, level 3. This means that the driver is allowed to take the hands off the steering wheel for shorter times. [Lambert 2015] In Sweden, Volvo has its DriveMe project that will start large-scale long term testing with 100 self-driving XC90 (level 3) on public roads in Gothenburg during 2017 [Volvo Cars 2016c].

1.4 In Cooperation with Autoliv

This master thesis is done in cooperation with Autoliv Research in Vårgårda. Autoliv was founded in 1953 in Vårgårda and develops and manufactures passive and active safety systems to all major automotive manufacturers around the world. Autoliv Research is the global research department for Autoliv. [Autoliv 2016]

1.5 Aim

The aim of this master thesis is to define new potential load cases in fully automated cars and to determine how well today's passive safety system is able to restrain the occupant and fulfil legal requirements in these new load cases. The thesis should result in a clear problem description of possible future challenges that may form the basis for further work at Autoliv.

1.6 Definition

Load case in this thesis is defined as the pattern of loads on an occupant in an impact. The load case depends of impact direction, impact severity, seating position and sitting posture. Automated cars open up the possibility for new seating positions compared to what has been evaluated in legal requirements and consumer rating programs, and thereby new load cases.

1.7 Limitations

- The effect of pre-crash maneuvers prior to impact are neglected in the sled test.
- Only passive restraint solutions that already have been presented by Autoliv are used.
- Only the driver position is evaluated in the sled tests.
- Only one dummy size is evaluated, the 50th percentile male.
- Today's pulses and impact directions are used in the sled testing (frontal, side and rear-end).

2 Defining New Load Cases in AV

When the driver no longer needs to be involved in the driving, there is no need to be seated forward-facing in front of the steering wheel. This first part of the study explores how occupants expect they would spend the time in a fully automated car and how they prefer to be seated. Identification of new activities in the car is important to understand what drives the new seating positions. A literature review and qualitative study was performed in this part. The qualitative study was designed to complement the modest result from the literature study.

2.1 Aim

The aim of this part of the master thesis is to identify activities, and to define new potential load cases, in fully automated cars.

2.2 Theoretical Framework

2.2.1 Qualitative Studies

Qualitative studies are used to understand people's perspectives and motivations. The result from a qualitative study cannot be quantified or analysed by using statistical methods; instead the data is grouped based on meaning units. The data can be collected using deep interviews, focus groups, observations and semi-structured interviews. The choice of method affects the type of data that is collected; hence this must be considered in the study design. Ethical aspects must be taken into considerations during the study. Even if no approval from an ethics committee is needed, the test persons must be informed about the aim of the study and that the participation is voluntary. All test persons should be guaranteed confidentiality. [Bengtsson 2016]

2.2.2 "Setting the Stage"

There is always difficult to design a study with the purpose of investigating the future, hence research in autonomous driving involving users is limited [Brandt and Grunnet 2002; Vavoula et al. 2015]. Pettersson [2016a] is doing research in exploring user experiences and has developed new methods for exploring future user experiences. The methods have been tested and evaluated for autonomous cars and one of these methods, "Setting the Stage" will be used in this study [Pettersson and Karlsson 2015].

"Setting the Stage" is a simple method which aims to explore the participant's user experience in their own future life, without unrealistic visions. The participant is placed in an empty room with a car outline in full scale drawn on a paper on the ground; in the "car", four chairs are placed. The participant is asked to enter the "car" and to envision that it is an autonomous car. Sitting in the "car", the participant is told scenarios from his or hers everyday life and a semi-structured interview is held. The participant is encouraged to rearrange the seats or redesign the interior to fit his or hers needs. [Pettersson and Karlsson 2015; Pettersson 2016b] The intention with this methodology is to encourage imagination and reflection based on some main principles [Pettersson 2016b]:

- **Placement inside the "car"** – A simple design of a car is used, since research has shown that it stimulates the participant's imagination more than a more developed mock-up. [Ehn and Kyng 1991] The "car" should also be placed in an open space to provide a better environment for the participant to think more abstract and freely. [Meyers-Levy and Zhu 2007]
- **Enactment of future use** – Both body and mind is involved in the actual usage of the autonomous car, which eliciting detailed information. [Pettersson 2016b]
- **Generating future designs** – The participant is encouraged to redesign the car which has a positive effect of the engagement and imagination. [Pettersson 2016b]
- **Relating to past experiences** – Through telling the participant different scenarios, the responses relates to the individual's perspective. [Pettersson 2016b]

2.3 Method

Two different methods were used to explore future seating positions in autonomous cars: a literature study and a qualitative study.

2.3.1 Literature Study

Internet. The purpose of using Internet was to figure out how media and automotive manufactures describe the AV. Searches was done using combinations as “self-driving + car/vehicle”, “autonomous + car/vehicle” and “autonomous + driven + car/vehicle”. Results from automotive manufacturers, newspapers and technology or automotive blogs were prioritized.

Literature. Various sources were used to find interesting and relevant research; Conference papers from NHTSA’s ESV (Enhanced Safety of Vehicles) Conference, SAE’s (Society of Automotive Engineers) database, Google Scholar and Chalmers’s library. Various combinations of the following words were used in the searches: “autonomous”, “self-driving”, “car”, “vehicle”, “sit”, “seating positions”, “activities”, “interior”, “motion sickness”, “passenger position”. The focus was to find research on what people envision they would do in a self-driving car and how they expect they would sit, as well as how the passengers sit and what they do in today’s cars.

2.3.2 Qualitative Study

A study was designed with the purpose to achieve a better understanding of people’s expectations on AV: what activities they would engage in and how they prefer to sit. The method ”Setting the stage”, developed by Pettersson and Karlsson [2015], was used but with modifications to fit the pre-requisites for this study

Design. The study took place in Autoliv’s booth on an exhibition called *Vårgårdamässan* during two days in the middle of April 2016. The exhibition was for locals in Vårgårda, the place where Autoliv was founded, and the exhibitors were from local sports associations, local companies and different areas in the municipality. The method “Setting the Stage” was modified to fit the pre-requisites in the exhibition booth. In the original method, an outline of a simple car was drawn with chalk on the ground on a parking lot. In this study the stage was a printed vinyl picture mounted on the wall, representing the outline of the Mercedes-Benz autonomous car concept F015 with a futuristic view in the window (see figure 2.1). As in the original method, four chairs representing the car seats were placed “inside the car”. The modifications were discussed with Ingrid Pettersson prior to testing to ensure that the main principles described in 2.2.2 were kept [Ingrid Pettersson, 04/07/2016, pers. comm.].

Figure 2.1: *The test environment at Vårgårdamässan.*

A semi-structured interview was held with the participants, consisting of three parts. The first part was structured questions about their gender, age, driving license, vehicle travelling habits, and when they thought self-driving vehicles will be available on the market. The last question aimed to find out people’s opinion to self-driving cars in general. The purpose of these structured questions was to gather some basic information about the participants and to choose the appropriate scenario in the next part. In the second part, the participants were encouraged to enter the “self-driving car” as they were told different scenarios. The scenarios were used as triggers and as an attempt to make self-driving cars more real. In this study the self-driving car was defined as “the vehicle does not need any more input than the destination”, which means the highest level of automation according to the definition by NHTSA [2013]. For each scenario, the participants got questions about how they wanted to sit and what they would like to do. They were also encouraged to speak freely about their thoughts during the exercise. Adult participants (18 years or older) were told two scenarios in random order, and the younger participants were only told one. All participants were told the longer journey scenario. They were encouraged to envision that it was weekend and that they should do a trip to their summerhouse in Varberg (less than two hours ride from Vårgårda) together with their family. The shorter journey scenario depended on the answers in the first part. If they drove car regularly to work, they were encouraged to visualize the last time they did that. Otherwise, they were encouraged to visualize the last time they drove or travelled a shorter distance, like to the supermarket or the school. The third part of the study aimed to investigate the opinion to possible future passive safety solutions. This part is outside the scope of this master thesis and will not be discussed any further in this report, but is included in the appendix for Autoliv (appendix D). The test session took between 10 to 20 minutes for all three parts. The full test protocol is available in Appendix A in both Swedish and English.

Participants. The 52 participants were chosen randomly from exhibition visitors that looked to be in the correct age range, passing by Autoliv's booth. Eligible age for participation in the study was 10 to 55 years, but the actual age range was between 11 to 63 years. The age range was chosen to include people that potentially will travel with a self-driving car. Participants below 18 years were included since they were thought to provide reflections not restricted by driver experiences. The participants needed to be able to express there thoughts and motivate them, which justified the lower age limit. The participants were alone or in groups of 2-3 persons, depending on how they were visiting the exhibition. In this type of method, groups are to be preferred since the discussion between the participants promote more in-depth analysis of the questions [Strand et al. 2011]. Participation in the study was voluntary and the participants got oral information about the purpose of the study before choosing to participate, and received written information afterwards. The participant were informed that they were allowed to stop the test session whenever they wanted.

Data Collection and Analysis. During each test, the test leader made notes, and the seats' position were documented using mobile camera. After each test session, more detailed notes were written down. Afterwards, the data were analysed; activities were grouped (e.g. playing PlayStation and playing video games were grouped together) and the various seating positions were classified according to figure 2.7.

2.4 Result

2.4.1 Internet

Many vehicle manufactures have presented AV concept, e.g. Volvo Concept 26, Nissan IDS Concept, Rinspeed XchangE Concept, Mercedes-Benz Concept F015 and Zoox [Volvo Cars 2016a; Orphanides 2015; Dima 2014; Barret 2015; Driverless Transportation 2016]. Other manufactures have presented concept solutions for specific parts of the AV; Johnson Control has presented a new seat concept and TRW has developed a new steering wheel [Buckholz 2015; Ponticel 2014]. Pictures of all these concepts give an idea of how the automotive manufacturers envision that people will sit in AVs and what activities they will engage in. The found positions aim to facilitate working, surfing, relaxing, having conference, playing games, eating and watching movies [Dima 2014]. Four different categories of positions were found.

The first category of positions was conversation position and which mainly is interesting when two occupants are travelling together. This was seen on pictures from Johnson Controls and Nissan (figure 2.2). The front seats are rotated inboard to facilitate conversation in the front seat. [Buckholz 2015; Orphanides 2015] Johnson Control proposed a rotation of 18° [Buckholz 2015]. Notice also the steering wheel that has been moved toward the instrument panel or removed. The next popular category was the working position seen on pictures from Continental AG and Volvo (figure 2.3). The "driver" is sitting forward-facing, but with a distance to the steering wheel and has a more slouched position. The "driver" also has some equipment, like a phone, computer or book. [Wernle 2015; Volvo Cars 2016a] The relaxing position was the third category and was found on pictures from Volvo and Rinspeed (figure 2.4) [Volvo Cars 2016a; Floyd 2015; Acharaya 2013]. The occupants recline their seats, sitting either forward-facing or rearward-facing. Note also the steering wheel that has been moved to the centre of the car. The last category, living room position, is also the most popular position and is found in some variations. The position representing the "extended living room" and both Mercedes-Benz and Rinspeed have it, as well as many newspaper and blogs (figure 2.5). This seems to represent the epitome of an AV. The front seats rotate 135-180° inboard to create a space for four occupants to socializing. These positions are usually seen with a table in the middle. [Stone 2015; Sorokanich 2014; Part Catalog 2015; Davies 2015; Waldrop 2015]

(a) [SAE International 2015] (b) [Nissan 2015]

Figure 2.2: *The conversation position was seen in concepts from Johnson Control and Nissan.*

(a) [Volvo Cars 2016b] (b) [Automotive News 2015]

Figure 2.3: *Volvo and Continental show picture on the working position.*

(a) [Rinspeed 2015] (b) [Volvo Cars 2016d] (c) [Rinspeed 2013]

Figure 2.4: *The relaxing position was presented by Rinspeed and Volvo.*

2.4.2 Literature Study

The result from the literature study was very modest. A few studies have investigated new potential seating positions, and an Internet survey had one question about activities in a self-driving car. More studies have been found about autonomous vehicle and the potential problem with motion sickness.

Activities. AV will free time from the driver and creates the ability to use the time spent in the car more productive. Diels and Bos [2016] suggest that reading, responding to emails and using tablets and gaming console most likely will be popular activities in the AV. Pettersson and Karlsson [2015] developed two methods

(a) [Gizmodo 2014]

(b) [Rinspeed 2013]

(c) [Chapple 2015]

(d) [Mercedes-Benz 2015]

Figure 2.5: *Various positions were found that could be classified as living room positions.*

to explore people's expectation on AV. In pilot studies in Copenhagen, Denmark, and Gothenburg, Sweden, various activities were mentioned: relaxing, working, sleeping, reading, socializing, eating, tending to children, playing games, drinking alcohol, watching videos and using social media. Similar activities were also identified in the internet survey done by Schoettle and Sivak [2014] at University of Michigan Transportation Research Institute. This study included China, India, Japan, USA, UK and Australia. Except the activities mentioned in previous studies, "whatch the road" came up as the top one activity in all countries.

Seating Positions. Two interesting scientific papers were found regarding seating positions in AV. The first one is the limited studies by Pettersson and Karlsson [2015]. Swivelling seats were commonly mentioned as well as the car as the extended living room. The positions were mostly relaxed and slouched, and some even threw out the "seats " completely. The other study is also a small study done by Ive et al. [2015]. They had 17 participants whom they placed in the front passenger seat of a right hand driven car. All participants were used to left hand driven cars, so the participants should imagine that it was a self-driving car. During a think aloud exercise and a semi structured interview, the passengers were given various "probes " and they were asked to show how they would have used them in an AV. Six of ten participants wanted to be seated forward-facing, while the others preferred swivelling seat to have the ability to be seated rearward-facing. Sleeping was reported as a popular activity and three different positions were reported:

- Upright: In other words, a normal driving position but without the hands on the steering wheel.
- Sprawled outward: The individual takes more space than normal; recline their seat and move the seat track rearward.
- Fetal: The individual take up less space than normal; move the seat track forward and lift up their knees onto the seat or press them against the dashboard.

Motion Sickness. Many of the activities and seating positions mentioned earlier are known to increase the susceptibility to motion sickness. Motion sickness, or kinetosis, is a condition marked by physical discomfort in general; symptoms are nausea and dizziness, or in more severe cases vertigo and vomiting. Motion sickness is mainly caused by three factors, that all are more common among passengers than drivers. [Reason and Brand

1975] *(1) Conflict between visual and vestibular inputs* is influenced by various aspects in AV; the non-forward gaze in some of the activities mentioned and the sideward- or rearward-facing positions described are aspects that increase this factor, while having the eyes closed or having a supine posture might have a positive effect on motion sickness in passenger vehicles. The other factors influencing motion sickness are the *(2) ability to anticipate the direction of movement* and the *(3) control over the direction of movement.* The first is also negatively influenced in AV by activities having a non-forward gaze and sideward- or rearward-facing seating positions and in AV all occupants are passengers without control over the movement. [Schoettle and Sivak 2015]

2.4.3 Qualitative Study

The two days at the exhibition *Vårgårdamässan* resulted in 31 tests and 52 participants; 18 tests had both scenarios (13 of these hade the work scenario as the short scenario) and 13 only the longer journey scenario. The distribution between gender and age was equal within the target group (10-55 year) and the age ranged from 11-63 years. 24 participants were children; distributed over 10.5 tests. Almost all participants travelled by car at least a few times every week and most participants above 18 years had driving license. The participants were in general positive to autonomous vehicles and thought that it will be available on the market latest during 2020 or between 2021 and 2025. The participants' background are shown in table 2.1.

Table 2.1: Summary of the participants.

		No of Tests	No of Participants
Age/Has driving license	<18	10.5/0	24/0
	18-30	7/4	12/9
	31-50	9/8	19/18
	51-65	4.5/4.5	6/6
Vehicle travelling habits	Every day	18	36
	A few times every week	11.5	14
	A few times every month	1.5	2
AV on the market	Latest during 2020	15.5	27
	2021-2025	8.5	14
	2026-2030	2.5	4
	Far into the future	4.5	7

Trusting AV. In general, there were concerns about trusting the self-driving car. Comments like *"the driver must have an eye forward and on the technology"*, *"I must sit so I can see what's happening"* and *"to begin with, I would like to have a steering wheel"* were common in the discussions, but there were also concerns about what other drivers would think. One lady expressed this concern; *"It must look like I drive, not everyone will have a self-driving car"*. The trusting issues also reflected what activities people would engage in and the seating positions. In 12 of 31 tests, the driver were placed forward-facing or at most 90° inboard rotated with additional comments expressing the trusting concerns.

