OSCCAR:

FUTURE OCCUPANT SAFETY FOR CRASHES IN CARS

Test Case Matrix and selecting Demonstrator Test Cases

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1 EXECUTIVE SUMMARY

This report presents a methodology to structure combinations of aspects relevant for occupant protection evaluation in future passenger cars. The methodology is created based on a matrix structure and some processes. The three-dimensional matrix structure, so called Test Case Matrix, comprises the three dimensions; Occupant UseCases (comprising mainly seating configuration, sitting posture and seat position), Crash Configurations and Individual Human Variations (individual differences). Pre-selection processes are created to help narrow the scope and content of the Test Case Matrix, when applied. In addition, a Process of Grading is developed to help motivate the selected Demonstrator Test Cases, in comparison to other Test Cases. A Test Case contains a combination of the three dimensions, with specifications to allow for a crash test or simulation to be performed. The Demonstrator Test Case is a Test Case that is selected for the OSCCAR project to be used in investigations on occupant protection principles and/or for demonstration of a virtual tool chain evaluation.

A literature study and two user studies performed within the project on preferred seat rotation and sitting postures in future cars, provide input to the Occupant UseCases dimension. The first user study shows that the preferred seat rotation is straightforward when only traveling in a car, and that participants turn their heads in the direction of travel in the different forward-facing rotations of the seat. The second user study collected data of sitting postures and seat positions when riding in a car with seats facing each other, varying activities and co-passengers. Lower back, shoulders, and legs centralized and lower back, shoulders and head in contact to the backrest were found as the most frequent postures, however far from 100% of the time.

Real-world accident data analyses by OSCCAR WP1 provide input to the dimension of Crash Configuration. The analyses enable prediction of representative remaining crash configurations using pre-crash simulations with different collision mitigation systems. When relevant, pre-crash vehicle kinematics can be included in the crash pulse derived from the parameters in the Crash Configuration dimension.

The third dimension, called Individual Human Variation, comprises information such as age and size. A Baseline simulation study was performed, highlighting important aspects and limits of state-of-the art human body models' capabilities. Five different set-ups were simulated investigating varieties of crash configurations using some different human body models.

An example is provided to exhibit how the developed methodology can be used; including the pre-selection processes, Test Case Matrix reduction, and the Process of Grading. One Demonstrator Test Case which is to be used within OSCCAR for the whole tool chain evaluation, as well as for investigating protection principles, is briefly presented. Additional Demonstrator Test Cases will be added throughout the project.

Keywords: autonomous vehicles, human body model, protection principles, test case, user studies

2 BACKGROUND AND OBJECTIVES

2.1 Background

Mobility is an important aspect of society and it has been evolving since the beginning of human history. Cars are nowadays one of the more important transport modes and future cars are likely connected and autonomous. The occupants will be partially or totally unengaged from the driving activities; changing the perception of transport and also the activities carried out during the transport.

Currently, autonomous driving is not very well received according to Schoettle and Sivak [54]. Their study included responses from 3,255 adults in the U.S., in addition to China, India, Japan, the U.K., and Australia, showing that between 3% (China) and 33% (Japan) of the population would not ride an autonomous vehicle. Autonomous driving is accompanied with pronounced doubts on safety, together with the difficulty of imagining oneself using this system. It is apparently connected with fears of the new technology, which ultimately could lead to a comparably high level of rejection. In particular in the vehicles in which the “steering wheel” is no longer available, the assessments and evaluation rating are not overwhelmingly positive. In an open survey performed by Fraedrich et al. [18], the top five positive values that people associate with an Autonomous Vehicle (AV) were: comfortable, good, safe, relaxing and modern, which describes how people hope or expect it to be. It was observed that people had different reactions to the different autonomous vehicle cases: ‘Parking Pilot’, ‘Highway Pilot’, ‘Fully-Automated Vehicle’ and ‘Vehicle on Demand’. ‘Vehicle on Demand’ is the case in which direct, driver-initiated “steering” is no longer an option. The closer to the current technology the higher acceptance and higher benefit was perceived. For example, the number of “no idea” answers for the vehicle on demand was 51% which indicates that most of the interviewed population couldn’t imagine this concept nor knew what to expect. The reaction regarding the four different AV options is summarized as follows: The ‘Parking Pilot’ function was widely accepted since it leads to less stress and increased comfort. The ‘Highway Pilot’ function was actually seen as helpful by a large share of the respondents in view of its comfort value and being a supporting system. Those who already use driver-assist systems are also noticeably more willing to use the ‘Highway Pilot’. The respondents view ‘Fully-Automated Vehicle’ and ‘Vehicle on Demand’ as being very similar in many respects. An Automated Vehicle is seen as particularly useful for longer trips, even more so than ‘Highway Pilot’. The user evaluations of ‘Vehicle on Demand’ are accompanied with pronounced doubts as to the safety of such a vehicle, even when its comfort, usefulness and potential cost benefits are stressed. The difficulty of actually imagining oneself using this system is apparently connected with fears of the new technology, ultimately leading to a comparably high level of rejection.

It is clear that most of the doubts potential users have on the introduction of AV system are related to some anxiety regarding their personal safety when using a Highly Autonomous Vehicle (HAV). In order to rise acceptance, it is essential to provide evidence that research and industry are taking the needed steps to ensure that these vehicles have superior safety. This includes crash avoidance and in-crash safety assessments of relevant accident scenarios beyond what is addressed by today’s regulations or consumer information organisations. In addition, assessment of new accident scenarios for future mixed traffic where HAVs and conventional driven vehicles share the same infrastructure and roads is required. As future HAVs are expected to provide new, alternative seat configurations and seat positions enabling additional sitting postures, also these will be introduced in the extended safety evaluation. Hence, methods and tools for evaluating occupant safety in HAVs in the future are needed. The occupant tools in focus are likely human body models (HBMs), which are more capable of providing detailed injury assessments, reproduce a larger part of the occupants at risk and be adjusted to reproduce occupants in future driving/riding postures, as compared to anthropometric test devices (ATDs). Future methods include, among others, the selection of representative test set-ups. Meaning that methodologies to identify combinations of test cases, i.e. combinations of occupant use cases, crash configurations and individual human characteristics are required. These tools and methods are an essential part of the provision of improved safety for HAV.

2.2 Purpose and objectives

With the overall OSCCAR objective of developing a fully integrated assessment method for future automated passenger cars, this report serves the purpose to describe the work on the creation of a methodology to structure combinations of aspects relevant for occupant protection evaluation in future cars. Specifically, the objective of this methodology is to identify and motivate among the large variety of combinations of test set-ups (in this study called Test Cases), the Test Cases to be used in future occupant safety evaluation using simulation tools and/or in crash testing, the so-called Demonstrator Test Cases.