Activities. The participants envisioned how they would do activities that they do not have time to in their everyday life. *"Oh, imagine being able to watching TV series when you go to Gothenburg every day. It would be an episode there and another on the way home!"*, *"I would sit rearward-facing and playing guitar on the way to work"*, *"I would take a rest, to be up and running when coming home"*, *"we would just hang out...maybe playing board games"*. The type of activities varied depending on the different scenarios: shorter journeys alone or longer journeys together with the family. When travelling alone, surfing the web, sleeping and just look out were the most frequent mentioned activities and when travelling together with the family for a longer time, watching movies, playing games and socializing were the most popular. Figure 2.6 sums up all answers for both scenarios. Motion sickness was not mentioned by the test leader, but was raised as a concern in six of the tests. Some solutions to this issue also came up: *"The car would go smoothly, I should not feel that it is moving"*.

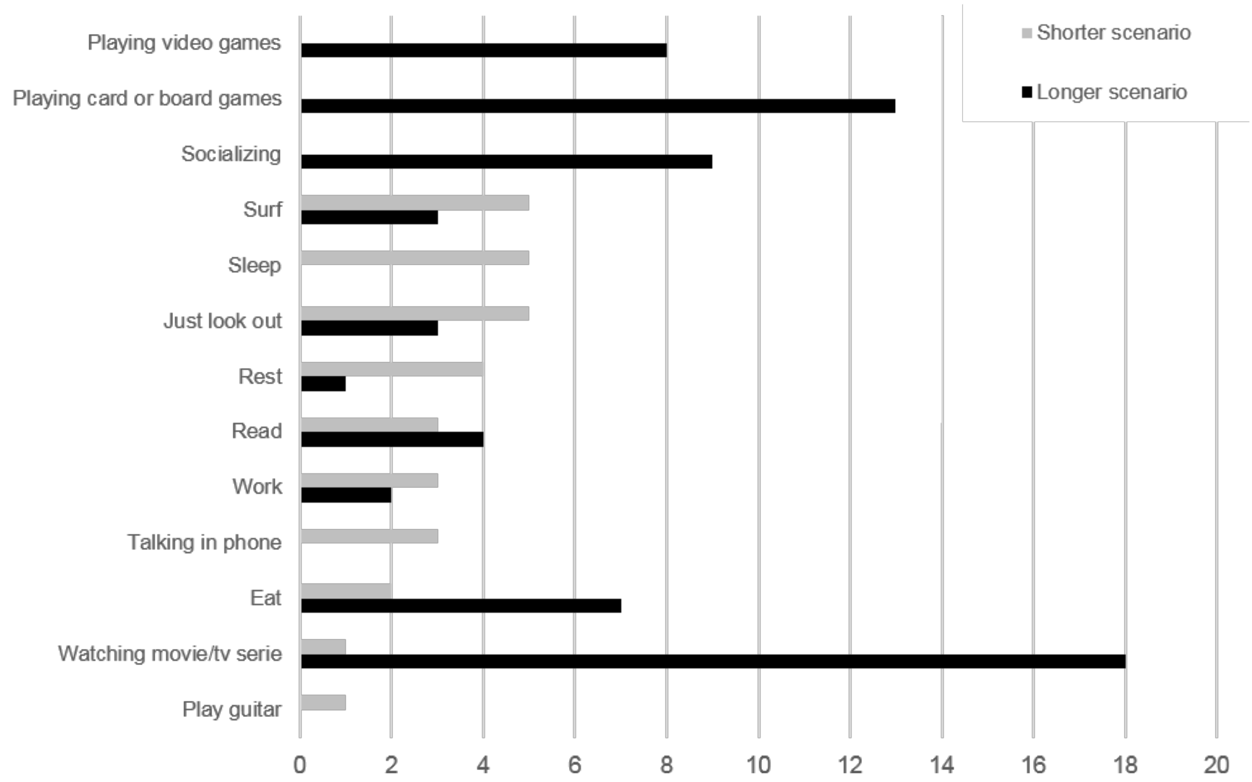


Figure 2.6: *Summary of people's answers regarding what kind of activities they would engage in. Shorter scenario: 18 tests. Longer scenario: 31 tests.*

Seating Positions. Most people preferred to sit like "normal" when travelling a short distance (*"When there is such a short distance, it is not worthwhile to sit rearward-facing"*), but for longer journeys they envisioned the autonomous car as the extended living room. Some variants of this position were suggested. Position 4, with all seats rotated 90° facing inboard the vehicle (figure 2.7), was justified by better view forward for all passengers and the ability for the driver to have an eye on the road. The most preferred position was number 3, followed by number 5 and 4 in figure 2.7 (12, 6 and 5 tests respectively). Better view forward for all passengers and the ability for the driver to have an eye on the road justified position number 4. In four tests the participants preferred to sit like "normal" and one test preferred position number 2 in figure 2.7. The ability to rotate the seats or recline them to achieve a more comfortable resting or sleeping position were mentioned frequently. In 16 of the tests, swivelling seats were mentioned as a good option, 13 tests wanted to recline their seat during a shorter ride (3 for resting and 8 for sleeping) and 20 tests during a longer ride (12 for resting and 8 for sleeping). The chosen seating positions were, of course, strongly connected to the activities the users want to engage in.

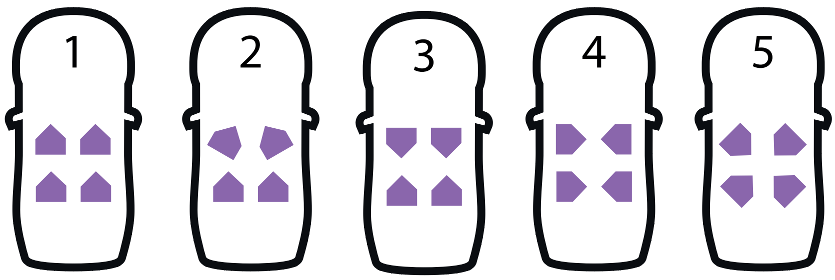


Figure 2.7: *The seating positions seen in the qualitative study at Vårgårdamässan.*

New Interior Design. The participants wanted to "redesign" the car more than just rearrange the seats. In 17 tests, people envisioned a large table in the middle of the car in the living room positions and fixed screens were popular among children and mentioned in all tests with participants under 18 years. 5 tests wanted a fixed screen in the rear-end, 2 in the front and 4 wanted to have individual screens. People above 18 years did not mention fixed screens. An overall feeling was that the participants envisioned the car as more than just an object for transportation. *"It would be a luxurious interior with beverage holders between the seats, a large screen in the rear window, high-quality speakers, voice control of the car... very comfortable seats – think cinema!" "The car would have a "limousine-feeling"!* The car would be their extended home, with the ability to do things from your everyday life that you do not have time to do today and the car expects to be very luxurious.

2.5 Discussion

Four categories of positions were found on Internet: conversation, working, relaxing and living room position. These categories of positions was supported by Diels and Bos [2016], Pettersson and Karlsson [2015], and Schoettle and Sivak [2014] whom investigated what activities user expect they will engage in. A qualitative study was designed to complement the modest result from the literature study. This study showed that relaxing position and variations of the living room position were the most popular positions. As in the literature, swiveling seats were commonly requested in autonomous vehicles [Pettersson and Karlsson 2015; Ive et al. 2015]. Problem with motion sickness is a concern in the literature, but are neither commonly mentioned in the semi-structured interviews by Pettersson and Karlsson [2015] and Ive et al. [2015] nor in the qualitative study in this thesis.

Concerns about trusting AV were not seen on Internet, but in the literature and the qualitative study. The concerns in the qualitative study were almost exactly the same as in the study by Pettersson and Karlsson [2015]. Some participants wanted to have the ability to control the technology or at least easily monitor it, and some were concerned about scaring other people with their futuristic car even if they had trust in it. This trusting issue must be considered in the development of new design and seating positions in AV.

2.5.1 Activities

Most of the activities mentioned in the study at *Vårgårdamässan* were also found in the literature, but which activities that were the most popular ones differed between the studies. In the internet survey by Schoettle and Sivak [2014], 35.5% of the respondents in the US wanted to *watch the road.* The second most popular activities were *reading* or *texting* followed by *sleeping* and *watching movies.* In the study in this thesis, *watching movies* and *playing games* were the most popular activities followed by *eating* and *socializing.* Working was frequently seen in car manufactures marketing pictures for their self-driving car concepts, but were neither common in the study by Schoettle and Sivak [2014] nor in this study. The reason might be that this activity is connected to other parameters dependent on the location for the study. This study was performed in Vårgårda, a small town 60 km outside Gothenburg Sweden. Many people in the study had physical work, like being a farmer or lumberjack, and short travelling distance to work. In larger cities, where more people working at offices and are spending much time in congestions, work will probably be a more popular way of spending the time in the car.

Another challenges for autonomous cars, except new seating positions, will be all free flying objects in the car. When the car goes from being a way for transportation to an extended home, tablets, computers, gaming consoles and coffee cups are seen as natural parts of the car.

2.5.2 Seating Positions and Interior Design

Five different seating positions were identified for the future´s autonomous vcars:

- Normal position
- Working Position, forward-facing but with more space for the legs
- Sleeping/relaxing position, with reclined seatback

- Conversation position with the front seats rotated inboard 18-30°
- Living room positions in three variations, number 3-5 in figure 2.7

It is interesting to note that both in this qualitative study and in the studies by Pettersson and Karlsson [2015] and Ive et al. [2015], the normal position is frequently mentioned. Except the normal position, the living room position, with the front seats rotated 180°(number three in figure 2.7), was the most popular position together with a relaxing or sleeping position with reclined seats. The conversation position was seen in self-driving concept cars, but rarely suggested by test participants or found in the literature. This does not necessarily mean that this position is not realistic. The conversation position is mainly for two occupants in the car, and this was not a scenario in this study. In the qualitative study, changes in interior design were proposed to other areas than just the seating positions. Swivelling seats were frequently requested, as well as built in screens. Pettersson and Karlsson [2015] reported a similar result from their study. All suggested positions and design solutions in this pre-study corresponded to a need or expectation by potential users, however the solutions might not be the best when taking parameters as safety, space and motion sickness into account.

2.5.3 Motion Sickness

Only a few participants in this qualitative study and the studies by Pettersson and Karlsson [2015] and Ive et al. [2015], considered motion sickness to be a problem, but researchers expect this to be an issue which might limit the activities and seating positions in self-driving cars or lead to new technical innovations. Reading, texting, watching movies, working and playing games are some activities that have a negative effect on motion sickness as well as swiveling seats. The reason is that the gaze is not focusing forward on the road. [Schoettle and Sivak 2015]. Various solutions have been proposed in the literature to decrease the frequency and severity of motion sickness. Diels and Bos [2016] have proposed large windows and screens placed so that the gaze is focused forward or head-up displays. Benson [2002] propose to have a supine posture looking upward, but other articles do not confer this theory [Cheung and Nakashima 2006]. Other studies have focused on active suspension instead, like one woman suggested in the qualitative study. Ekchian et al. [2016] presented good result with their high-bandwidth active suspension system, but in the summary by Cheung and Nakashima [2006] active suspension only claimed to be positive if the system was controlled by the occupant.

2.5.4 Limitations

The method used in this qualitative study was originally developed by Pettersson and Karlsson [2015] as a method to investigate users' expectations on future product. It was tested and evaluated on AV, both with groups of users and with individual users [Pettersson and Karlsson 2015; Pettersson 2016b]. An important part of the methodology was the simple car representation; it is enough to trigger the participants' fantasy, without limiting their reflections. "Setting the stage" worked good also for this study at the exhibition *Vårgårdamässan*. The method had some start up time before the participants were into the creative process, so each test session needed some time. When the participants were in groups, the start up time was much shorter. The result from the qualitative study is not representative for the whole range of self-driving car occupants. The study was performed in Vårgårda, which is a small town 60 km outside Gothenburg, Sweden. Travelling distance to work was generally short and the awareness of crash safety was high since Autoliv is founded in Vårgårda. The result in the qualitative study is not representative for the whole range of autonomous car occupants, consequently similar studies in other cities and countries are needed to achieve a more comprehensive results.

2.6 Conclusions

The living room position and relaxing position were the most popular seating positions in AV, except the normal position. Of the living room positions, the variant where the front seats were rotated 180°, was the most frequently seen and is also interesting in a passive safety perspective. Small children are travelling rearward-facing, since this is the safest way for children to travel in a car [Henary et al. 2007]. Motion sickness is mostly not thought of as a problem by potential occupants in AV, but in the literature. This might limit the possible seating positions and lead to new innovative solutions to enable engaging in requested activities.

3 Evaluate Passive Safety for New Load Cases in AV

New load cases were identified in the first part of this thesis. In this part, some of these load cases will be run in sled tests to evaluate the passive safety systems. Are today's systems enough to keep the occupant safe in the future autonomous car? This is a question that this part aims to answer. Possible future challenges will also be identified and discussed, which might be the starting for further work at Autoliv.

3.1 Aim

The aim with this part of the master thesis is to determine if today's passive systems is able to keep the dummy safe and in position during impact in new potential seating positions i fully automated vehicles.

3.2 Theoretical Framework

3.2.1 Anthropometric Test Devices

Anthropometric test devices (ATDs), or dummies, are used to evaluate the protection of various restraint systems. They are mechanical models of the human in various sizes, ages and sex, and they are classified according to the impact direction they are developed for. In an impact, the ATDs aim to have a human like response in terms of trajectory, deformation, velocity, and acceleration. Therefore, the ATDs have the same size, shape, mass, articulation, stiffness, and energy absorption and dissipation as the human. The ATDs are equipped with sensors measuring forces, accelerations, angular velocities and deformation in different body parts; data from these sensors can lately be compared to specific injury criteria and risk curves to analyse the severity of the impact with the tested restraint system. [Mertz 2002]

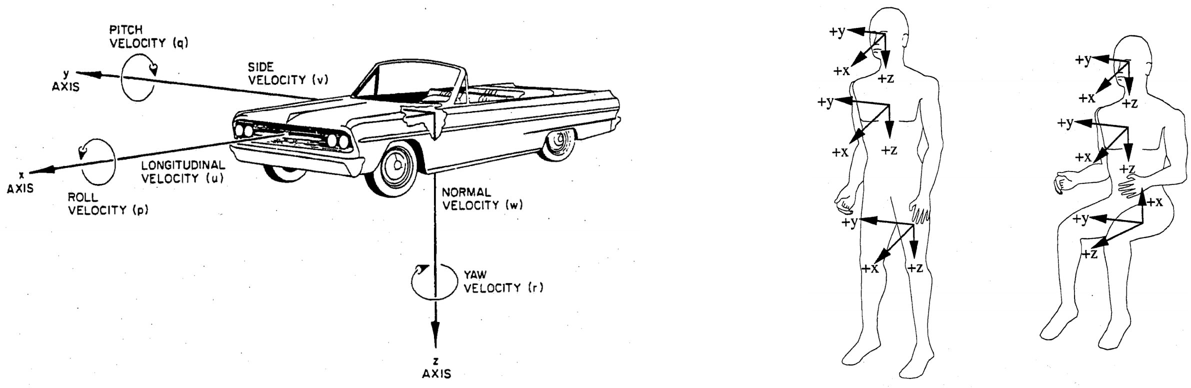
The most used dummies are the frontal impact dummies belonging to the Hybrid III family. These dummies are available in sizes representing a 3-year-old, a 6-year-old, a 5th percentile female, a 50th percentile male and a 95th percentile male. The midsize male is the most used size when evaluating restraint systems in the automotive industry. [Mertz 2002] A new dummy, called THOR (Test device for Human Occupant Restraint), has been developed for frontal impact condition. This dummy has enhanced biofidelity and is more instrumented than the Hybrid III. THOR is currently available as the midsize male and is considered for the consumer rating programs. [Humanetics 2016]

THOR. NHTSA has a research program since 1980s, with the aim to develop a new advanced crash test dummy to replace the Hybrid III 50th percentile male [Parent et al. 2013]. This has resulted in THOR, which is currently considered for frontal impact tests in Euro NCAP [Humanetics 2016]. THOR both has enhanced biofidelity and instrumentation compared to Hybrid III. The most important features for THOR for this thesis is the articulating thoracic spine with more flexible joints, the more human-like ribcage and shoulder, the muscle representation in the neck, and the improved pelvis design with submarining detection features. [Mertz 2002; Krayterman 2013]

THOR exists in a variety of versions. THOR-NT was released in 2005 and was an extensive upgrade of the first THOR Alpha. SAE and NHTSA started the evaluation of THOR-NT in 2006 and in 2010 a new improved dummy was released, called THOR-K. The version currently available for purchase is THOR-M and is a new version of THOR-K. [Humanetics 2016]

3.2.2 Measurements

Coordinate System. The coordinate system used in the automotive industry is standardized in SAE J670 and SAE J211. X-axes is in longitudinal direction of the car, Y-axes in lateral direction and Z-axes in vertical direction (figure 3.1). The same coordinate system is used for dummies, but it is defined as standing erect. The coordinate system will move and rotate with the dummy. Figure 3.1 shows the coordinate system also for the seated occupant. [SAE J1733 1994]



(a) SAEJ670 (b) SAEJ211

Figure 3.1: *The coordinate system according to SAE standard.*

Sensors. The ATDs are instrumented with sensors that measure forces, accelerations, angular velocities, moments and deformations in different body region. The instrumentation varies between different ATDs. Forces are measured in the SI-unit Newton. The forces in X- and Y-direction represent shear forces in the sagittal and frontal plane respectively, and the Z-forces or axial forces are tension-compression forces. The acceleration is generally measured in G, which is not an SI-unit. One G represents the acceleration of free fall, which means 9.81 metres per second squared. The angular velocity is only measured in the head and is measured in the SI-unit radians per second. The angular velocity in X-, Y- and Z-direction is also called roll, pitch and yaw. Moments are measured about each axes, meaning that M_x is the moment around the X-axes. Moments are measured in the SI-unit newton meter. Deformation is only measured in the chest and the unit is millimetre.