To create this methodology different aspects were detailed and means to structure these aspects were outlined. The aspects detailed in this study include different occupant characteristics, seat positions, sitting postures and seat configurations, in addition to potential pre-crash vehicle kinematics. These aspects were structured, hereafter referred to as a Test Case Matrix, in three dimensions; Occupant UseCases (comprising mainly seating configuration, sitting posture and seat position), Crash Configurations and Individual Human Variations. Specifically, the Test Case Matrix should serve as a logical structure and reference to provide foundation for the selected Demonstrator Test Cases.

With the purpose to help describe the context and to limit the number of simulations, ways of reducing the number of combinations of aspects are required, while still addressing the scope in question. Hence, development of pre-selection processes and grading processes, are also important objectives of this study.

Two studies providing input to the overall OSCCAR purpose, the Test Case Matrix and the next steps in OSCCAR WP2 activities are also within the scope of this report. With the objective of providing input to limit the Test Case Matrix and to gain deeper understanding on the parameters in the Occupant UseCases dimension; user studies are made on preferred seating / activities that people take / execute in a car as passengers, especially against the background of AV. With the objective to demonstrate the injury prediction capabilities of today’s state-of-the-art HBMs, simulation studies within pre-crash and crash applications are made, mainly providing input to the Individual Human Variation dimension, as well as next steps within OSCCAR WP2 and WP3.

In summary, the objectives of the work summarized in this report are; to create a methodology to structure and help motivate selected Test Cases for occupant safety evaluation of future AV crashes, to summarize published information and data gathered within OSCCAR Task T2.1, and to present an example of a first proposal of Demonstrator Test Case to be further explored at a later stage within the project. It is not within the objective of this report to provide an overall assessment of all possible Test Cases, and to present all Demonstrator Test Cases for further studies within the project

3 DESCRIPTION OF WORK

A methodology is created with the purpose to provide input to and a guide for selecting Demonstrator Test Cases for occupant safety evaluation in future crashes. The methodology is created as a three-dimensional matrix structure, so called Test Case Matrix, comprising three dimensions given the following names; Occupant UseCases (comprising mainly seating configuration, sitting posture and seat position), Crash Configurations and Individual Human Variations (individual differences). Pre-selecting processes are created to help narrow the scope and content of the Test Case Matrix, when applied. In addition, a Process of Grading is developed to help motivate the selected Demonstrator Test Cases, in comparison to other selected Test Cases. This report provides a description of this methodology. Several new terms are developed and will be defined and explained throughout the report. A list of definitions is shown in Appendix 4.

In addition to the development of the methodology, a literature study, two user studies involving in total 81 participants and a Baseline study comprising five simulations using HBMs, are performed within the project. They provide input to the Test Case Matrix as well as guidance for further activities within OSCCAR.

Several activities, including defining, structuring and selecting the input of the dimension of Occupant UseCases are performed. The proposed structure as well as some input data is presented, summarizing the literature study and the two user studies performed in the project.

The activities providing the Crash Configurations are developed by OSCCAR WP1 and presented in OSCCAR Report D1.1 [44], describing how the draft future crash configurations are determined based on available data and insight. The present report includes mainly the structure of the Crash Configuration dimension in the Test Case Matrix in addition to a short summary of some of the relevant OSCCAR WP1 activities.

The Baseline study helps illustrate some of the shortcomings of existing HBMs, providing reference and input to the third dimension of the Test Case Matrix: Individual Human Variation.

A number of Test Cases are selected from a chosen context of an Operational Design Domain (ODD), applying the elaborated methodology and including the process of grading. Finally, one representative Demonstrator Test Case is briefly presented. It will be used for the whole tool chain evaluation throughout OSCCAR, as well as to investigate protection principles. Additional Demonstrator Test Cases will be added throughout the project.

3.1 Specification of partner contributions

In total eleven project partners have been involved in this work. Joint activities mainly during regularly Web-meetings, in addition to a whole day workshop. The workshop was held in November 2018 (halfway through the Task T2.1.) with the purpose to create the structure of the Test Case Matrix and corresponding processes, reaching for an alignment and joint view to facilitate an efficient completion of the Task. In addition, the purpose was to summarize and discuss the content of the dimension of Occupant UseCases. The following partners participated at the workshop: IDIADA, IKA, fka, Autoliv, Daimler, Bosch, BASt, TME, ZF, VW, ViF, Volvo Cars.

Autoliv and Volvo Cars summarized own research and provided input to the Occupant UseCases dimension. Bosch contributed with input to the Test Cases process, mainly on the Process of Grading and the interface to OSCCAR WP1; specifically clustering of variables for activities, seat position and individual parameters, and mapping on the crash configuration. Autoliv took a lead in the description of the Process of Grading. TME contributed to the definition of the Process of Grading.

The input regarding Crash Configuration was provided by OSCCAR WP1. Throughout the task, a dialogue was held to ensure alignments.

IDIADA performed a literature study, supported mainly by Autoliv, Volvo Cars and TME, and is main responsible for Appendix 1 and the related text in the main part of the report. In addition, IDIADA hosted the workshop.

RWTH performed the OSCCAR user studies providing input to the Occupant UseCase dimension of the Test Case Matrix. Two phases of the user study were performed. IKA is main responsible for Appendix 2 and the related text in the main part of the report.

Daimler performed simulations creating insight on base-line performance of available HBMs in five different configurations, the so-called Baseline study. Daimler is the main responsible for Appendix 3 and the related text in the main part of the report.

Volvo Cars took the lead on the description of the overall process, organized the workshop and packaged the report, in addition to the overall responsibility of the report.

3.2 Creation of Test Case Matrix

This chapter describes the **Test Case Matrix**, its building blocks and processes.

The Test Case Matrix is a three-dimensional matrix, comprising the following dimensions:

- Occupant UseCases
- Crash Configurations
- Individual Human Variations

Figure 1 illustrates the Test Case Matrix in two schematic representations. To the left, a three-dimensional illustration is shown. To the right, in order to present the results more clearly, the three-dimensional matrix is modified into a two-dimensional matrix focusing on the Crash Configurations and Occupant UseCases, while the third dimension of Individual Human Variation is illustrated as a spectrum that can be applied all over the other two dimensions. This simplification is motivated by the fact that this spectrum will be limited by the capabilities of the available occupant substitute test tools today.

The **Test Cases** are illustrated as red dots in Figure 1. A Test Case always contains a combination of the three dimensions, with specification to allow for a crash test or simulation; where

- the Crash Configuration specifies the impact point, impact force direction and velocities by which a crash pulse can be created,
- the Individual Human Variation describes the individual human parameter like size, weight, age, gender adding up to the occupant tool, and
- the Occupant UseCases provides the level of detail needed to complete the test set-up, including the environment and the occupant posture.

A **Demonstrator Test Case** is a Test Case selected for further study.

The representation of restraint systems is not included in the Test Case description, since they are the purpose of the further investigation and in focus for the study on protection principles in OSCCAR WP2.

Generally, the Demonstrator Test Case shall start with the pre-crash event (or earlier if intervention starts earlier) to allow the occupant kinematics caused by the vehicle kinematics to be part of the study.

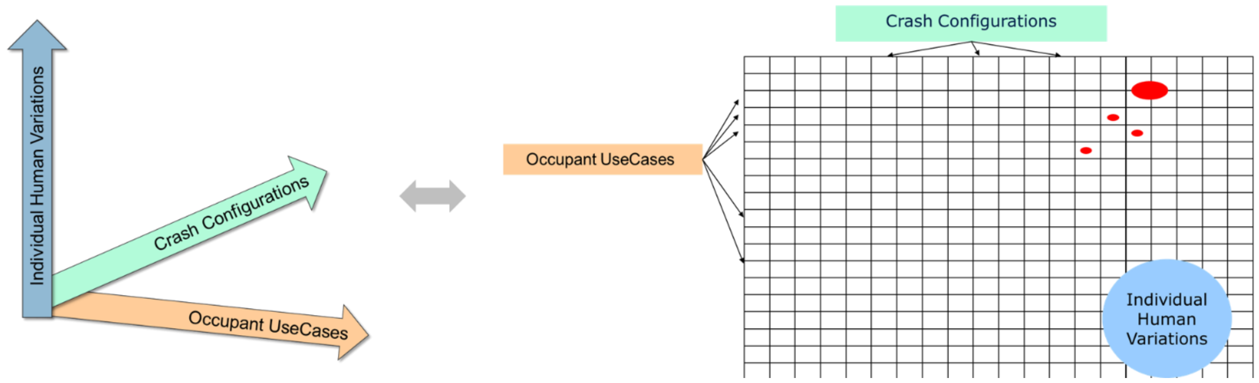


Figure 1 Test Case Matrix principles. The red dots illustrate exemplary Test Cases.

3.2.1 Test Case Matrix objectives and requirements

With the purpose of the Test Case Matrix to provide a tool for structuring and combining the three dimensions for selection and motivation of Test Cases, the following main objectives and requirements to the Test Case Matrix apply:

- As generic as possible, enabling several future ODDs
- Modular and easy to adapt to selected applications
- Capable of addressing a large scope, targeting a wider application than expected in the OSCCAR project
- Usable for all types of car occupants in all seat positions and configurations
- Allows for requirement elicitation and identification regarding tools necessary to investigate the Test Cases, e.g. HBMs or traffic simulation and accident scenarios definition

3.2.2 Relevant prior studies with the purpose of the Test Case Matrix

A literature review was performed to provide input on prior work within the area of the Test Case Matrix purpose, see Appendix 1. No study was found addressing the exact objective as in the OSCCAR project; i.e. development of a methodology illustrating the combination of crash configurations, sitting postures/activity and individual differences, to be used in studies on the challenges in occupant protection evaluation in future crashes.

Some published studies are investigating occupant protection evaluation in future cars with different sitting postures and seat positions as compared to today [25][31][36][55]. They all investigate the capability of the available occupant tools (HBMs and ATDs) and/or restraint systems in future transportation modes, such as reclined sitting postures or rotated seats. No specific methodology was developed or applied in the selection of the combination of crash configuration, occupant posture and sizes. The primary purpose was not the same as for the OSCCAR project.

Seven EU funded platforms and H2020 projects linked with the autonomous vehicle development were reviewed, and relevant parts were summarized in the literature review in Appendix 1. None of the projects has addressed the topic of this report in complete context. The main challenges of those projects are the improvement and development of autonomous driving systems, vehicle connection, infrastructures, autonomous driving safety, legal and ethical considerations, human factors and needs, user behaviour and human machine interaction, energy or thermal comfort. Moreover, most of the reviewed H2020 projects are not yet finished, many of their objectives have not been achieved so far and their deliverables are not yet available.

Nevertheless, the following aspects are relevant for OSCCAR:

- The automation levels described by ERTRAC that classifies the different levels of automation, since they have an impact on the considered situations and occupants' behaviour [14].
- The study done in the AdaptIVe project may also be interesting since it evaluates the behaviour and the level of attention required by the occupant [1].
- It is also relevant to explore societal values, user acceptance, behavioural intentions, road safety, social, economic, legal and ethical considerations regarding the implementation of autonomous vehicles intended to be studied in the Brave project [6].
- The development of radical new cabin and Electric Vehicle (EV) designs and the methodology for virtual assessment of EV (cabin) designs that includes comfort perception, efficiency, well-being and safety aimed in the DOMUS project [12].

3.2.3 Test Case Matrix overall principles and structure outline

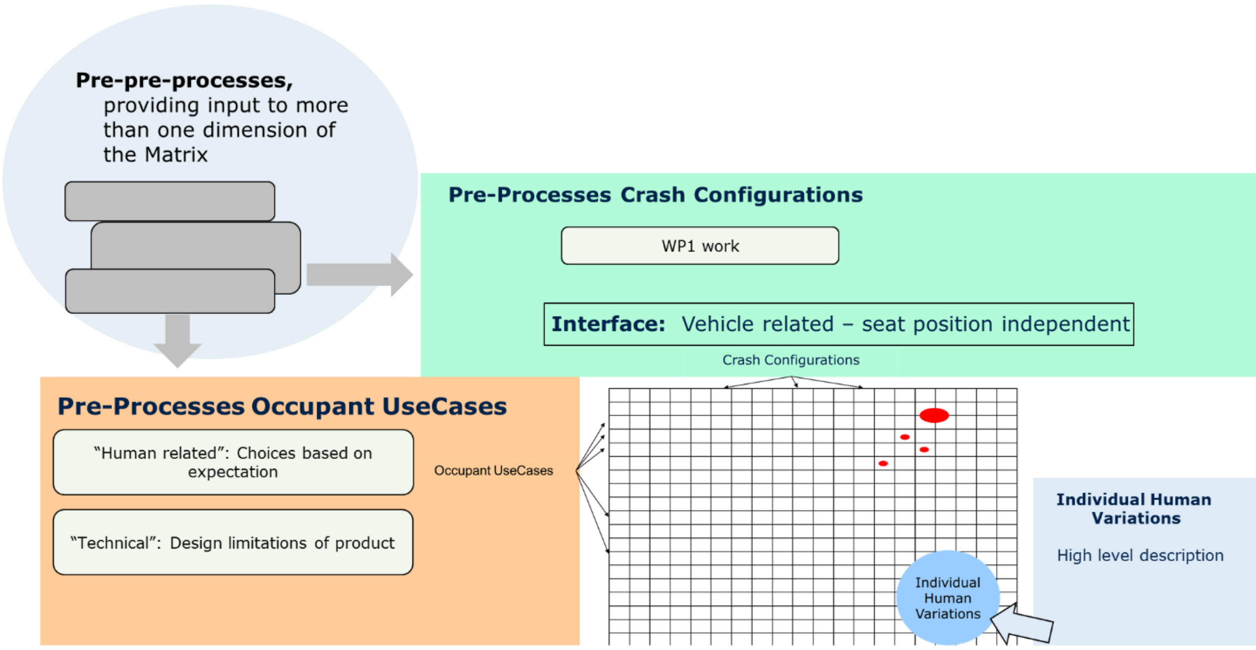


Figure 2 Test Case Matrix process

Figure 2 describes the building blocks and overall process to generate the Test Case Matrix. The following sub-chapters provide input on level of detail for the dimensions. The overall approach is to make the methodology applicable for a large scope, and thereby include all details that can be relevant for evaluation on occupant protection in future crashes. This is done with the ambition to enable usage in a wide range of applications. To account for the feasibility of this to be done, several steps are taken to identify what parts of the Test Case Matrix are applicable for the specific study. The main purpose of these steps is to filter out non-relevant combinations for the focus applications. The steps are called Pre-pre-processes and Pre-processes, see Figure 2.