Injury Criteria. Injury criteria have been developed to relate the mechanical responses from the ATD to injuries and risk to life for living humans. The injury criteria have risk curves, which relate a specific value to a probability for an injury of a specific severity in that body region. The abbreviated injury scale (AIS) is used to describe the severity of the injuries. The AIS group injuries based on the threat to life; 1 is minor injury and 6 is maximum injury. It is complicated to develop tolerance levels and risk curves for injury criteria due to the individual differences between humans and the indirect test methods that must be used. Computer simulations, reconstruction of crashes, and tests with cadaver, animals and human volunteers below injury level are methods commonly used. [Eppinger et al. 1999]

HIC: Head Injury Criteria (HIC) uses head acceleration to calculate a HIC-value which could be related to the risk of skull fractures. The equation for calculating HIC is shown in equation 3.1, where $a(t)$ is the acceleration pulse and t_1 and t_2 are the outer limits of the time interval having the highest mean acceleration. The time interval could either be 15ms or 36ms, depending on which type of HIC that should be used. [Schmitt et al. 2004]

$$HIC = max \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \mathrm{a(t)d}t \right]^{2.5} (t_2 - t_1) \tag{3.1}$$

BrIC: Brain Injury Criteria (BrIC) is a new criterion related to the risk for traumatic brain injuries and is still under development. BrIC uses the maximum angular velocities about X-, Y-, and Z-axes (ω_x, ω_y and ω_z) and the critical angular velocities around each axes (ω_{xC}, ω_{yC} and ω_{zC}) to calculate the BrIC-value according to equation 3.2. The critical angular velocities are still preliminary, but in this thesis the values proposed by Takhounts et al. [2013] was used ($\omega_{xC} : 66.25 rad/s$, $\omega_{yC} : 56.45 rad/s$, $\omega_{zC} : 42.87 rad/s$).

$$BrIC = \sqrt{\frac{\omega_x}{\omega_{xC}}^2 + \frac{\omega_y}{\omega_{yC}}^2 + \frac{\omega_z}{\omega_{zC}}^2} \tag{3.2}$$

NIC: Neck Injury Criteria (NIC) is developed by Boström et al. [1996] and used for rear-end impacts. NIC assumes that injuries in the neck are related to a sudden change of flow inside the fluid compartments in the cervical spine. This change is caused by pressure gradients and the risk for injuries can be predicted by equation 3.3. The relative acceleration and velocity in the equation (a_{rel} and v_{rel}) are between the centre of gravity (CoG) of the head and the first thoracic vertabrae, T1, in X-direction. [Schmitt et al. 2004]

$$NIC(t) = 0.2a_{rel}(t) + v_{rel}(t)^2 \tag{3.3}$$

N_{ij}: Neck Injury Criteria (N_{ij}) is developed by NHTSA for frontal impacts. This criterion uses the axial force and the flexion/extension moment to assess the risk for injury. N_{ij} is calculated using equation 3.4 where F_{int} and M_{int} represents critical intercept values specific for each dummy size (THOR: $F_{int} = -4227/3216$ N, $M_{int} = -94/67$ Nm). [Schmitt et al. 2004; NHTSA 2015] There is also a new criteria discussed for the THOR dummy, called cervical osteoligamentous spine injury criterion or cN_{ij}. The calculations are the same as for N_{ij}, but cN_{ij} has other critical values and risk curves (THOR: $F_{int} = -3640/2520$ N, $M_{int} = -72/48$ Nm). Note that the criterion still is preliminary. [NHTSA 2015]

$$N_{ij} = \frac{F_z}{F_{int}} + \frac{M_y}{M_{int}} \tag{3.4}$$

Multipoint Thoracic Injury Criteria: The thoracic injury risk can be determined in many different ways, where multipoint thoracic injury criteria is one suggestion based on the chest deformation. The chest deformation is measured on four points at the chest, right/left and upper/lower, and the maximum resultant deformation, R_{max}, is used in the risk calculation. The risk calculation is age dependent; older occupants are exposed to a higher risk for the same R_{max} compared to younger occupants. [Saunders et al. 2015] Note that also this injury criteria and its related risk curves are preliminary.

Femur Performance Criteria: The femur performance criteria protects the hip-thigh-knee complex through limiting the maximum compression force in femur, the negative F_z value. [Schmitt et al. 2004]

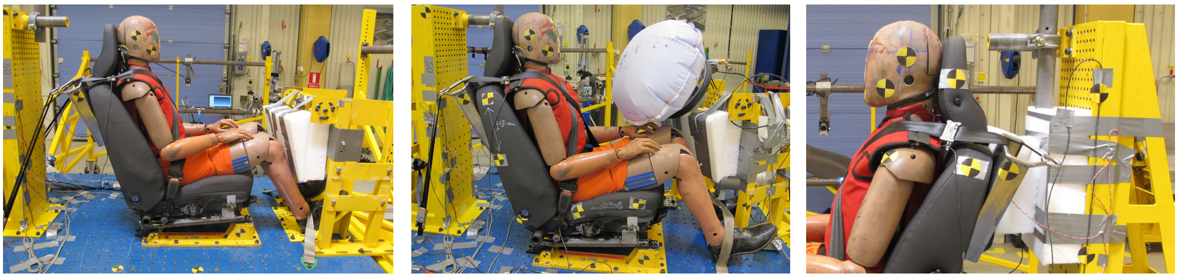
3.3 Method

New potential seating positions were defined in the first part of this study and three of them were chosen for sled testing: the relaxing position, the living room position with front seats rotated 180° and the conversation position. The first two positions were interesting for testing since those were the most popular positions; relaxing position is also a position that probably already exist among passengers and might be a common position in the early phase of self-driving cars. The living room position represents the epitome of self-driving cars and it is also considered realistic from a safety perspective, since research within child safety shows that it is safer for small children to travel rearward-facing [Henary et al. 2007]. The conversation position was not the most frequently seen position, and might not be realistic due to the space in the car, but is still interesting since it gives an understanding of the kinematic in odd impact directions. Twelve sled tests in frontal, side and rear-end impact directions, were run in total. For Autoliv employees there is an additional appendix, Appendix D with more detailed information concerning the method.

3.3.1 General Experimental Design

The crash tests were run at a HYGE crash track with a sled representing the interior of a driver compartment. The sled had a driver seat and a steering wheel rig mounted, and a strap over the ATDs tibia simulated the limited legroom. Figure 3.2 shows the setup. The seat was a Volvo V70 driver seat, redesigned with a belt in seat system, which means the belt is mounted in the seat instead of the B-pillar. The original seat was not designed for belt in seat loads, hence reinforcements were needed to prevent the seat from collapsing during the crash. The base of the chair was reinforced with weldments and the WHIPS (whiplash protection system) was welded stiff. The seat back was reinforced with a steel plate and had straps mounted to the sled to transfer some loads from the seat.

Two seatbelt systems were used, a three-point belt and a two-point belt of crisscross type, both mounted in the seatback. The three-point belt was always used, while the two-point belt, or extra belt, only was used in some tests. The seatbelts were Autoliv standard belts with the ability to change between two different levels of load limiting: 2.3 kN and 3kN. The belts always had pretensioning in the retractor and sometimes also in the end mounting for the three point belt. This last mentioned pretensioner is called pre lap pretensioner (PLP) and is a pretensioner on the outboard side of the lap belt.. The retractor pretensioners (RPs) were trigged 7 ms after impact and the PLP was trigged 7 ms later. The three point belt was also equipped with a crash locking tongue (CLT), making it impossible for the belt to pass through the tongue above a certain load. The belt geometry for the belt in seat was optimized through static testing to avoid the belt from slipping off the shoulder. The buckle and PLP had originally similar mounting as in Volvo V70, but in some tests the end mounting and buckle were moved downward to optimize the fit of the lap belt and avoid submarining. The setup of airbags differed between different tests; driver airbag, pelvis restraint cushion (PRC) and simulated knee airbag were used. A PRC is an airbag built into the seat cushion, which pushes the front part of the seat cushion upwards, towards the thighs, to better restrain pelvis. The simulated knee airbag was mounted to the steering wheel rig and consisted of relatively stiff foam with a short distance to the knees (approximately 20 mm). The seat cushion was set to its lowest position.



(a) *Test no. 3.* (b) *Test no. 10.* (c) *Test no. 1.*

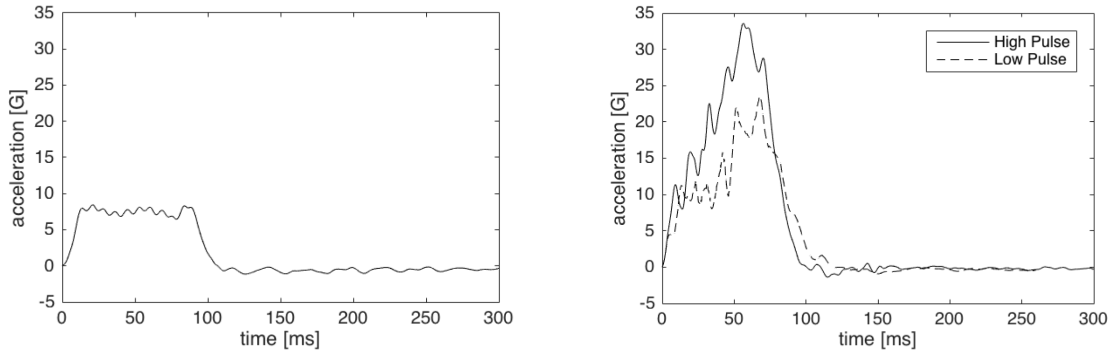
Figure 3.2: *Example of the test setup.*

3.3.2 Pulses

Three different pulses were used, one representing a rear-end impact and two representing frontal impacts in different speeds (figure 3.3). The frontal impact pulses were both the average of three pulses from the US legislation testing FMVSS 208. The higher speed pulse was based on a full barrier test in 56 kph with a Volvo XC60 2011, Volvo S60 2012 and Kia Optima 208 2009. Data for the Volvo cars were found in a public NHTSA's database [NHTSA 2016b] and data from the Kia Optima was from internal testing. The pulse in lower speed represented a 40 kph full frontal barrier test. The pulse was calculated as the average of three of the most sold car models in the US: Mercedes Benz E350 2014, Toyota Corolla 2014 and Nissan Altima 2014. Data was found in a public NHTSA's database [NHTSA 2016a]. The rear-end impact pulse is a standard Euro NCAP rating pulse for whiplash testing in 24 kph. To avoid confusing, the pulses are from now on called low, medium and high pulse which represents the rear-end pulse in 24 kph, the low frontal pulse in 40 kph and the high frontal pulse in 56 kph respectively.

3.3.3 Test Matrix

The initial aim was to test the three different positions in all three impact directions, but some combinations were excluded because of limitations in the test setup and ATD. There are ATDs developed for frontal, side and rear-end impacts, but not for other impact directions. The restraint systems vary between different tests. The purpose was to add all relevant restraint systems for the specific load case and adjust the parameters in order to keep the dummy in position during the impact. After each test, the setup was evaluated and based on the result parameters were adjusted or restraints were removed or added. Which restraint systems that initially were used in each test were decided before testing, after internal discussions at Autoliv. The final test matrix is presented in table 3.1 and a visualization of all combinations of positions and impact directions are found in Appendix B.



(a) *Low pulse in 24 kph.* (b) *Medium and high pulse in 40 respectively 56 kph.*

Figure 3.3: *Pulses used in the testing.*

Table 3.1: The test matrix (LB = lap belt).

Test description					Seatbelt		Pretensioner		Load limiting		Airbags				Extra			
No	Autoliv Internal test no.	Load case	Impact direction	Pulse	3pt belt	Extra belt	PLP	RP	Low	High	Driver	Knee	Side	PRC	Uptilted cushion	Optimized o LB	Optimized i LB	Seatback support
1	T-16163239	Living room	Frontal	Medium	X	X	X	X		X								X
2	T-16163240	Living room	Frontal	High	X	X	X	X		X								X
3	T-16163241	Relax	Frontal	Low	X	X	X	X		X		X			X			
4	T-16163242	Relax	Frontal	Medium	X	X	X	X		X		X			X			
5	T-16163243	Relax	Frontal	Medium	X			X		X		X			X			
6	T-16163244	Relax	Frontal	Medium	X		X	X	X			X			X	X		
7	T-16163250	Relax	Frontal	Low	X		X	X	X		X			X	X	X	X	
8	T-16163251	Relax 180⊠	Frontal	Low	X	X	X	X		X						X		
9	T-16163246	Discussion	Frontal	Medium	X	X	X	X	X		X	X			X	X		
10	T-16163247	Discussion	Frontal	Medium	X	X	X	X		X	X	X			X	X		
11	T-16163245	Normal	Frontal	Medium	X	X	X	X		X		X						
12	T-16163249	Normal	Frontal	Medium	X	X	X	X	X		X	X						

Living Room Position. In the upright test positions, i.e. living room position and conversation position, the seatback angle was set to the standard angle for crash testing, 19° measured from the vertical line. The living room position was evaluated in frontal impact, which means rear-end impact for the ATD but in a more aggressive pulse. Rear-end impact and side impact were excluded since those load cases are the ordinary ones. Two tests, no 1-2, were run in different speeds but with the same configuration: extra belt, PLP and supporting foam behind the seatback (see figure 3.2c). The foam was too soft for the high load in the first test, so to the next run the foam was replaced with a stiffer type.

Relaxing Position. Six tests were run in relaxing position and frontal impact, five of them were forward-facing and one was rearward-facing. The seatback angle were chosen to 35° measured from the vertical line. This seatback angle represents a comfortable relaxing position, but still offers the ability to see the road (figure 3.4). For all forward-facing tests, the seat cushion was up tilted to its highest level. Test 3 and 4 had exactly the same configuration and differed only in speed, low and medium: extra belt, PLP, high load limiting and simulated knee airbag. Test 5 was run in medium pulse and almost had the same configuration, but without extra belt and PLP. Test number 6 was also run in medium pulse without extra belt, but with improved outer lap belt geometry, PLP, simulated knee airbag and the low level of load limiting. To test 7 the knee

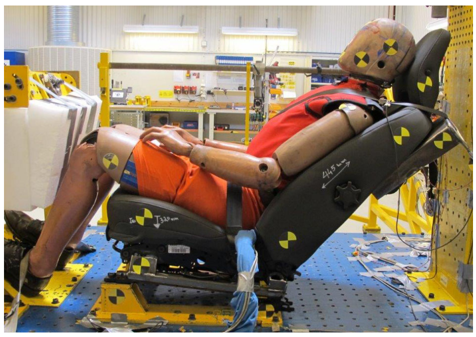


Figure 3.4: *In relaxing position the seatback angle was set to 35° from the vertical line.*

airbag was replaced with a PRC and the inner lap belt geometry
was improved. Test 8 was rearward-facing and in this test the PLP, extra belt and the high level of load limiting was used together with an optimized outer lap belt geometry. Test 7 and 8 were run in the low pulse to avoid damaging the dummy. Side impact was excluded, since this load case was considered to be handle with modifications on existing Autoliv products. Rear-end impact was covered by the rearward-facing relaxing position (test no. 8).

Conversation Position. In conversation position, the seat was rotated 30° inboard using approximately the middle point of the seat base as the centre of rotation; the rotation centre was a little more rearward (negative x) in test 10 than in test 9. This angle was an internal customer requirement. For the conversation position, two impact directions were considered interesting for physical testing: frontal impact and side impact. During testing, only a few frontal tests, 9 and 10, were run in medium pulse because of the similarity with small overlap/NHTSA oblique testing. Both tests had extra belt, PLP, driver airbag, simulated knee airbag, up tilted seat cushion and improved outer lap belt geometry. The difference was the level of load limiting, which was higher in test 10, and the changed centre of rotation for the seat base. The side impact setup was considered too simplified without penetration hence this load case was excluded. Rear-end impact was excluded due to limitations in the ATDs; there is no available ATD that are valid for oblique rear-end impacts.

Reference Position. Two tests were run in upright, forward-facing position as references. The tests had the same configuration except for the level of load limiting in the belt. Test number 11 had the high level of load limiting in the belt and test number 12 had the low level of load limiting. The tests were run with extra belt and simulated knee airbag, but without PLP.

3.3.4 ATD and Position

Submarining and retaining the dummy the restraints were important aspects of this testing, hence THOR was chosen. THOR has a more developed shoulder than HIII and is also better developed and equipped for evaluate submarining.Due to the unusual loads in these tests and the high risk of damaging the dummy, the older version of THOR, K, was used instead of the newer THOR-M. The ATD was positioned in "normal" position the first time. The position was measured using FaroArm and was then reproduced in the following tests.

3.3.5 Data Acquisition and Analysis

The data acquisition consisted of data from the ATD's sensors, belt force sensors, sled acceleration sensors and high-speed cameras. Four high-speed cameras were mounted on the sled; one top view, one side view from each side (perpendicular to the impact direction) and one frontal view. The cameras were recording in 1000 frames per second, 10 ms prior to impact until 300 ms after. Before analysis, all sensor data were filtered with appropriate CFC-filter (channel frequency class) using an auto sequence in the software DIAdem 2012. This auto sequence also calculated all injury criteria. The injury risk was calculated using the equations and risk curves proposed for NCAP [NHTSA 2015] and is presented in Appendix B. HIC, BrIC, N_{ij} and cN_{ij} are compared to risk curves for AIS3+ injuries and femur loads are compared to a risk curve forAI2+. The chest deflection has two different risk curves corresponding to the risk for AIS3+ injuries to occupants aged 45 and 65. Spinal compression is not included as an injury criterion in the automotive industry, but research from the space industry has presented risk curves for spinal fractures which was used as a reference [Somers et al. 2014]. In THOR, a load cell in T12 measures the spinal compression.

3.4 Result

Sled tests were carried out as first attempt to estimate the injury risk in potential new load cases in fully automated cars. The new load cases were defined in chapter 2 in this thesis. The results from the twelve sled tests are summarized and presented in this section. Freeze frames from the high speed video and measurement data are added in appendix C for the interested reader. The belt geometry in this setup was optimized to keep the dummy in position during the impact and not for obtaining low injury risk values. During impact, the shoulder belt was translated very close to the dummy's neck, especially when having an extra belt. This was seen in all positions including the reference tests (no. 11-12) (figure 3.5), hence it was considered to be a behaviour for this belt installation and not any specific position. The aim with this testing was to keep the ATD in position during the impact, but this had side effects. The chest deflection values in the tests were between 34.5 and 63.22 mm, which correspond to 29-99% risk for AIS3+ injuries for people above 65 years. The chest deflection generally peaked around 90-130 ms, which is the time when the belt was stopping the torso. The PLP was trigged at 14 ms and this caused a peak in the abdominal accelerations around 20 ms.

Figure 3.5: *During impact, the shoulder belt was translated close to the dummy's neck in this test setup. Time stamps (ms): 0, 42, 65. Freeze frames from test no. 4.*

3.4.1 Living Room Position

Two tests, in different speeds, were run in frontal impact with the "driver" rearward-facing in a living room position (test no. 1-2). The seatback flexed a lot and this, together with a rotation of the seatback and headrest around the upper part of the supporting foam, caused the seat to impact the camera fixture (see freeze frames in Appendix C). This affected the tests, especially the dummy measurements, but some conclusions could still be drawn. Overall, there was small relative motion between the dummy and the seat, which is a desirable behaviour resulting in low risk for Whiplash injury. Most of the measurements presented low injury risk. HIC and BrIC corresponded to less than 5% injury risk for AIS3+ and the femur values corresponded to less than 5% injury risk for AIS2+ (BrIC value in the first test, no. 1, was slightly higher at the moment where the dummy hit the camera fixture). Figure 3.6 compares some measurement to a forward-facing reference test in 40 kph (test no. 11). Even though the values were at low injury risk, they were usually higher compared to the forward-facing reference. Data was lost for the spinal compression in the first test, but for test 2 the value peaked at 7.6 kN around 40 ms (figure C.13, Appendix C).

The NIC values peaked when the headrest started to rotate around the supporting foam, the acceleration in T1 was higher than the head acceleration; the peak values were 34 and 42 in test no. 1 and 2 respectively. THOR does not have any tolerance limits for NIC, but 25.5 is the capping limit in Euro NCAP's high severity whiplash testing using BioRID [EuroNCAP 2015]. Through video analyse, it was noted that the extra belt did not have any necessary function in these tests since the dummy did not have a tendency to ramp out the seat. The chest deflection in Z was extremely high during the rebound (62.9 mm), but a behaviour that caused such high chest values could not be identified in the videos or in other data, hence sensor distortion was thought to be the explanation.

3.4.2 Relaxing Position

Six tests in total were run in relaxing position; five of them were forward-facing (test no. 3-7) and one was rearward-facing (test no. 8). Except these tests, two references in upright, forward-facing position were performed (test no. 11-12). The reference tests were run in the same speed in with different level of load limiting. Test number 11 had the high level of load limiting in both belts and test number 12 had the low level in both belts.

In general, the extra belt was not needed to keep the dummy in position in the active phase when the dummy was forward-facing, since there was no rotation of the upper torso around Z. However, the extra belt controlled

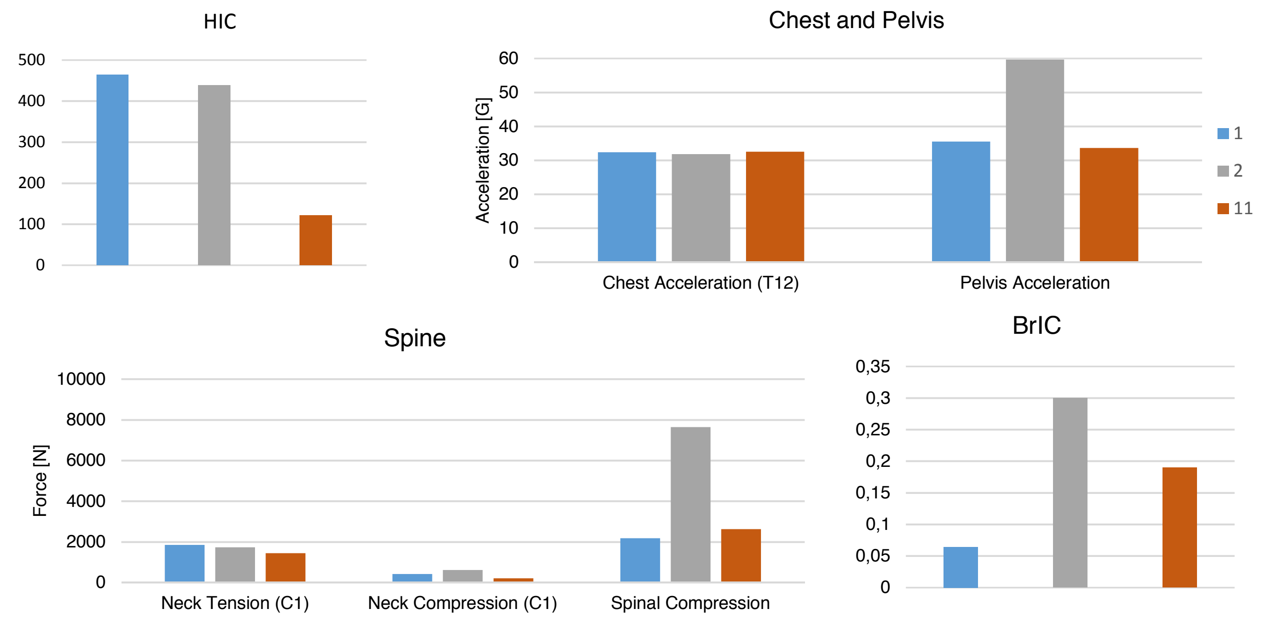


Figure 3.6: *Values for HIC, BrIC and chest, as well as some chosen values for pelvis, neck and spine for the tests in living room position. The orange bar is a forward-facing reference test in the same speed as test 1. Test no. 2 was run in higher speed.*

the long rebound so that the dummy hit the centre of the seat and headrest. Without the extra belt, the dummy's head almost missed the headrest in the rebound phase; the head only engaged with the side of the headrest. For the rearward-facing test (no. 8), the dummy had more tendencies to ramp out the seat compared to test no. 1 and 2 and the extra belt helped keeping the dummy in seat. Figure 3.7 presents some measurement data. The values could be compared to the upright reference (orange bars) and the rearward-facing test (green bar).

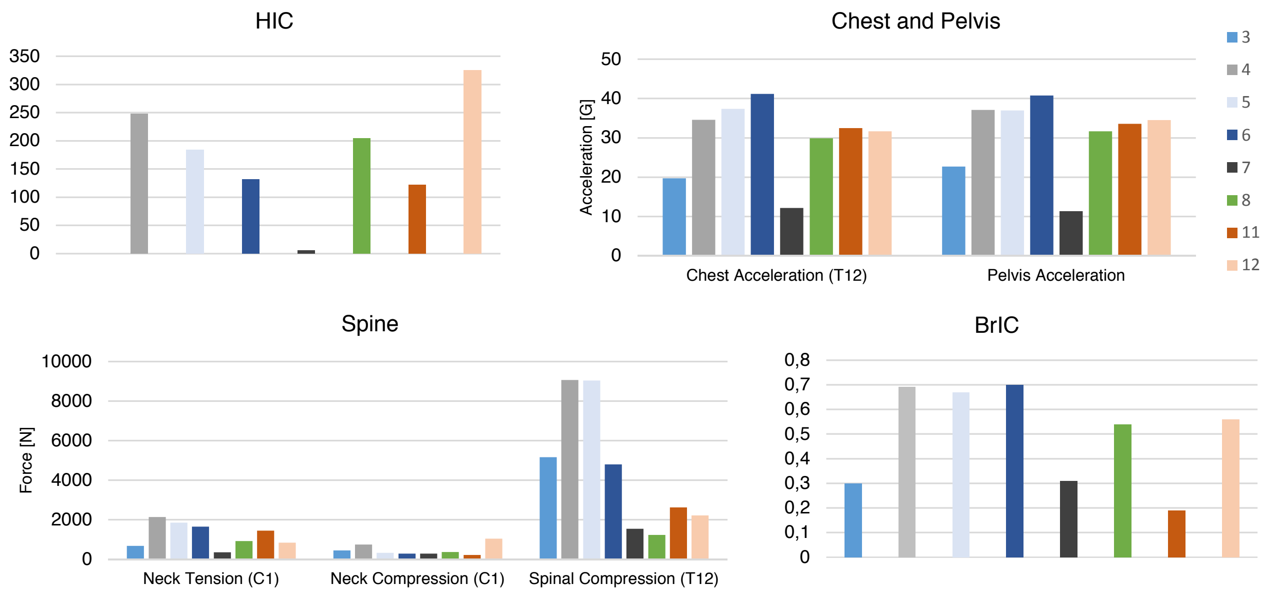
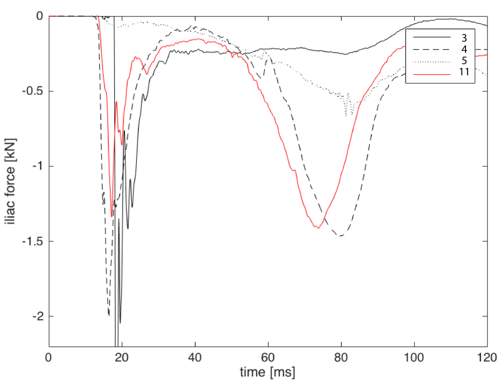


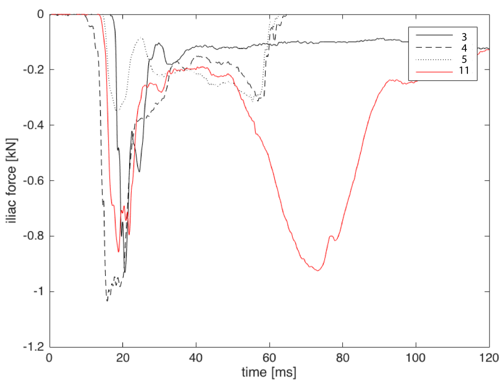
Figure 3.7: *Values for HIC, BrIC and chest, as well as some chosen values for pelvis, neck and spine for the tests in relaxing position. The orange bars are forward-facing upright reference tests with two levels of load limiting (dark = high load limiting, light = low load limiting). Be aware of the lower speed in test 3, 7 and 8*

Initial Tests with High Load Limiting (test 3-5). The general kinematic in these tests is shown in figure 3.8. Initially in the impact, the dummy was pressed into the seat cushion by the downward-forward movement forced by the up tilted seat cushion and the high load limiting in the seatbelt. This movement caused high compression loads in the thoracic spine (T12); above 5 kN in 24 kph (no. 3) and as high as 9 kN in 40 kph (no. 4 and 5). This could be related to the upright reference test which reached around 2.6 kN (see figure 3.7) or the article by Somers et al. [2014] which proposed a tolerance limit of 5.8 kN for spinal fractures. The spinal compression is shown as a function of time in figure C.13, Appendix C. The downward-forward motion also made the dummy prone to submarining, which occurred on both sides of the lapbelt in 24 kph (no. 3) and on the buckle side in 40 kph (no. 4-5). Submarining was detected by the iliac force sensors and data from these sensors are shown in figure 3.9. When the loads on the sensors drop before the active phase of the impact is finished (approximately 120 ms), the belt has slipped over the iliac wings and submarining has occurred. After this initial movement, when the body was stopped by the seatbelt around 120 ms, the head rotated fast forward and in 40 kph this caused high values on BrIC ($M_y = 38.5/36.9$ rad/s, 30.4/28.3% risk for AIS3+), N_{ij} (based on flexion-tension, 21.5/16.1% risk for AIS3+) and cN_{ij} (based on flexion-tension, 54.5/37.7% risk for AIS3+). Comparing to the upright reference test (dark orange bar in figure 3.7), the values were generally slightly higher.

Figure 3.8: *The kinematic for test number 4, which also represents the kinematic in test number 3 and 5. Time stamps (ms): 0, 60, 70, 80, 90, 100, 110, 120, 130, 140.*



(a) *Left iliac force*



(b) *Right iliac force*

Figure 3.9: *The iliac forces were used to identify submarining.*

Test with Low Load Limiting and No Extra Belt (test 6). The aim with this test was to avoid submarining and lower the compression loads in the spine. The lap belt geometry was improved by moving the PLP downwards and only a three-point belt with the low level of load limiting was used (figure 3.10). The kinematic became completely different (see figure 3.11). The upper body immediately started a forward rotation and this, in combination with the improved lap belt geometry, was enough to avoid submarining. As could be seen in figure 3.7, BrIC, N_{ij} and cN_{ij} were similar as previous tests, but the compression force in the spine dropped to 4.8 kN which still is high compared to the upright references which had 2.2-2.6 kN in spinal compression loads, but it corresponds to less than 5% risk for spinal fracture. The spinal compression is shown in figure C.13, Appendix C Most of the measured values were lower compared to the previous test (test no. 5), but BrIC, N_{ij} and cN_{ij} were still high and in the same range as test 5. BrIC again had its peak when the seatbelt stopped the torso around 120 ms.