The Pre-pre-processes provide input to more than one dimension of the Matrix, e.g.: target year of market introduction, level of automation, market, transport mode and vehicle use case including user expectation. This process has an impact on two dimensions of the Test Case Matrix, namely the Crash Configurations and the Occupant UseCases. The objective of this activity is to derive overall boundary conditions and to help focusing on the characteristics of the autonomous driving function and the usage area of interest.

Having the same overall purpose, the Pre-processes relate to one dimension only. Examples of Pre-processes related to the Occupant UseCases dimension could be the design of the vehicle allowing for some specific seat configurations only. The Pre-process related to the Crash Configurations dimension includes the process from interpreting the results of the Pre-pre-processes (e.g. what accident scenario is relevant for the function) up until prospectively determining potentially relevant crash configurations in mixed traffic.

With the purpose to allow for futuristic seating configurations, the Crash Configurations dimension is made vehicle depended, which means that the seat position in the car is included as a variable in the Occupant UseCases dimension. As an example, the aspect of “near side” versus “far side” is included in the Occupant UseCases dimension, and not as a variable in the Crash Configurations.

If applicable, the Demonstrator Test Case can start with a kinematical event prior to the crash to allow the occupant movements (caused by this event) to be part of the simulation. This is especially of interest if the pre-crash vehicle kinematics is induced by active safety systems. Including this into the simulation enables that they can be a parameter varied in line with the restraint systems as part of the occupant protection evaluation. To accommodate this, occupant postures due to pre-crash vehicle kinematics are not included in the Occupant UseCases dimension of the Test Case Matrix. Instead, the specifics of the kinematics are a part of the crash pulse when running tests or simulations for the selected Demonstrator Test Case. The likelihood of occurrence of such vehicle kinematics can be included as a parameter in the Crash Configurations dimension.

3.2.3.1 Structure for Occupant UseCase dimension

The main body of the Occupant UseCases dimension consists of four headlines/aspects, which are described in this section:

- Seating Configuration
- Interior Feature
- Seat Position
- Sitting Posture

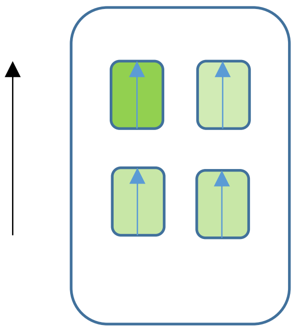
Occupant activities during driving are not considered as a separate part of the main structure. Instead, they are indirectly included in the other aspects. As examples, relaxing is likely related to a sitting posture close to the seatback and potentially even a seat position with reclined seat back. Reading a book or using a laptop is reflected in the Interior feature aspect.

Although aiming at providing a wide representation of real-world combinations, the variations of dimensions of the four aspects as presented in this report does not provide a complete coverage of all possible combinations in cars.

Traditional seating configuration, single

All seats facing forward.

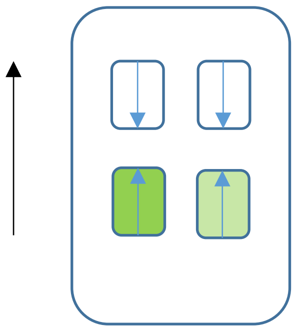
Occupancy: Positions 1, 2, 3 or 4, without other occupant.



Face-2-Face, forward single

Front seats turned 180° rearward facing.

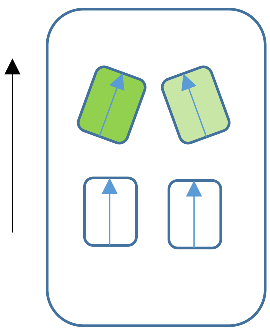
Occupancy: Positions 3 or 4 (facing forward), without other occupant.



Swivel front seats, single

Front seats turned 10°-30° inboard.

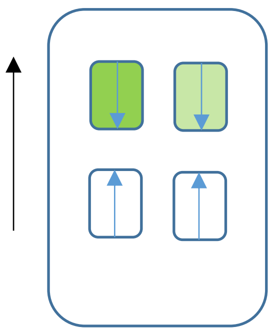
Occupancy: Positions 1 or 2, without other occupant.



Face-2-Face, rearward single

Front seats turned 180° rearward facing.

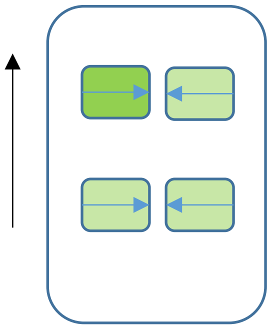
Occupancy: Positions 1 or 2 (facing rearward), without other occupant



Lateral, single

All seats turned 90° inboard.

Occupancy: Positions 1, 2, 3 or 4, without other occupant

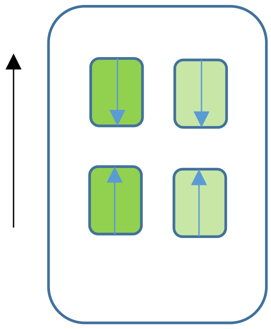


Face-2-Face, double

Front seats turned 180° rearward facing.

Occupancy:

- Pos1 with Pos3,
- Pos3 with Pos1,
- Pos2 with Pos4,
- Pos4 with Pos2

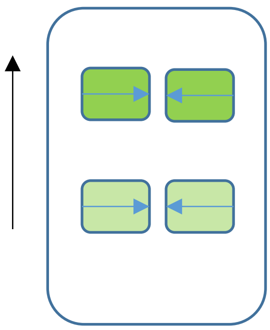


Lateral, double

All seats turned 90° inboard.

Occupancy:

- Pos1 with Pos2,
- Pos2 with Pos1,
- Pos3 with Pos4,
- Pos4 with Pos3



Face-2-Face, swivel, double

Front seats turned 150°-180°. Rear seats turned 10°-30°.