(a) *Original geometry.* (b) *Improved geometry.*

Figure 3.10: *The PLP was moved to improve the lap belt geometry.*

Figure 3.11: *The kinematic for test number 6. Time stamps (ms): 0, 40, 60, 70, 80, 90, 100, 110, 120, 130.*

Test with PRC instead of Knee Airbag (test 7). The immediately forward rotation of the upper torso in previous test, test number 5, was beneficial for this load case. The aim with this test was to investigate if a similar kinematic could be achieved without the "knee airbag" and instead using a PRC in combination with an even more improved lap belt geometry (both the end mounting and the buckle were moved downward). The test was run in 24 kph as a precaution. This test resulted in a slightly changed kinematic, but no submarining occurred and the spinal compression load (1.5 kN) were lower than the upright reference in 40 kph. In this test, the dummy's pelvis moved forward in the seat before it was stopped by the lap belt. The torso followed the same movement, and did not start to rotate forward until the pelvis' forward motion was stopped. This caused a straighter movement path, with a later rotation of the torso compared to test no. 6. This difference in kinematic could easily be observed in the high-speed video, but is hard to see in freeze frames (figure 3.12). Since test was run in lower speed compared to test 6, the measured values were generally low and not comparable to the other tests.

Figure 3.12: *The kinematic for test number 6 (upper) compared to test number 7 (lower). Time stamps (ms): 0, 40, 60, 80, 100.*

Rearward-facing Relaxing Position (test 8). In this test the dummy was placed in a rearward-facing relaxing position. The kinematic was similar as the results from the first tests in "living room" position. The relative motion between the dummy and the seat was small, but the seatback flexed a lot and rotated around the supporting foam causing the headrest to impact the sled fixture. The low pulse resulted in measured values that generally were low (below 5% risk for AIS3+) and NIC peaked 26.3. BrIC was not affected by the headrest hitting the sled structure and measured 0.54, which corresponds to 16.5% risk for AIS3+. The measurements in this test were in the same range as the upright reference in higher pulse (test no. 12).

3.4.3 Conversation Position

The conversation position was run in frontal impact and the kinematic resembled the kinematic seen in small overlap tests or NHTSA oblique tests, even though the test condition differed. The driver and knee airbag were now positioned angled and slightly to the left of the driver. The dummy's rotation and the head to bag interaction resembled that of small overlap/NHTSA oblique testing; the head slipped off the driver airbag at 120 ms and the extra belt was necessary to stop the rotation of the upper torso and keep the dummy in position during the impact. BrIC (0.79/0.61; 41.2/22.5% risk for AIS3+), N_{ij} (0.81/0.5; 16.4/9.6% risk for AIS3+) and cN_{ij} (0.62/0.38; 36.5/11.3% risk for AIS3+) peaked when the head tweaked off the driver airbag.

3.5 Discussion

Twelve sled tests have been run in this first attempt to investigate the future need of new passive safety products at Autoliv. Early in this project it was decided to use a belt in seat solution. This contradict the original aim and limitations for this master thesis, since Autoliv does not produce this solution, but was thought to be a fundamental condition for these new load cases with rotated and reclined seat. The same applies for other passive safety solutions. The seat will be very important in the future, since all safety must be integrated in it.

THOR is not included in consumer rating program or legal requirement today, hence this analysis is based on injury criteria and risk curves that are preliminary or still under development. This must be kept in mind when reading the result. The high chest deflection was common for all tests and was not a surprise. The first step is to understand which kinematic that is beneficial, after that the systems could be optimized for criteria such as chest deflection. During the testing, distortion was commonly seen for the chest deflection sensors and sometimes also for the load cell in T12 measuring spinal compression. Problem with the chest deflection sensors is a known problem for the THOR, especially for this older version. The data has been checked for abnormalities and some measurements have been excluded, however this is not an assurance that all the other data is correct.

3.5.1 Living Room Position

No dummy is validated for the high-speeds rear-end test conducted in this study, hence it was decided to use THOR even for this load case. The NIC values were of interest for this position, but there is no published injury threshold for NIC using the THOR dummy. In the result, a tolerance limit for BioRID was presented as a reference but it is not known how realistic this comparison is. The three tests in rearward-facing position (1,2 and 8) showed the importance of some energy absorbing solution in the seat. The seatback flexed a lot, even with immediate contact with the supporting foam. The foam that was used in this testing was not energy absorbing at all. When designing the energy absorbing solution, NIC is an important parameter and reference values must be developed for the THOR if this dummy will be used in this load case.

The general kinematic when sitting rearward-facing was good, since there was a small relative motion between the dummy and the seat. However, the measurements were generally higher than the forward-facing reference (test no. 11). The restraint systems are developed for load cases similar to the reference test and not optimized at all for a rearward-facing load case. This explains why the measured values were high, even though the kinematic was beneficial. To travel rearward-facing is considered to be the safest position for children [Henary et al. 2007], and with optimized restraint systems that might be true also for adults. However, this seating position was only evaluated in full frontal impacts, with lateral acceleration added to the load case other restraint systems might be needed; than the torso and head must be kept in position, which might motivate the extra belt or a new design of the seat and headrest. This is an important next step to evaluate for this position.

In test no. 2, the spinal compression had high values early in the active phase. This peak could not be explained by analysis of the high-speed video, but it is an important parameter to take into account in further testing. This load case is similar as today's rear-end collisions when travelling like normal, except for the more severe crash pulse. The WHIPS then handle the energy absorption, but in this case, a WHIPS adapted for the higher load, might not be suitable since the pre-requisites are different regarding space behind the seat. While designing this solution, one must have in mind that the occupant might also want to recline the seat to a relaxing position like in test number 8.

3.5.2 Relaxing Position

The tests in relaxing position showed that Autoliv's products can handle this load case through using a simulated, perfect knee airbag, pretensioning, improved lap belt geometry and low load limiting. High spinal compression loads and submarining were avoided by keeping the pelvis tight in position, limiting the forward motion, and by the immediate rotation of the upper body of the dummy. However, this might not be the solution of choice when starting to rotate the seat. In one test, a similar kinematic was tried to be achieved, only by using safety integrated in the seat, in this case a PRC instead of a knee airbag. The ATD then got a straighter movement path with a later rotation of the torso, but still no submarining; on the other hand, this test was run in 24 kph. This kinematic did not look as beneficial as the one in test number 6, so in a higher speed, new solutions might be needed.

In the forward-facing test, the extra belt was not necessary for keeping the ATD in position, but for position it in the long rebound. The long distance in the rebound was due to the relaxed seatback angle and the low level of load limiting. Without the extra belt, the head almost missed the headrest and hit the side of it causing peaks in HIC and BrIC. However, there might be a more sober solution to this problem, either by energy absorption to decrease the rebound or by making the rebound shorter. An advantage for this load case is the long distance between the occupant and the steering wheel or dashboard. This gives space and time to control the occupant's movement in the crash moment. The extra belt was probably not necessary even in the rearward-facing test, but it will probably play an important role in order to maintain the occupant restrained in higher speeds, with more extreme seatback angles and in oblique tests. However, a good belt geometry can go a long way.

All tests in relaxing position were run in the same seatback angle, 35°. This seatback angle represents a relaxed position were the occupant still can see the road. Tests with more extreme reclined seating positions should also be investigated. For those load cases, the submarining issue will probably be even more difficult to handle and a more creative solution to initiate the upper body's forward rotation would probably be needed.

3.5.3 Conversation Position

In these tests the rotation was chosen to 30°based on internal discussions. The rotation angle of course affects the kinematic. A study is needed that evaluate which rotation that is needed to achieve the wanted benefits for this seating position. 30°is probably a maximum rotation for this position; a smaller rotation angle is more space efficient in today's car interior and also positive regarding motion sickness. It is also an easier load case to handle.

In the tests in conversation position the extra belt was a necessity to keep the dummy restrained during the impact, since the extra belt stopped the rotation of the upper torso around Z. In these tests, the dummy hit the airbags with a different angle compared to full frontal tests, which lead to a need of modifications on the existing products. This need resembles the need seen in small overlap and oblique tests, hence solutions for these load cases also might be applicable for the conversation position. One possibility though, that is not an option in small overlap, is to rotate the seat prior to or in crash.

Only one impact direction was tested for this load case due to limitations in the test setup and the ATD¡. In order to fully understand this position, much more testing needs to be done and simulation is preferred instead of physical testing due to earlier mentioned limitations. This is a difficult load case to handle and one need to consider if it is a realistic and wanted position that is worth the effort. The position has been proposed by car manufactures, but was only seen in one test in the qualitative study. Another aspect is space in the car; will there be enough space in the car for this position?

3.5.4 Problem Description

This bullet list summarizes the difficulties for each load case and describes possible future challenges and work. The aim is to point out findings that may form the basis for further work at Autoliv.

Living room Position:

- This position has potential to be a safe position for the occupant, but the energy in the impact has to be absorbed. The challenge is to design a solution that allows different seatback angles and results in low NIC values, meaning low relative difference in acceleration between head and upper neck. Spinal compression might also be a challenge, but this parameter must be further evaluated. This position needs to be evaluated for load cases with a sideway component.

Relaxing Position:

- A beneficial kinematic was achieved through restraining the pelvis and immediately rotate the upper body forward. This lead to a more optimal hip angle regarding submarining. Some concepts were tested, but other solutions might be more suitable. Preferably, all passive safety should be integrated in the seat to allow various seating positions. The relaxing position causes a long forward excursion and the rebound must be controlled in some way.

Conversation Position:

- Simulation is needed to complete the understanding for this position, but it must first be evaluated if this is a desired and interesting position for autonomous vehicles. Much could be gained from small overlap/NHTSA oblique testing, but this position also offers new pre-requisites that could be used.

3.5.5 Limitations

These tests were a first attempt to understand the kinematic and challenges in these new load cases and further work is needed. The variation in parameters is limited as well as the number of parameters. Among other parameters, pre-crash maneuvers were excluded and it could really be discussed whether or not this is realistic when considering self-driving cars. Swerving maneuvers and pre-braking may be common pre-crash maneuvers with self-driving cars, which may put the occupants in less optimal restraint positions prior the crash. This parameter needs to be added in future studies. It was decided to use pulses from today's legal requirements and consumer rating. The future pulses for autonomous vehicles could just be guessed, hence it was considered more reasonable to use today's pulses. A lower pulse was used in some tests due to risk for damaging the dummy.

Focus when designing the restraint system was to keep the dummy in position using existing Autoliv products; the injury criteria were secondary. This resulted in a belt geometry where the shoulder belt translated too close to the neck during impact. Except from causing unnecessarily high loads and moments on the neck, this belt geometry might cause injuries to the common carotid artery [Pugh and Taylor 2005] or the major cerebral vessels [Chedid et al. 1989]. Based on this, the belt geometry was not optimal in this test setup which could have affected the testing.

THOR has not been evaluated for relaxing position or rear-end impacts. Nevertheless, this dummy was considered to be the best dummy for the job when doing this type of testing. To handle the future load cases, it is necessary to develop both physical and mathematical ATDs that are valid for these new load cases.

Free flying objects is an additional parameter for autonomous cars that were excluded in this test setup, but needs to be adressed in other studies. Many images found on Internet show a lot of free flying objects in the car, like water bottles, computers, tablets and gaming consoles. This also agreed with the result from the qualitative study at *Vårgårdamässan*. Free flying objects will especially be a concern in the living room position when the occupants are seated towards each other. As been said before, this was a first attempt to evaluate new potential load cases and the test method would be refined if repeated. Still a lot could be learned about where to put the effort to handle these new load cases in autonomous cars.

3.6 Conclusions

This was a first attempt to understand the need in autonomous cars for new passive safety solutions. Living room position, relaxing position and conversation position were tested in full frontal impact. In total twelve sled tests were run. The testing showed that the kinematic in the rearward-facing living room position was good, but the challenge is how to absorb the impact's energy in the seat and how to restrain the occupant without sustaining high spinal compression. The relaxing position increases the risk for submarining, but offers much time and space in the car for new creative solutions. A beneficial kinematic observed for this load case was to obtain an immediate rotation of the occupant's upper body, which could be achieved by various solutions. The conversation position was hard to evaluate in physical testing, hence simulation is needed for a more complete evaluation. For the frontal load case though, much could be gained by applying the knowledge gained in the work of oblique and small overlaps tests for both nearside and far side occupants.

In general, it is preferred that the solutions are integrated in the seat to allow rotation and the possibility to recline the seat. One must also consider what unique benefits each possible seating position in an AV have, and set them in relation to the effort needed to handle it.

4 Conclusions

This master thesis was a first exploratory attempt to evaluate the need at Autoliv for new passive safety systems in fully automated cars. In the first part of this study, new potential load cases were identified through a literature study and qualitative study. The result presented a living room position, with the front seats rotated 180°, and a relaxing position as the most interesting load cases.

In the second part, these seating positions were then run in sled test together with a conversation position with the front seats rotated 30° inboard. The conversation position needs more investigation; simulations are needed, but it is also important to determine whether the position is relevant or not. The tests showed that the extra belt was an important restraint system for this position. The rearward-facing living room position had a beneficial kinematic. The challenge is to develop a solution to absorb the energy in the seat and to optimize the restraint systems' parameters. The challenge with the relaxing position was to avoid submarining. Tests showed that this could be achieved through restraining the pelvis and allow an immediate forward rotation of the upper body. All seating positions were only evaluated in full frontal impact; with sideway components other challenges will be raised. Different concepts were investigated, but new solutions integrated into the seat are to be preferred. With fully automated cars, the passive safety systems must be adapted for more seating directions and various seatback angles than what is done today. This is a limited study and more studies are needed.

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Appendices

A Method Part 1

The test protocol from the qualitative study at the exhibition *Vårgårdamässan* is available here in Swedish and translated to English. Note that the Swedish version is the one that was used in the study.

Testprotokoll

Test nr:

Vårgårdamässan

Förberedelser

Ställ iordning stolar från tidigare test
Sätt upp provnummer för fotning

Introduktion till studien

Vill du delta i vår studie och föreställa dig hur du skulle vilja sitta i en självkörande bil? Jag håller på med ett projekt kring självkörande bilar och gör nu en studie kring hur människor tror att de skulle vilja sitta och vad de skulle vilja göra i en sådan bil. Jag har lite frågor och sedan får du spåna fritt och visa hur du skulle vilja sitta. Det tar max 10 min att delta och då har du chansen att vinna en biobiljett om du lämnar din mailadress.

Bakgrund (Part 1)

1:1 Kön?
- ○ Man
- ○ Kvinna

1:2 Ålder? Minst 10, max 55 år.

1:3 Körkort?
- ○ Ja
- ○ Nej

1:4 Kör du bil till jobbet regelbundet?
- ○ Ja
- ○ Nej

1:5 Hur ofta åker du bil?
- ○ Varje dag
- ○ Några gånger i veckan
- ○ Några gånger i månaden
- ○ Mer sällan

1:6 När tror du att det kommer att finnas självkörande bilar på marknaden?
- ○ Senast under 2020
- ○ 2021-2025
- ○ 2026-2030
- ○ Långt in i framtiden
- ○ Aldrig

Introduktion till övningen **(markera den som används, och ordningen på 1 och 2)**

Variant 1: Kortare resa

a) Kör bil regelbundet till jobbet (fråga 1:4 besvarad med "Ja"):

Föreställ dig senaste gången du körde bil till jobbet och tänk sig in i situation att du istället hade haft en självkörande bil. Du kunde bara gå ut till bilen, sätta dig och ställa in din rutt. Sedan körde bilen dig till jobbet, utan mer input från dig. Vad skulle du göra i bilen? Hur skulle du vilja sitta? Inred bilen med stolarna och berätta hur du tänker.

b) Kör inte bil regelbundet till jobbet (fråga 1:4 besvarad med "Nej"):

Föreställ dig senaste gången du tog bilen en kortare sträcka. Kanske när du du körde hit, handlade eller lämnade av barnen någonstans.Tänk dig in i situationen att du istället hade haft en självkörande bil. Du kunde bara gå ut till bilen, sätta dig och ställa in din rutt. Sedan körde bilen dig till rätt ställe utan mer input från dig. Vad skulle du göra i bilen? Hur skulle du vilja sitta? Inred bilen med stolarna och berätta hur du tänker.

Variant 2: Längre resa - Vuxen

Föreställ dig att det är helg och att du och din familj ska åka till sommarstugan i Varberg. Alla hoppar in i bilen och du ställer in rutten. Bilen kör sig själv och du behöver inte engagera dig i körningen eller ge någon mer input förrän du är framme. Vad skulle ni göra i bilen? Hur skulle ni vilja sitta? Inred bilen med stolarna och berätta hur du tänker.

Variant 3: Längre resa - Barn (under 18 år)

Föreställ dig att det är helg och att hela familjen ska åka till sommarstugan i Varberg. Ni hoppar in i er bil, mamma eller pappa ställer in vart ni ska och sedan kör bilen själv. Vad skulle ni göra i bilen? Hur skulle ni vilja sitta? Hur skulle ni vilja att mamma och pappa sitter? STäll iordning stolarna i bilen och berätta hur du tänker.

Dokumentera (Part 2)

Ta kort på bägga varianterna; kort och lång resa.

2:1 Kommentarer från testledaren

2:2 Vad tror du att du kommer att göra i bilen? (Inga alternativ ges!)

- ○ Äta
- ○ Sova
- ○ Prata i telefon
- ○ Vila
- ○ Jobba
- ○ Surfa
- ○ Umgås
- ○ Kolla på film/tv-serie
- ○ Bara titta ut
- ○ Använda datorn privat
- ○ Läsa
- ○ Spela spel
- ○ ______________________
- ○ ______________________

Följdfrågor (Part 3)

3:1 Om du skulle få vrida stolen, skulle du då kunna tänka dig att ta på ett extrabälte? Visa bild!

3:2 Om du skulle få lägga dig ner för att sova/vila, skulle du då kunna tänka dig att spänna fast dig på något mer sätt än att bara använda ett vanligt bälte?

Test Protocol

Test No:

Vårgårdamässan

Preparations

Rearrange the chairs from previous test.
Put up a new test number.

Introduktion till studien

Would you like to participate in our study and imagine how you would like to sit in a self-driving car? I'm doing a project about self-driving cars and now a study about how people expect they would sit and what htey would do in a self-driving car. I have som questions for you to answer and then I want you to imagine you´re entering a self-driving car and show me how you would like to sit. The study will take maximum 10 minutes of your time and you can choose to particpate in a raffle afterwards having the chance to win tickets to the cinema.

Bakgrund (Part 1)

1:1 Gender?
- ○ Man
- ○ Woman

1:2 Age?

1:3 Driving license?
- ○ Yes
- ○ No

1:4 Are you driving to work regularly?
- ○ Yes
- ○ No

1:5 How often are you travelling by car?
- ○ Every day
- ○ A few times every week
- ○ A few times every month
- ○ More seldom

1:6 When do you think self-driving cars will be available on the market?
- ○ Latest during 2020
- ○ 2021-2025
- ○ 2026-2030
- ○ Far into the future
- ○ Never

Introduction to the excercise (mark which one you used)

Case 1: Shorter journey

a) Driving car to work regularly (question 1:4 answered with "Yes"):

Visualize the last time you was driving to work and imagine the situation that you had a self-driving car instead. You just walked out to the car, entered it and typed in your destination. Then the car drove you to work, without any more input from you. What would you like to do in the car? How would you like to sit? Design the car's interior and tell me your thoughts.

b) Not driving car to work regularly (question 1:4 answered wiht "No"):

Visualize the last time you was driving a shorter distance. Maybe when you´re driving to this exhibition, were shopping food or left off your kids. Imagine the situation that you had a self-driving car instead. You just walked out to the car, entered it and typed in your destination. Then the car drove you to work, without any more input from you. What would you like to do in the car? How would you like to sit? Design the car's interior and tell me your thoughts.

Case 2: Longer journey - Adults

Imagine that it is weekend and you and your family will travel to your summer house in Varberg. You enter the car and type in the destination. Then the car drive you, without any more input from you. What would you like to do in the car? How would you like to sit? Design the car's interior and tell me your thoughts.

Case 3: Longer journey - Children

Imagine that it is weekend and you and your family will travel to your summer house in Varberg. You enter the car and one of your parents type in the destination. Then the car drive you, without any more input. What would you like to do in the car? How would you like to sit? How would you like your parents to sit? Design the car's interior and tell me your thoughts.

Document (Part 2)

Take pictures

2:1Comments from the test leader

2:2 2:2 What do you think you will do in the car? (No options are given!)

- ○ Eat
- ○ Sleep
- ○ Talk cellphone
- ○ Rest
- ○ Work
- ○ Surf
- ○ Socializing
- ○ Watching movie/tv-serie
- ○ Look out
- ○ Use the computer
- ○ Read
- ○ Play games
- ○ ______________________
- ○ ______________________

Follow up questions (Part 3)

3:1 If you were allowed to rotate the seat, would you mind using an extra seat belt? Show picture on examples of the extra belt.

3:2 If you were allowed to have a resting/sleeping position, would you mind fasten you in any additional way beyond the ordinary seat belt?

B Method Part 2

The appendix includes the injury criteria and risk curves used in this thesis. These criteria are also the criteria currently proposed for NCAP [NHTSA 2015].

Criterion [ref]	Calculation	Variable	Variable Definition	Risk Function
HIC_{15}	$HIC_{15} = \left\| (t_2 - t_1) \left[\frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} \right\|_{max}$	t_1	Beginning of time window in s	$p(AIS \geq 3) = \Phi \left[\frac{\ln(HIC_{15}) - 7.45231}{0.73998} \right]$
		t_2	End of time window in s	
		$a(t)$	Head CG resultant acceleration in g	
$BrIC$	$BrIC = \sqrt{\left(\frac{\max(\|\omega_x\|)}{\omega_{xC}}\right)^2 + \left(\frac{\max(\|\omega_y\|)}{\omega_{yC}}\right)^2 + \left(\frac{\max(\|\omega_z\|)}{\omega_{zC}}\right)^2}$	$\omega_{[x,y,z]}$	Angular velocity of the head about the local [x, y, or z] axis, in rad/s, filtered at CFC60	$p(AIS \geq 3) = 1 - e^{-\left(\frac{BrIC}{0.987}\right)^{2.84}}$
		$\omega_{[x,y,z]C}$	Critical angular velocities in rad/s	
		ω_{xC}	66.25 rad/s	
		ω_{yC}	56.45 rad/s	
		ω_{zC}	42.87 rad/s	
N_{ij}	$N_{ij} = \frac{F_z}{F_{zc}} + \frac{M_y}{M_{yc}}$	F_z	Z-axis force measured at upper neck load cell in N	$p(AIS \geq 3) = \frac{1}{1 + e^{3.227 - 1.969N_{ij}}}$
		F_{zc}	Critical force (tension or compression) in N [2520/-3640]	
		M_y	Y-axis moment measured at upper neck load cell Nm	
		M_{yc}	Critical moment (flexion or extension) in Nm [48/-72]	
cN_{ij}	$cN_{ij} = \frac{F_z}{F_{zc}} + \frac{M_y}{M_{yc}}$	F_z	Z-axis force measured at upper neck load cell in N	$p(AIS \geq 3) = 1 - e^{-\left(\frac{cN_{ij}}{0.83}\right)^{2.71}}$
		F_{zc}	Critical force (tension or compression) in N [3216/-4227]	
		M_y	Y-axis moment measured at upper neck load cell Nm	
		M_{yc}	Critical moment (flexion or extension) in Nm [67/-94]	
Multi-point	$R_{max} = max(UL_{max}, UR_{max}, LL_{max}, LR_{max})$	R_{max}	Overall peak resultant deflection in mm	$P(AIS \geq 3\| \, age, R_{max})$

Thoracic Injury Criterion – Peak Resultant Deflection	where $[U/L\|R/L]_{max} = max\left(\sqrt{[L/R]X^2_{[U/L]S} + [L/R]Y^2_{[U/L]S} + [L/R]Z^2_{[U/L]S}}\right)$	$[U/L\|R/L]_{max}$	Peak resultant deflection of the [upper/lower | left/right] quadrant in mm	$= 1 - exp\left(-\left[\frac{R_{max}}{exp(4.4853 - 0.0113age)}\right]^{5.0389}\right)$
		$[L/R][X/Y/Z]^2_{[U/L]S}$	Time-history of the [left/right] chest deflection along the [X/Y/Z] axis relative to the [upper/lower] spine segment in mm	
Femur Axial Load		F_z	Z-axis femur load in kN, filtered at CFC600	$p(AIS \geq 2) = \frac{1}{1 + e^{5.7949 - 0.5196F_z}}$

C Result Part 2

Figure C.1-C.12 are an attempt to visualize the kinematic in the different tests. These are followed by a summary of some of the data from the sled testing. The injury criteria are colour coded based on the risk level: green < 20% risk, orange = 20-50% risk and red > 50% risk. Last in this appendix, the spinal compression for test 2-6 are presented.

C.1 Living Room Position

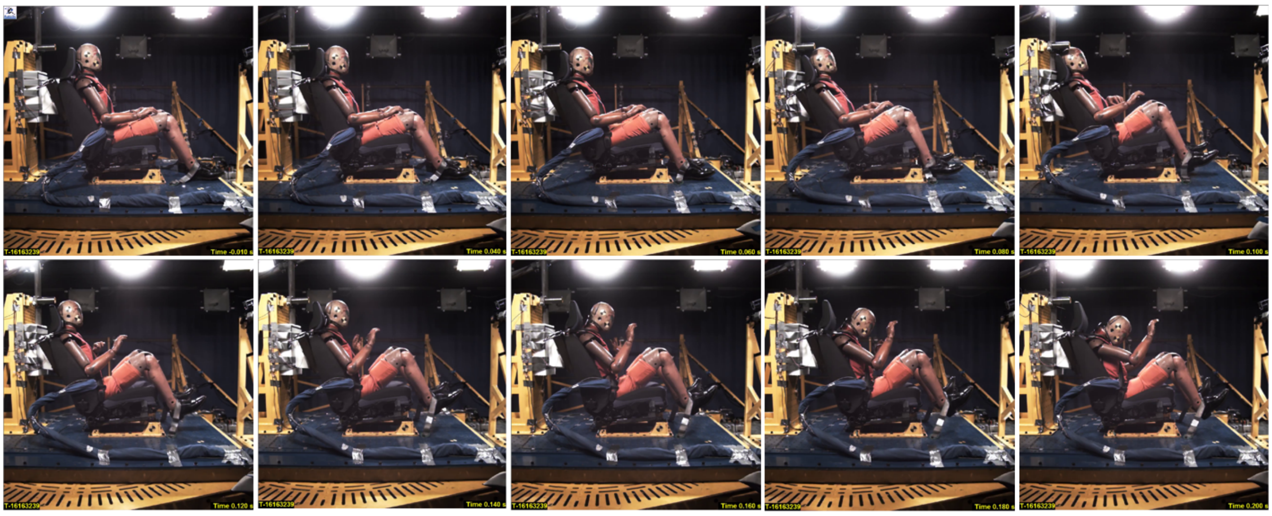


Figure C.1: *The kinematic for test 1. Time stamps (ms): 0, 40, 60, 80, 100, 120, 140, 160, 180, 200.*

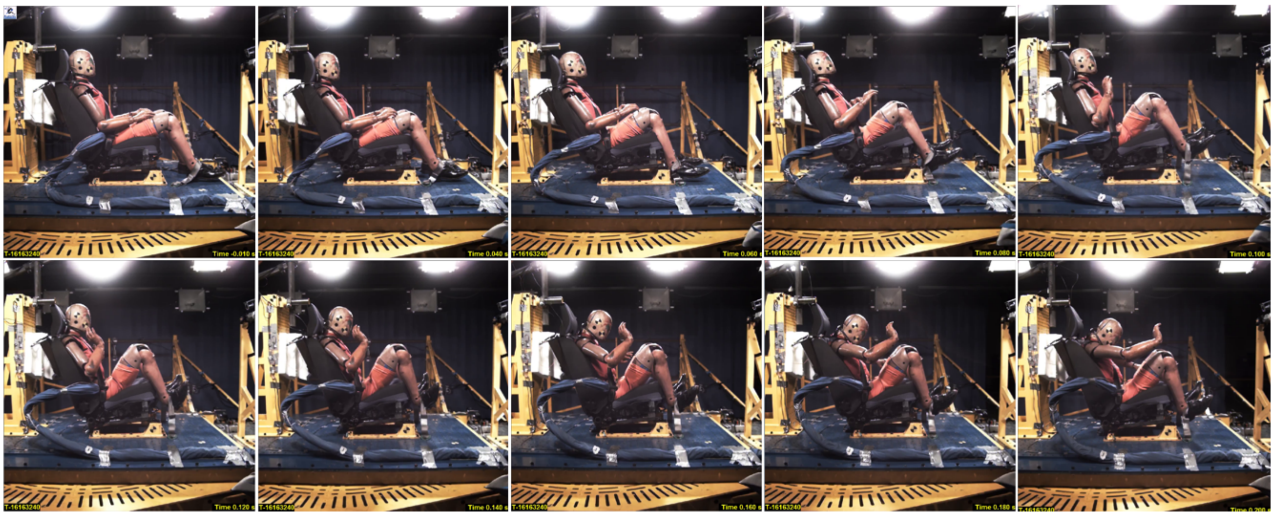


Figure C.2: *The kinematic for test 2. Time stamps (ms): 0, 40, 60, 80, 100, 120, 140, 160, 180, 200.*

C.2 Relaxing Position

Figure C.3: *The kinematic for test 3. Time stamps (ms): 0, 60, 70, 80, 90, 100, 110, 120, 130, 140.*

Figure C.4: *The kinematic for test 4. Time stamps (ms): 0, 60, 70, 80, 90, 100, 110, 120, 130, 140.*

Figure C.5: *The kinematic for test 5. Time stamps (ms): 0, 60, 70, 80, 90, 100, 110, 120, 130, 140.*

Figure C.6: *The kinematic for test 6. Time stamps (ms): 0, 40, 60, 70, 80, 90, 100, 110, 120, 130.*

Figure C.7: *The kinematic for test 7. Time stamps (ms): 0, 40, 60, 70, 80, 90, 100, 110, 120, 130.*

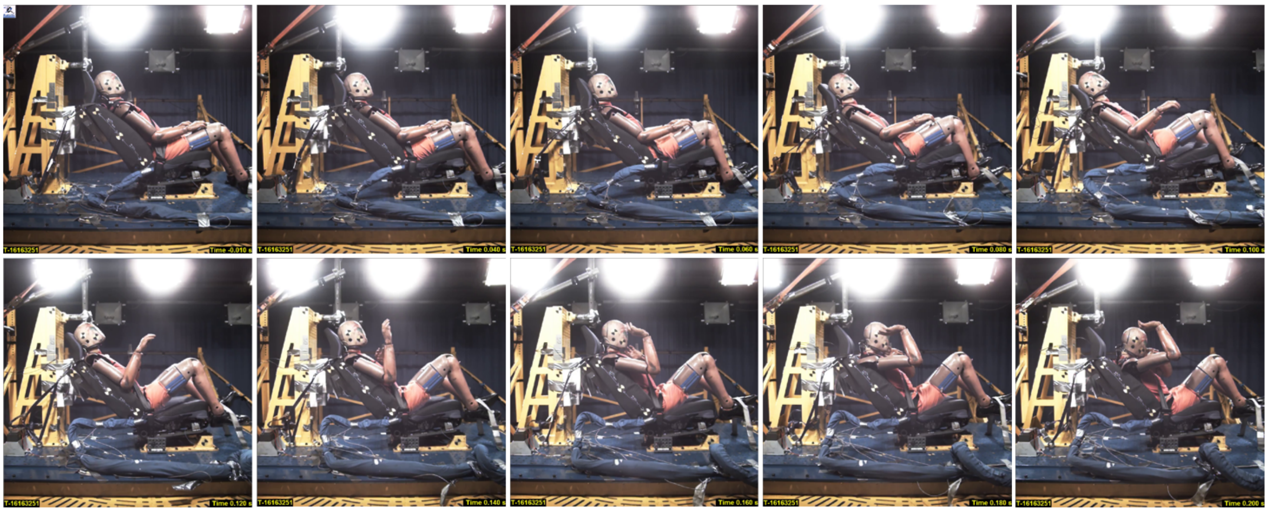


Figure C.8: *The kinematic for test 8. Time stamps (ms): 0, 40, 60, 80, 100, 120, 140, 160, 180, 200.*