Occupancy:

- Pos1 with Pos3,
- Pos3 with Pos1,
- Pos2 with Pos4,
- Pos4 with Pos2

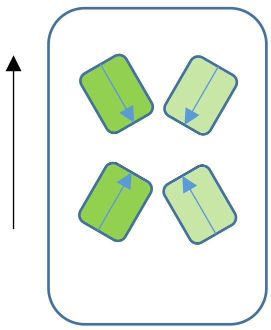


Figure 3 Selected Seating Configurations, including level of details. The coloured seats specify occupancy positions included for evaluation. Number of darker coloured seats indicate whether single or double occupancy are considered

3.2.3.1.1 Seating Configuration

Seating Configuration describes how the seats are positioned inside the vehicle, in terms of number of seats, seat location relative to the direction of travel and also seat occupancy. The positions are identified as position 1 (first row, left side), position 2 (first row, right side), position 3 (second row, left side), position 4 (second row, right side). The Seating Configurations chosen within the project at this stage are illustrated in Figure 3, including information on level of detail and occupancy details. The chosen Seating Configurations could include one or several occupants; indicated as single and double. The coloured seats specify occupancy positions included for evaluation. Number of darker coloured seats indicate whether single or double occupancy are considered.

The configurations include traditional all seat forward facing (single only), lateral facing (single and double), swivel front seat 10-30 degrees (single only), and four different combinations of Face-2-Face configurations, including swivel and combinations of single and double, see Figure 3. The selection offers 26 different individual combinations, as a starting point. Additional combinations and degrees of rotation can be included to provide an even larger coverage of possible Seating Configurations.

3.2.3.1.2 Interior Feature

Interior Feature includes information of relevant interior space and interior design details that may affect the outcome in case of a crash. The proposed features and interior structures for the Test Case Matrix within the project at this stage are summarized in Table 1, with the three main headlines: ‘restriction in front of occupant’, ‘restriction on the side of the occupant’ and ‘loose objects’.

In the Test Case Matrix, the alternative ‘yes’ is used, e.g. if ‘1a) presence of steering wheel’ is included in the Matrix, there is likely to be a steering wheel in close proximity in front of the occupant, otherwise the row of the Test Case Matrix will be removed. Obviously, several combinations of Interior Features and Seating Configurations are not relevant and will hence limit the total combinations in the Test Case Matrix. In addition, depending on the combination, the different aspects are more or less relevant. As an example, loose objects may mainly be relevant to evaluate in Face-2-Face Seating Configurations.

The ‘restriction on the side of the occupant’ is an example of feature that is more or less relevant depending on the crash configuration in question.

Table 1 Structure for Interior Feature

	Alternatives
1. Restriction in front of occupant	
a) Presence of steering wheel	yes/no
b) Knee support area (closeness to instrument panel or back of a seat in front of the occupant)	yes/no
c) Table in front of the occupant (if needed broken down into position, size and shape)	yes/no
2. Restriction on the side of the occupant - Presence of centre console or vehicle interior structure (if needed broken down to shape and size)	yes/no
3. Loose objects - objects that are brought into the vehicle, e.g. laptop, phones (if needed broken down to size and position)	yes/no

3.2.3.1.3 Seat Position

Seat Position includes information on the seat position adjustability in terms of seatback angle and seat pan tilt. It also includes examples of seat design features such as leg support and articulated seatback. The selected Seat Positions chosen within the project at this stage are illustrated in Figure 4 , including level of detail. The seat position in longitudinal direction or height are not included in seat position, it is partly reflected in the interior feature dimension.

To limit the number of total combinations, only five seat position alternatives are selected at this stage. Additional alternatives, and degree of angulation can be added to provide an even larger coverage of possible Seat Positions.

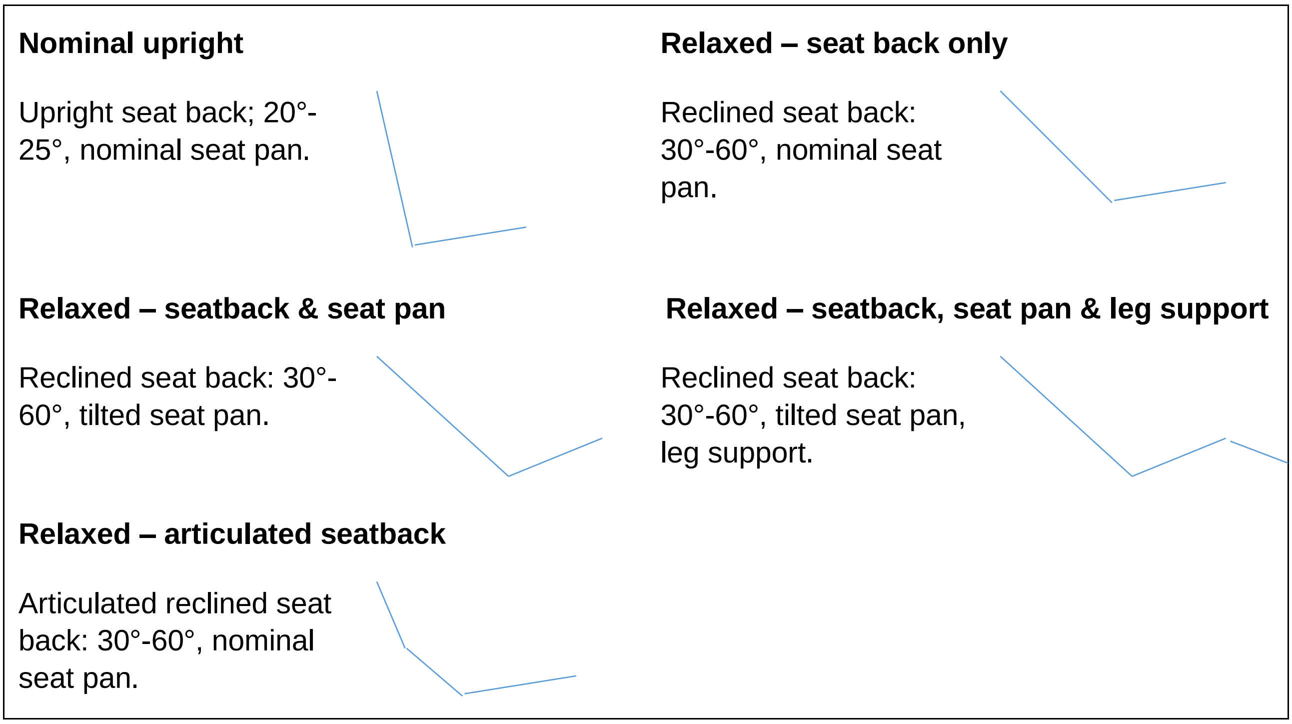


Figure 4 Selected Seat Positions, including level of details

3.2.3.1.4 Sitting Posture

Sitting Posture includes information on how the person is sitting in the seat, relating different body parts to the seat, in sagittal and lateral direction. The sagittal position includes information of head position (contact with head restraint, shoulder/torso position, lower-back/torso position, and buttocks). The lateral positions include upper torso position (centralized, tilted left or right around x-axis, rotated left or right around z-axis). To limit the complexity of the Test Case Matrix, the level of detail has been limited at this stage. The selected aspects of sitting postures to be addressed within this project are illustrated in Figure 5, including level of details. In total 27 combinations of sitting postures are included.