C.3 Conversation Position

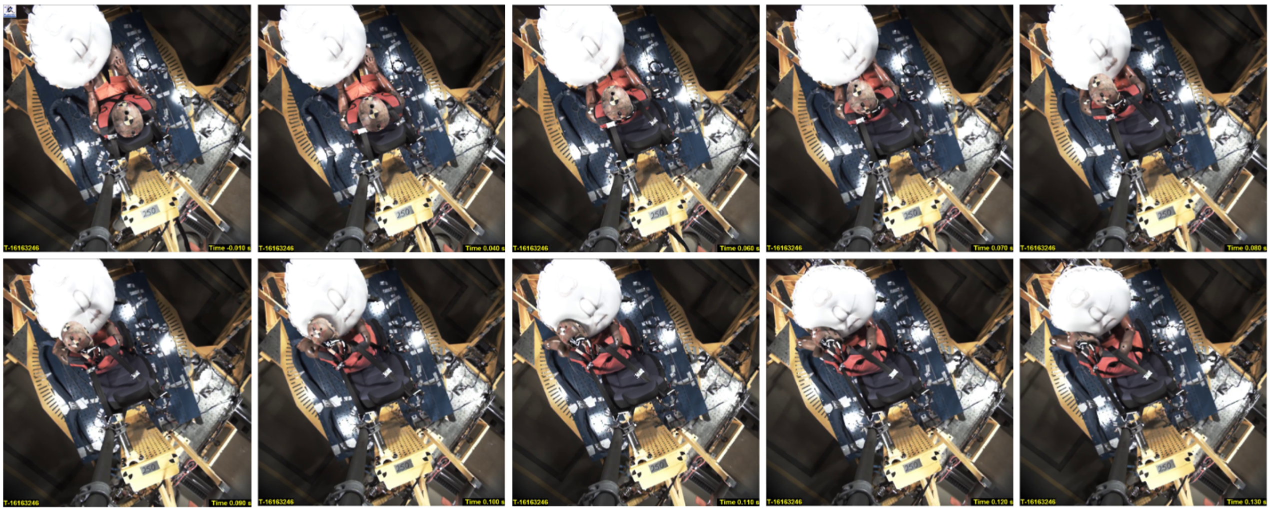


Figure C.9: *The kinematic for test 9. Time stamps (ms): 0, 40, 60, 70, 80, 90, 100, 110, 120, 130.*

Figure C.10: *The kinematic for test 10. Time stamps (ms): 0, 40, 60, 70, 80, 90, 100, 110, 120, 130.*

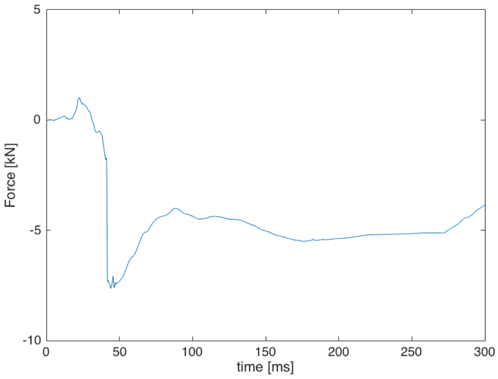
C.4 Reference

Figure C.11: *The kinematic for test 11. Time stamps (ms): 0, 40, 60, 70, 80, 90, 100, 110, 120, 130.*

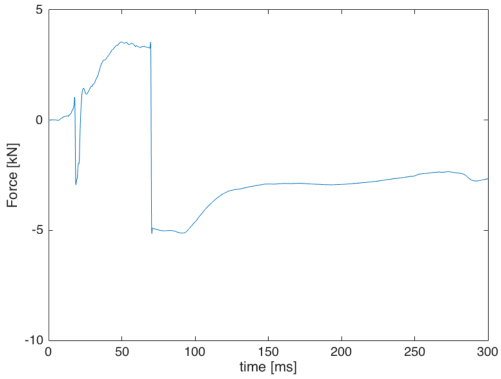
Figure C.12: *The kinematic for test 12. Time stamps (ms): 0, 40, 60, 70, 80, 90, 100, 110, 120, 130.*

		Test 1		Test 2		Test 3		Test 4		Test 5		Test 6	
		Value	*Risk*	*Value*	*Risk*	*Value*	*Risk*	*Value*	*Risk*	*Value*	*Risk*	*Value*	*Risk*
Head	HIC15	464	0,038	379	0,02			248	0,004	184	0,001	132	0
	HIC36	464		420				395		311		230	
	BrIC (AIS3+)	0,38	0,064	0,3	0,033	0,3	0,067	0,69	0,304	0,67	0,283	0,7	0,314
Neck	NIJ (AIS3+)	0.75	0,148	0.73	14,3	0,35	0,073	0,98	0,215	0,8	0,161	0,77	0,153
	cNIJ	0.59	0,327	0.57	0,303	0,26	0,042	0,76	0,545	0,63	0,377	0,59	0,327
	NIC	34		42									
Chest	Rmax [mm] (AIS3+ 45/65 YO)	34,5	0,11/0,29	63,22	0,91/0,99	38,3	0,17/0,45	54,5	0,67/0,97	50,1	0,52/0,90	33,1	0,09/0,25
Leg	Left Femur Z Comp Load [N] (AIS2+)	731,6	0,004	951,9	0,005	1131	0,005	2256,1	0,01	2523,4	0,011	3161,8	0,015
	Right Femur Z Comp Load [N] (AIS2+)	724,6	0,004	997,6	0,005	818	0,005	2289,1	0,01	2525	0,011	2234,6	0,01
Submarining	Left Iliac	NA		NA		Yes		No		No		No	
	Right Iliac	NA		NA		Yes		Yes		Yes		No	
Head	Head Y Angular Velocity [rad/s]	-13,6	16,7	-16,2	18,9	-16,55	17,89	-38,52	28,65	-36,9	25,65	-39,24	16,52
Neck	Upper Neck X Force [N]	-188,4	924,3	-34,9	705	-157,4	794	-333	1708,5	-334,8	1390,9	-36,5	1043,2
	Upper Neck Z Force [N]	-423,5	1854,5	-614,3	1731,7	-449,4	673,2	-750,2	2140	-325,9	1849,8	-280	1653,1
	Upper Neck Resultant Force [N]	1858,4		1732,6		839,1		2190,7		1911,4		1686,9	
	Upper Neck Y Moment [Nm]	-2,2	15,7	-7,8	13,4	-3,1	13,5	-4,1	26,1	-5	24,2	-2,5	16,9
	Lower Neck Resultant Force [N]	2118		1761,8		889,9		2461		1768,5		1312,6	
	Lower Neck Resultant Moment [Nm]	81,2		61,2		68,8		153,5		114,4		74,2	
Chest	Left Upper Chest X Disp [mm]	0		0		-0,6		-12,8		-13,4		-15,9	
	Left Lower Chest X Disp [mm]	0		-5,4		0		-4,5		Fel		-0,7	
	Right Upper Chest X Disp [mm]	0		0		0		0		-1,3		-4,2	
	Right Lower Chest X Disp [mm]	0		-3,4		0		0		-6,5		0	
Spine	Thoracic Spine 1 Resultant Acc [g]	33,1		45,5		20,5		27,1		27,7		26,9	
	Thoracic Spine 4 Resultant Acc [g]	31,2		46		16,8		33,4		33,2		36,9	
	Thoracic Spine 12 Z Acc [g]	19,1		31,8		-14,6		-34,4		-36,8		-37,9	
	Thoracic Spine 12 Resultant Acc [g]	32,4		50		19,7		34,6		37,4		41,2	
	Thoracic Spine Z Force [N]			-7633,4	1019,4	-5160	3550,2	-9071,7	5048,5	-9039	33,2	-4806,4	1304,8
Abdomen	Upper Middle Abdomen X Acc [g]	-49,1	75	-47,3	110,1	-82,4	149,7	-92,8	181,2	-36	24,6	-57,9	17,3
Pelvis	Pelvis X Acceleration [g]	-18,8	37	-28,9	63,2	-55,3	13,4	-23,5	5,1	-22,4	5,1	-26,3	5,1
	Pelvis Y Acceleration [g]	-38,3	23,4	-31,8	57,7	-54,23	57,3	-6,7	3,5	-5	3,9	-4,1	5,6
	Pelvis Z Acceleration [g]	-17,3	29,1	-16,3	64	-23,9	46,9	-30,6	21,9	-31,3	6,5	-34,5	6,4
	Pelvis Resultant Acceleration [g]	35,8		59,7		22,7		37,1		37		40,8	
	Left Iliac Force [N]	-1101,6		-3351		-3789,6		-2002,3		-664,8		-836	
	Right Iliac Force [N]	-574,9		-714,8		-931,7		-1034,9		-346,9		-1061,3	
Seatbelt	Upper 3pt Belt Force [N]	2091,5		1549,4		1834,9		3248,3		3301		2172,3	
	Upper Extra Belt Force [N]	1610,2		1568,8		1580,7		2934,2					

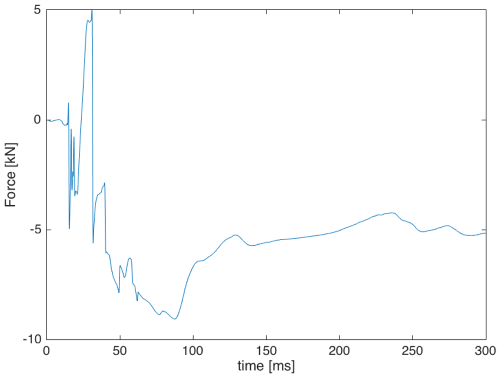
		Test 7		Test 8		Test 9		Test 10		Test 11		Test 12	
		Value	*Risk*	*Value*	*Risk*	*Value*	*Risk*	*Value*	*Risk*	*Value*	*Risk*	*Value*	*Risk*
Head	HIC15	6	0	204	0,002	123	0	121	0	122	0	325	0,012
	HIC36	14		226		269		179		194		437	
	BrIC (AIS3+)	0,31	0,037	0,54	0,165	0,79	0,412	0,61	0,225	0,57	0,19	0,56	0,181
Neck	NIJ (AIS3+)	0,34	0,072	0.61	11,7	0,81	0,164	0,5	0,096	0,75	0,148	0,4	0,08
	cNIJ	0,25	0,038	0.47	19,3	0,62	0,365	0,38	0,113	0,58	0,315	0,31	0,002
	NIC			26,3									
Chest	Rmax [mm] (AIS3+ 45/65 YO)	46,6	0,40/0,79	53,25	0,63/0,96	39,15	0,19/0,48	50,5	0,53/0,91			35,66	0,09/0,25
Leg	Left Femur Z Comp Load [N] (AIS2+)	191,7	0,003	815,2	0,005	1895,3	0,008	2051,5	0,009	1276,9	0,006	2809,2	0,013
	Right Femur Z Comp Load [N] (AIS2+)	198	0,003	630,3	0,004	138,7	0,003	87,7	0,003	897,4	0,005	2645,5	0,012
Submarining	Left Iliac	No		NA		No		No		No		No	
	Right Iliac	No		NA		No		No		No		No	
Head	Head Y Angular Velocity [rad/s]	-16,23	15,69	-23,05	21,51	-33,9	16,9	-21	18,1	-31,49	24,48	-30,77	18,73
Neck	Upper Neck X Force [N]	-101,6	797,6	-6,2	674,8	-183,7	459,9	-148,9	659,8	-152,5	1291	-100,1	266,7
	Upper Neck Z Force [N]	-280,3	351,7	-367,6	924,2	-160,1	1606,1	-125,7	981,2	-215,6	1451	-1043,8	845,2
	Upper Neck Resultant Force [N]	801,9		1085,8		1628,6		1190,8		1525,1		1063,1	
	Upper Neck Y Moment [Nm]	-2,8	15,6	-21,5	10,8	-5,1	13	-5,3	12,7	-6,2	18,2	-5,3	6,2
	Lower Neck Resultant Force [N]	743,1		860,4		1217,3		1658,6		2022,8		1058,3	
	Lower Neck Resultant Moment [Nm]	79,1		50,6		74,6		57,8		101,2		60	
Chest	Left Upper Chest X Disp [mm]	-8,3		0		-9,2		-0,4		Fel		-1,3	
	Left Lower Chest X Disp [mm]	-2,3		0		-6,8		-7,2		Fel		-6,7	
	Right Upper Chest X Disp [mm]	-1,2		0		0		0		0		-0,4	
	Right Lower Chest X Disp [mm]	-1		0		-10,5		-9,4		0		-6,6	
Spine	Thoracic Spine 1 Resultant Acc [g]	10		30		26,6		27,2		22		28,9	
	Thoracic Spine 4 Resultant Acc [g]	10,6		30,4		30,1		26,2		30,1		25,2	
	Thoracic Spine 12 Z Acc [g]	-10,7		22,5		-22,5		-19,3		-26,2		-20,3	
	Thoracic Spine 12 Resultant Acc [g]	12,2		29,9		34		28,5		32,5		31,7	
	Thoracic Spine Z Force [N]	-1539,9	330,9	-1233	1448,8	-2440,5	2988,6	-1949,6	1104	-2628,9	1219,1	-2222,4	899,3
Abdomen	Upper Middle Abdomen X Acc [g]	-67,5	63,1	-147,8	259,8	-36,3	15,7	-37,8	55,7	-110,3	208,8	-66,8	46,7
Pelvis	Pelvis X Acceleration [g]	-11,8	9,5	-20,5	38,7	-28,6	5,1	-28,6	4,4	-25,1	5,2	-32,6	3,1
	Pelvis Y Acceleration [g]	-3,4	2,5	-6,8	6	-4	21,2	-14,5	15	-12,3	6,4	-2,4	5
	Pelvis Z Acceleration [g]	-10,1	2,1	-7,5	18,4	-25,7	5,5	-20,3	12,1	-25	23,2	-15,3	3,1
	Pelvis Resultant Acceleration [g]	11,4		31,7		36,9		30,9		33,6		34,5	
	Left Iliac Force [N]	-393,3		-1248,1		-1967		-847,8		-1411,7		-394,6	
	Right Iliac Force [N]	-185,7		-475,7		-2429,5		-1389,9		-925,8		-248,4	
Seatbelt	Upper 3pt Belt Force [N]	1857,2		1734,7		2215,9		3508,3		3285,7		2123,9	
	Upper Extra Belt Force [N]			1490,6		2233,4		2439,4		2720,6		1854,4	



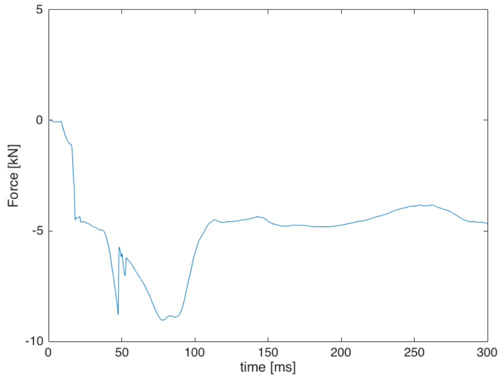
(a) *Test 2.*



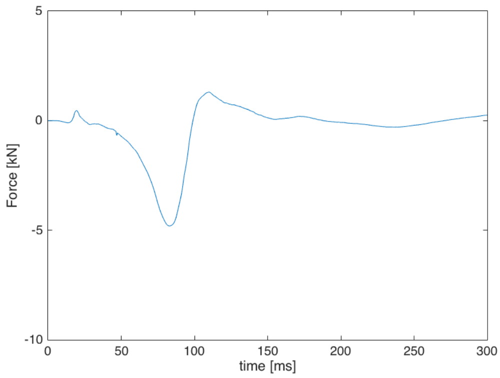
(b) *Test 3.*



(c) *Test 4.*



(d) *Test 5.*



(e) *Test 6.*

Figure C.13: *The spinal compression measured in T12 for test no. 2-6.*

D Autoliv's Appendix

This Appendix includes information that is only available for employees at Autoliv.

D.1 Addition to Chapter 2: Qualitative Study Part 3

Part 3 of the qualitative study that was performed at the exhibition *Vårgårdamässan* was considered to be outside the scope for this master thesis, hence this part is presented here in Appendix.

D.1.1 Method

Part 3 consisted of two questions about the opinion to extra belt or extra restraint systems in fully automated cars. The first question was "If you were allowed to rotate your seat, would you mind using an extra seatbelt?" Pictures of a girl using an extra belt of crisscross and rucksack type were shown for the participants as an explanation to extra belt. The second question was "If you were allowed to have a resting/sleeping position (reclined seat), would you mind fasten you in any additional way beyond the ordinary belt?" These questions are translated into English; in the study, the questions were asked in Swedish. The test protocols are seen in both Swedish and English in Appendix A.

D.1.2 Result

The participants were generally positive to using an extra belt or other additional restraints, if they were allowed to rotate or recline their seat. In 26 (question 1) respectively 27 (question 2) of the tests the participants were positive; example of the answers were *"Yes, absolutely!", "Yes, if it is safer!", "Yes, it would probably be needed!", "Yes, we should have it already today!", "Yes, as long as it is comfortable!", "Yes, otherwise it would be really dangerous in case of an accident"*. In three tests, the participants' attitude were more skeptical to having an extra belt if they were allowed to rotate their seat (*"It would have been uncomfortable, but if it is safer it´s worth it!"*) and in five tests the participants were totally against it (*"No, only lap belt so it´s easier to move.", "No, I prefer to not use the seatbelt at all. It can fasten in case of a crash.", "No, I feel so trapped with a seatbelt and moreover I get carsick."*). The participants that was negative to using any additional restraints if they were allowed to recline their seat claimed similar reasons as presented for the question about rotating the seat. In total, three tests had a negative attitude and in one test the participant claimed that she would never sleep in self-driving car.

D.1.3 Discussion

The result for these questions was interesting. Potential occupants of AV were generally positive to use additional restraints if they were given something in return, in this case an additional seating position. It was also clear that it was more natural for children than for adults to use extra belt. Many of the participants were very aware of car safety and discussed potential risks and challenges and suggested various possible solutions:

- *"... maybe something across the legs?"*
- *"... something across the tummy."*
- *"Otherwise I would prefer that you recline the whole seat (retained seat angle), and use the ordinary seat belt."*
- *"... something across the chest. Maybe fastened the legs in some way."*
- *"... something with pillows in it so it is cosy and comfortable."*
- *"... something for the feet and something above the shoulders."*
- *"... better with a seat that reclines in case of a crash."*

Limitations. This qualitative study was only performed in Vårgårda, Sweden. The car safety awareness is generally high in Sweden and it might also be even higher in Vårgårda. Autoliv was founded in Vårgårda and is also the largest employer in town.

D.2 Addition to Chapter 3: Testing details

This part includes testing details and comments about each test. If more information is needed, please check out TO-number 15025045.

D.2.1 Sled

Body: Blue perforated board that could be rotated.
Sled: Track 2 - HYGE.

D.2.2 Seat

Seat: Volvo Y285
Reinforcements: The seat had reinforced base and back, and welded WHIPS (see figure D.1).
Position: Mid X, lowest Z.
TEMA: Patrick mark seat back (Z) = 500 mm. Patrick mark B-pillar (Z) = 430 mm. Patrick mark seat fixture (X) = 455 mm.
BIS: See figure D.2.
Adjustments: The seat was set to the middle of the seat track and to the lowest height level. When the seat was up tilted, the front part of the seat cushion was adjusted to its highest level.

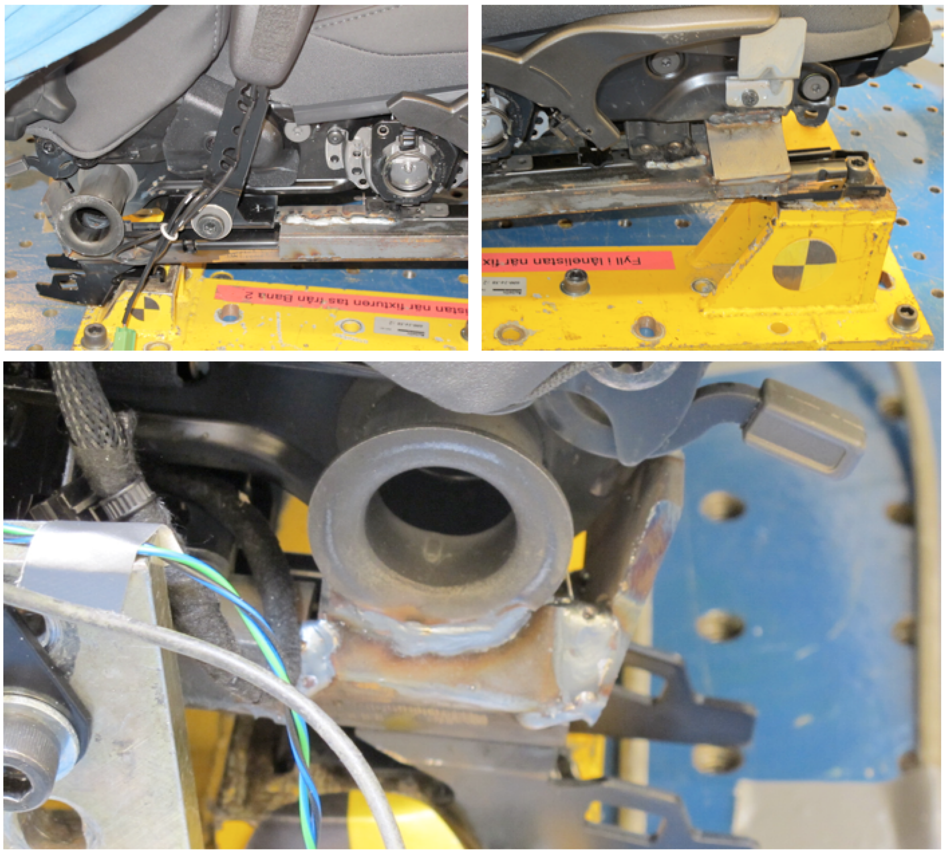


Figure D.1: *The weldments.*

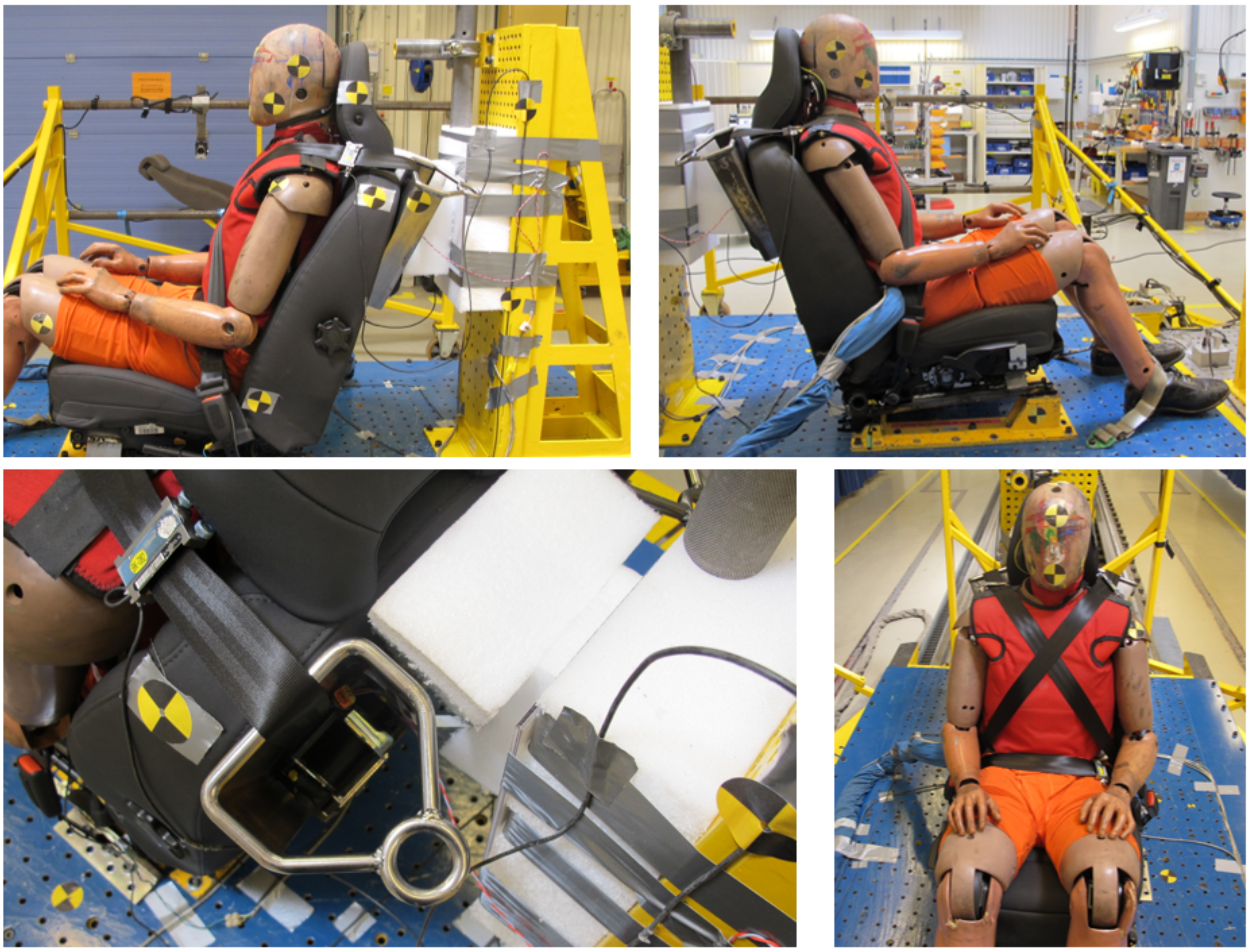


Figure D.2: *The BIS installation.*

D.2.3 Seatbelt

Belt: R230.2 LLA (JLR X761 631578100B).
Torsion bar: High: Diameter = 9 mm. Load = 53 Nm = 3kN; Low = Diameter 6.8 mm. Load = 21.5 Nm = 1.8 kN.
PLP: PLP 1.1.
Trigg time: 7 ms for the retractors and 14 ms for the PLP.
Buckle: X14, angled 20°.

D.2.4 Positioning

Dummy: Straight. Measurements are presented in table D.1. Origo was left, frontal seat attachment.
Belt geometry: Cervical vertebrae to edge of belt (Y): 65mm at both sides. Chin to edge of belt (Z): 135 mm.

Table D.1: FAROarm measurements.

	X	Y	Z
CoG	-536	-113	880
HP	-400	50	240
Femur	18	1	337
Chin	-431	-192	794
Shoulder	-580	8	596

D.2.5 Support in Rearward-facing Tests

Foam 1: Ethafoam 220E, density 35 kg/m3
Foam 2: Ethafoam 900E, density 145 kg/m3

The support consisted of two parts of foam: a rectangular parallellpiped 400*250*100 mm in foam 1 and a wedge 290*290*200 in foam 2, angle 40°. Figure 3.2c shows the foam parts.

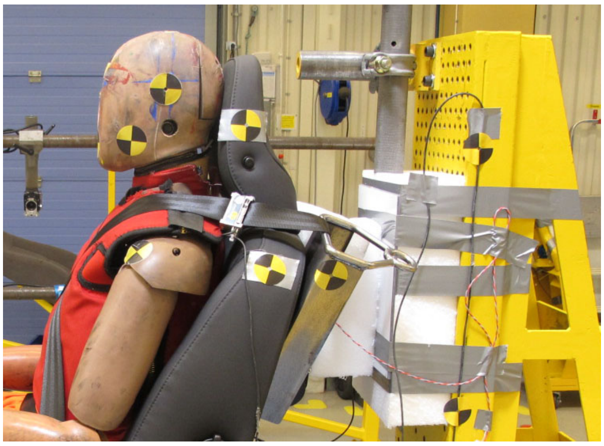


Figure D.3: *The support in the rearward-facing tests.*

D.2.6 "Knee Airbag"

The knee airbag consisted of two parts of foam: a rectangular parallelpiped 480*320*100 mm in foam 1 and a wedge 480*320*100, angle -12°, also in foam 1. The knee airbag was mounted on a 5 mm steel plate. Figure D.4 shows the foam parts.

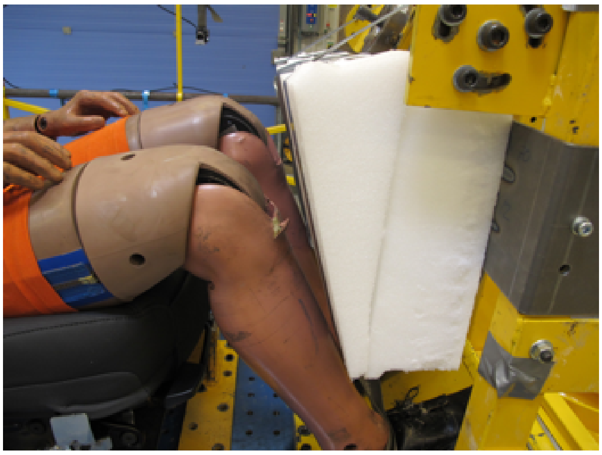


Figure D.4: *The simulated knee airbag.*

D.2.7 High-Speed Video

Number: 4.
Views: Top, right, left, front.
Position: RHS: Camera to Patrick mark seat = 2240 mm. Camera to floor = 1250 mm. Top: Camera to Patrick mark head = 390 mm.

D.2.8 Improved Belt Geometry

The belt geometry was improved in some tests. This is marked in the test matrix by improved outer lap belt position or improved inner lap belt position.

Improved outer lap belt position: The PLP's anchor point was moved 95 mm downward in Z and 60 mm out from the seat in Y.
Improved inner lap belt position: The buckle's anchor point was moved 50 mm downward in Z.

D.2.9 Comments from the Tests

Test 1 (T-16163239)
Purpose: The first attempt in this position.
Pre-requisites:
Result: The seatback was affected more than expected, despite reinforced recliner. The seatback flexed a lot, which leads to the headrest hit the camera fixture. The seatback angle after test was 21.5° (19° before test), distance between B-pillar and headrest was 330 mm before and 240 mm after. The extra belt's force sensor was hooked at the headrest.

Test 2 (T-16163240)
Purpose: Test the same configuration in higher impact speed.
Pre-requisites: Deformed seat from test -39 and stiffer foam to avoid the interaction between the headrest and the camera fixture.
Result: Headrest hit the camera fixture slightly. Distance between B-pillar and headrest was 240 mm before and 180 mm after.

Test 3 (T-16163241)
Purpose: First attempt in this configuration.
Pre-requisites: New seat.
Result: The extra belt's force sensor was hooked at the headrest.

Test 4 (T-16163242)
Purpose: Same configuration as previous test, but in higher speed.
Pre-requisites: Same seat as previous test.
Result: The seat cushion is 10 mm lower in the front (245 mm -¿ 235 mm). Seatback is ok, but headrest is 10 mm more rearward.

Test 5 (T-16163243)
Purpose: Reference system.
Pre-requisites: Same seat as previous test, deformed from previous test.
Result: The seat cushion is deformed 5 mm in the front (235 mm -¿ 230 mm, originally 245 mm).

Test 6 (T-16163244)
Purpose: Avoid submarining and lower spinal compression loads.
Pre-requisites: Same seat as previous test, deformed from previous tests (4-5). Foam under thighs to compensate for the deformed seat cushion.
Result: OK.

Test 11 (T-16163245)
Purpose: First reference test.
Pre-requisites: New seat.
Result: OK.

Test 9 (Test T-16163246)
Purpose: First attempt in this position.
Pre-requisites: Same seat as previous test. Generic driver bag, 20 kPa (leakage made it hard to ensure correct pressure). The bag is trigged at 30 ms.
Result: OK.

Test 10 (T-16163247)
Purpose: Changed centre of rotation, probably more realistic position now. Improved restraint systems.
Pre-requisites: Same seat as previous test. Steering wheel moved 50 mm to the left in Y.
Generic driver bag, 20 kPa, 5 mm vent hole. The bag is trigged at 30 ms.
Result: OK.

Test removed from report (T-16163248)
Purpose: Conversation position in side impact. Pulse 40 kph side car2car.
Pre-requisites: Same setup as previous test (test 10), but with side airbag that was trigged at 6 ms.
Result: NOK. No realistic dummy behaviour, too simplified method without penetration.

Test 12 (T-16163249)
Purpose: Second reference test, now with low level of lead limiting.
Pre-requisites: Generic static driver bag, vent was trigged after 30 ms (33.3 cm).
Result: OK.

Test 7 (T-16163250)
Purpose: Tried to achieve the same kinematic as test 6/-44 but with PRC instead of knee airbag.
Pre-requisites: Generic static driver bag, vent was trigged after 30 ms (33.3 cm).
Result: OK.

Test 8 (T-16163251)
Purpose: First test in rearward-facing relaxing position.
Pre-requisites: Same seat as the other tests with this seatback angle.
Result: OK.