The leg position (centralized, crossed at knees, crossed at ankles, stretched out, at least one leg up, legs under seat) could be included as well, though not linked to the positions of the upper body in order to reduce complexity for the Test Case Matrix content. For the user study performed within the project, this information was included. The complete matrix to deduct the seat and seating positions as well as leg positions and activities for the user study is displayed in Appendix 2.

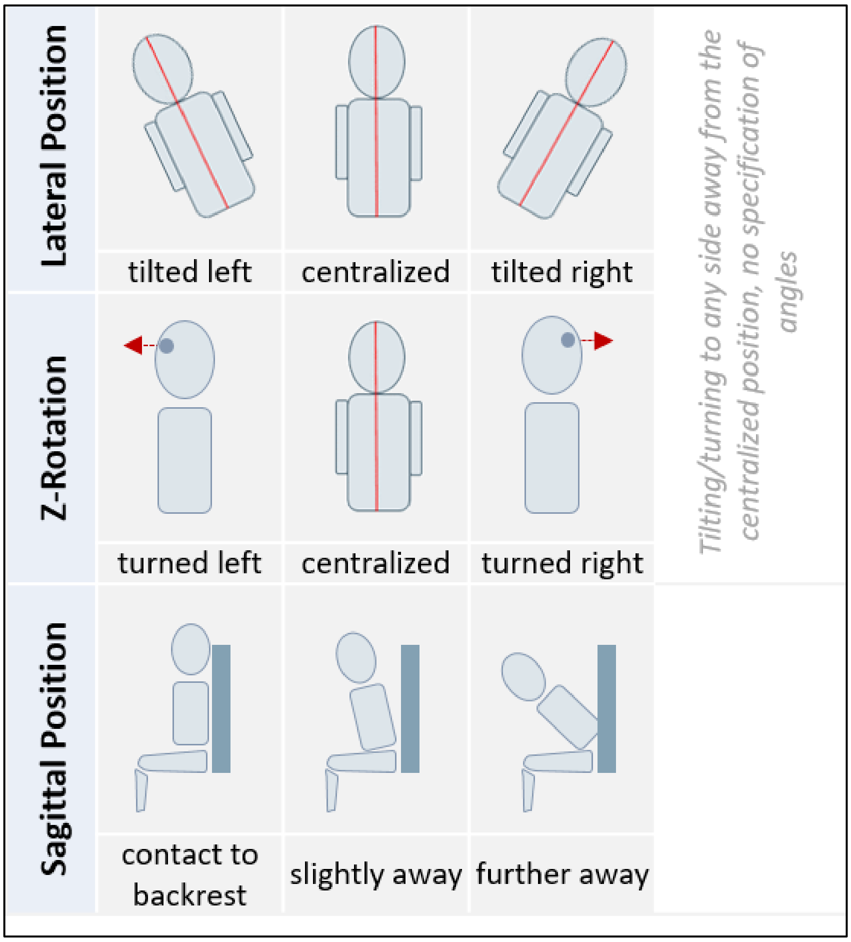


Figure 5 Selected Sitting Postures, including level of details

3.2.3.2 Structure for Crash Configuration dimension

The Crash Configurations dimension is structured based on a list of geometric parameters from which the impact point and direction in addition to severity can be described. The parameters describe the first point of contact (FPOC) between two colliding objects, as a birds-eye view of the physical appearance of the two objects when first contact occurs. Consequently, those parameters are independent of where the occupant is sitting in the car, which is a parameter which is addressed in the Occupant UseCases dimension. Based on the information on the parameters, an applicable crash pulse can be generated by either scaling an applicable existing pulse or conducting FE structure simulations to obtain not yet existing pulses.

This method of describing states at crash initiation regarding positions, orientations and velocities was originally developed by Wågström et al. [66] and is also presented in the OSCCAR Report D1.1.[44], using partly somewhat different names of the parameters. The parameters included in the main body of the Crash Configurations dimension in the Test Case Matrix are the following:

- Collision Point Angles of the host (called CA_AD) and opponent (called CA_opp) vehicles
- Collision yaw angle (yaw)
- Collision Velocities of the host (V_AD) and the opponent (V_opp) vehicles

Figure 6 shows the definitions of the five parameters. Since the description will be dependent on the vehicle width-to-length ratio, the method also include method to describe the angles in a more universal way. Therefore a transformation is made scaling into a square unit car as shown in Figure

7. The same procedure is applied to both vehicles. For more information on the method, see Wågström et al. [66] and the OSCCAR Report D1.1. [44].

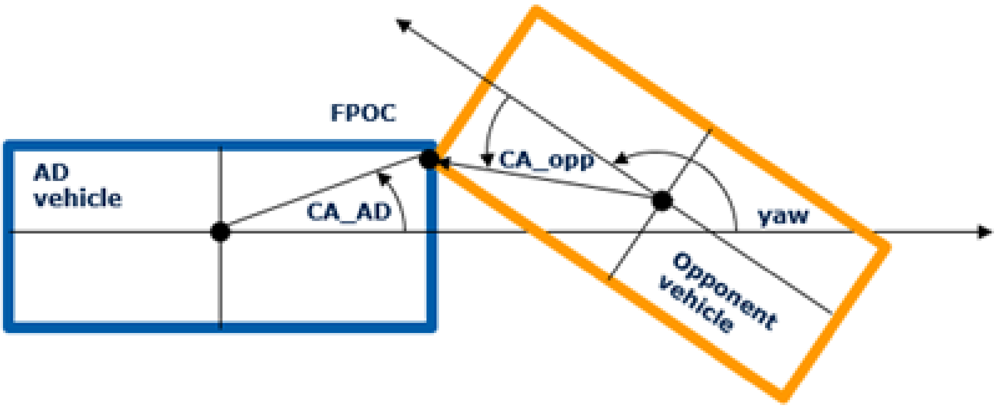


Figure 6 Crash Configurations parameters; definition of angles in host and opponent vehicle.

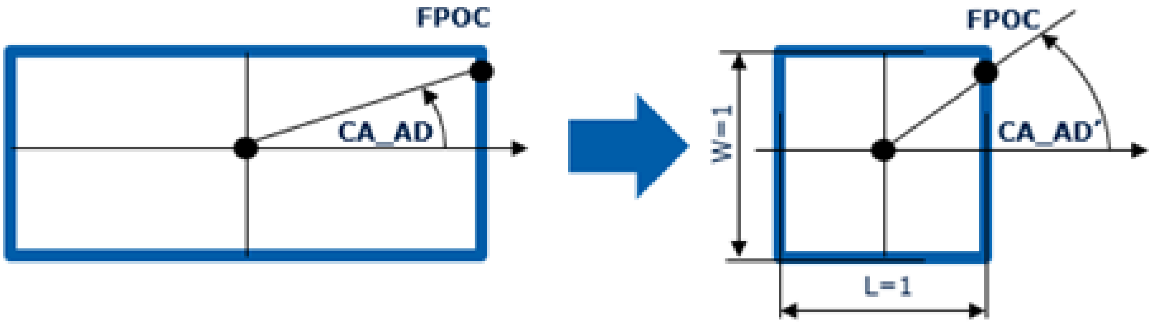


Figure 7 Crash Configurations parameters; transformation from actual appearance to square unit car system

The actual numbers for the five parameters will always be used when applying the Test Case Matrix results, e.g. when performing crash simulations. OSCCAR Report D1.1. [44] describes how they are derived, as well as some examples of OSCCAR WP1 results, see further in Chapters 3.3.2 and 3.5.2.

To limit the number of total combinations when visualising in the Test Case Matrix, the angles and speeds are grouped. The level of details chosen in this study for the three angle parameters when visualising is shown in Table 2. The velocities (V_AD, V_opp) are clustered in three groups: Low (0-15 km/h), Medium (16-30 km/h) and High (31 km/h and above). As for the grouped parameters in the Occupant UseCases dimension, these Crash Configurations parameters can easily be changed in the Test Case Matrix to allow for another level of details.

Table 2 Crash Configurations parameters; level of details for CA_AD, CA_opp and yaw

Host and opponent collision point angles (CA_AD, CA_opp) Opponent yaw angle (yaw)	
5° to -5°	
6° to 45°	-6° to -45°
46° to 85°	-46° to -85°
86° to 95°	-86° to -95°
96° to 135°	-96° to -135°
136° to 175°	-136° to -175°
176° to 180° and -176° to -180°	

3.2.3.3 Individual Human Variations dimension

Individual Human Variations completes the third dimension of the Test Case Matrix. At this stage within the project, no details on the structure is developed for this dimension. The ambition to include the Individual Human Variations is to start the discussion and provide available input to the enhancement of the HBMs in OSCCAR WP3. To highlight the impact of this dimension, two dedicated cases have been included in the Baseline simulation study (see Chapter 3.3.3.1.1 and Appendix 3). They refer to two different Individual Human Variation parameters, namely weight and size, i.e. an obese occupant and an occupant representing Asian population.

3.2.4 Process of Grading Demonstrator Test Cases

A process was developed that can be used for grading a Test Case, and to compare some relevant aspects between different potential Test Cases, so called Process of Grading. Specifically, a methodology and specification of Evaluation Criteria were defined to help grade selected Test Cases as potential candidates for Demonstrator Test Cases. Using this grading, will help to motivate the selected Test Case and put it into a larger context within a defined scope. Prior to applying the process of grading, the Pre-pre and Pre-processes are used to narrow down the scope, addressing the specific area of interest for the specific study. For example, a SAE level 3 function for a passenger car that drives autonomous on highways only limits the accident scenario that has to be considered for deriving relevant crash configurations (highway accidents). Since in SAE level 3, the driver is still responsible for the driving task, it will likely be designed similar to today's conventional vehicles, so the degrees of freedom regarding the Occupant UseCases are also limited.

The Process of Grading as support to the choice or motivation of the selected Test Cases is illustrated in Figure 8. The selected Occupant UseCases and Crash Configurations are described at the top. An unlimited number of combinations can be included. Five defined Evaluation Criteria are listed to the left:

1. Novelty
2. Severity / Challenging
3. Relevance / expected by end users
4. Urgency

5. Related to OSCCAR goal

The Occupant UseCases and Crash Configurations are rated individually by 0, 5 or 10 based on the Evaluation Criteria. The defined weight factor is used to calculate a total score, where a high score represents a more complex test case compared to a low score. Note that current legal and consumer test cases may score low in this grading matrix due to its definitions to identify weaknesses within current occupant protection systems.

At the bottom of the matrix a factor called 'Readiness' is included. This is used to judge if there are tools validated (virtual or physical) to be used in this Test Case, or if validation data will soon be available (within OSCCAR timeframe). If not, the Test Case will be disqualified for further analysis within this project.

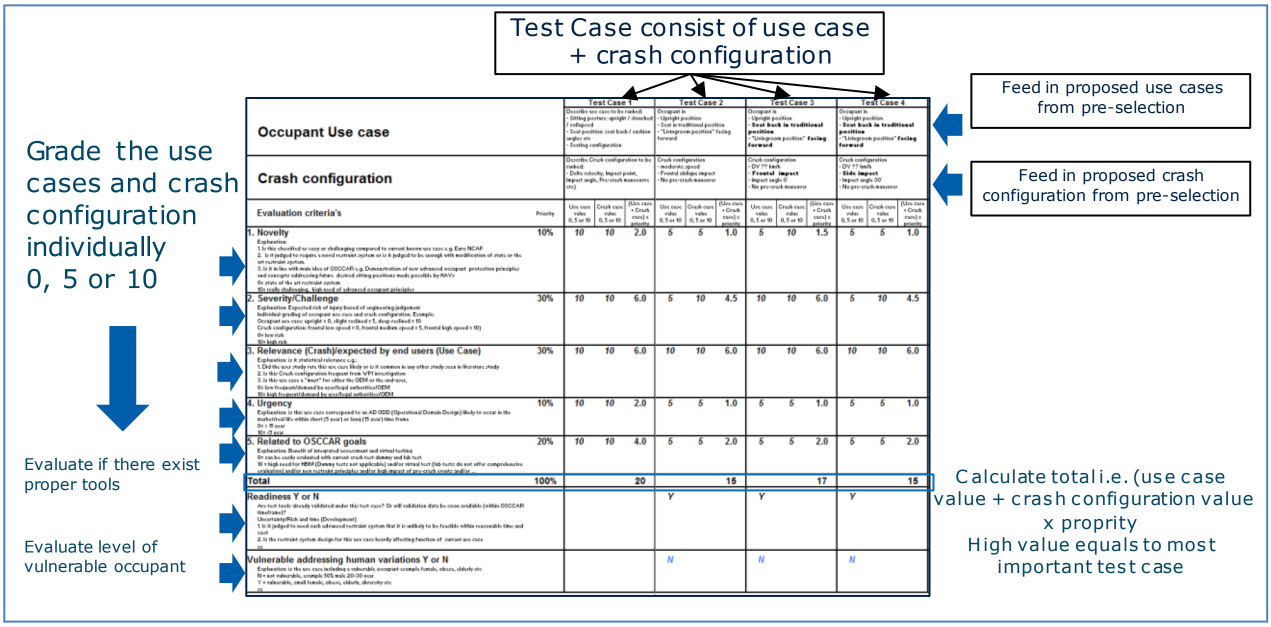


Figure 8 Process of Grading of different Test Cases

The Evaluation Criteria were selected making possible to use both quantitative data, such as crash frequency from accident data and more subjective data, such as engineering judgment. The priority is based on ranking. Each criterion was given a priority reflected by the weight factors, summing up to a total sum of 100%. The Evaluation Criteria and weight factors are presented in Table 3. The work leading to the list of Evaluation Criteria started with a brainstorming activity that gave thirteen different criteria, which were clustered reaching the selected five criteria. The criteria are applicable for both the Occupant UseCases and the Crash Configurations and should be used for each category before it is summed up.

Each Evaluation Criterion comprises sub-descriptions as follows:

1. **Novelty**: Is it judged to require a novel restraint system or is it judged to be enough with modification of state-of-the-art restraint system. For 0, a state-of-the-art restraint system could do the job and for a high score there is a need for research on new restraint principles.
2. **Severity / Challenging**: Compared to today's standardized test methods, e.g. Euro NCAP, is this classified as similar or challenging? A 0 equals same difficulty as today's methods and a higher score indicate this as more complex. A complex example could be a body posture that is challenging to restrain, e.g. lying flat.

3. **Relevance / expected by end users**: Is the Occupant UseCases or Crash Configurations frequently occurring, e.g. is there quantified evidence supporting this being a common situation? Low frequency equals low score and high frequency equals high score.
4. **Urgency**: If the Occupant UseCases or Crash Configuration corresponding to any AD ODD is likely to occur in the market / real life within short (5 years) timeframe, a high score should be given. For an expected long period (15 years) a low score is applied.
5. **Related to OSCCAR goal**: Does the Occupant UseCases and / or Crash Configurations benefit from the integrated assessment and virtual testing procedure that will be developed within the OSCCAR project? Or is it in line with main idea of OSCCAR e.g. demonstration of new advanced occupant protection principles and concepts addressing future desired sitting positions made possible by HAVs? If so, a high score should be given indicating the need of HBM (Dummy tests not applicable) and virtual test (lab tests do not offer comprehensive evaluation). A 0 is given if it can be evaluated with ATDs and conventional lab test.

Table 3 Evaluation Criteria and weight factors

Evaluation Criteria	Weight
1. Novelty	10%
2. Severity / Challenging	30%
3. Relevance / expected by end user	30%
4. Urgency	10%
5. Related to OSCCAR goal (use of HBM)	20%

3.3 Input data to the Test Case Matrix

This chapter summarizes available information to fill the different dimensions with quantified information. It serves the purpose to provide input to the process of selecting and motivating the selected Demonstrator Test Cases.

3.3.1 Occupant UseCases dimension

3.3.1.1 Literature review

A literature review was performed with the aim to understand and identify the more relevant aspects of the Occupant UseCases dimension in autonomous vehicles, see Appendix 1. In this chapter, use case is defined as a written description of how occupants of autonomous vehicles will perform tasks. The different levels of autonomy and driving characteristics substantially determine the vehicle users' behaviour and side activities to be engaged while riding as well as their seat position and sitting posture. Some published studies address behavioural, comfort and seating aspects of the vehicle occupants, and provide relevant information as input to the dimension of Occupant UseCases of the Test Case Matrix.

The analysis of the sitting posture, with the aim of designing comfortable seating in the transportation industry, suggests a relationship between most activities and the position of the head, trunk and arms although there are not as significant difference when using small electronic devices [28]. The posture is in general terms divided in three types: upright, standard and relaxed. These should be possible to be customized and adapted in the autonomous vehicle, thus leading to five options according to Bengtsson [4] as illustrated in Figure 9.

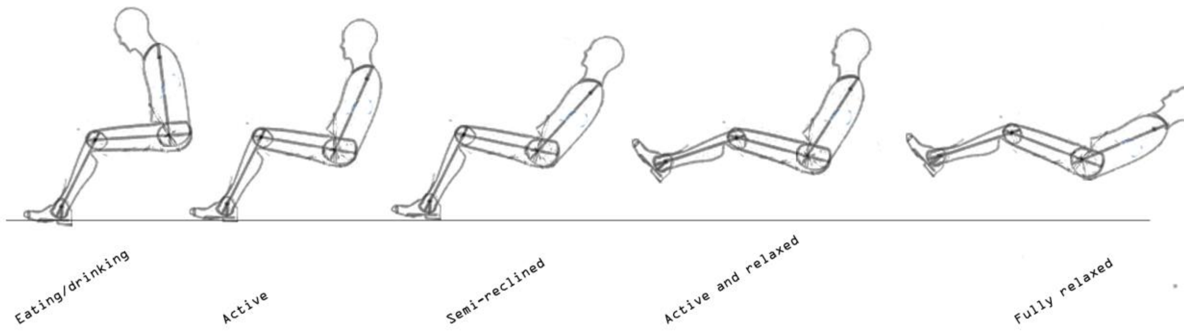


Figure 9 Seating positions and seat customization, from reference [4].

Further studies try to identify future seating configuration inside the vehicle. The most common seating configurations are forward facing and the conversation position, where the frontal row is turned and looking face-to-face to the rear row. Other studied seat position combinations include only the 2nd row or in conversation position but at different angles position [2][4][26].

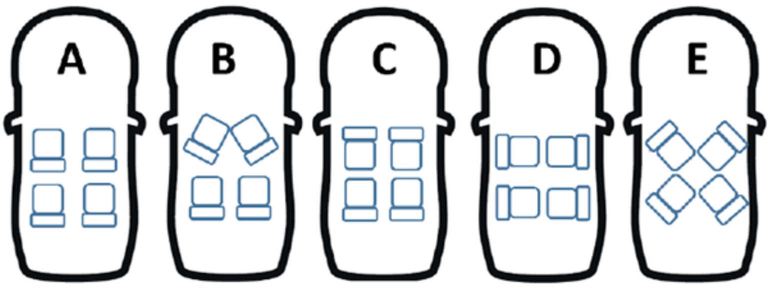


Figure 10 Possible seating configurations in an autonomous car, from reference [26].

Regarding the activities performed while travelling, queries and observations arrive to different conclusions about what travellers use to do during their trip [4][10][18][49]. According to these studies, travellers are influenced by aspects such as calm environment, stability, journey length and comfort. However, most people expect to be more active than they actually are. Moreover, most of the occupants expected to be more active while travelling in autonomous vehicles and desire to work and take profit of the travelling time [3][8][19][26][34][58]. It is difficult to put together all the information obtained in these studies, since they have been performed under very different conditions, methods and objectives. However, it is interesting to realize which activities have been asked the most and which are usually the most likely carried out. As part of the literature review, with the purpose to evaluate this, a list of common activities was defined and each of them was rated regarding their ranking in each of the previously commented surveys. Figure 11 shows the outcome of by this project created activity ranking, providing an illustration of the estimated importance of each current and expected activity carried out by travellers. The method for deriving at this outcome was as follows: First, the activities of each of the previous survey studies was associated with one of the listed activities. Secondly, each activity was rated regarding its ranking in the original surveys – for each survey. The activity that was the most usual or expected by transport users was given 15 points, the second activity most usual or expected was given 14 points and so on. Thirdly, all the points received for each activity were summarised and a rating percentage was calculated. Figure 11 shows the outcome of this activity ranking, providing an illustration of the estimated importance of each current and expected activity carried out by travellers. The most frequent activities in the present are about entertainment followed by relax, eat and drink, talk, work and others.

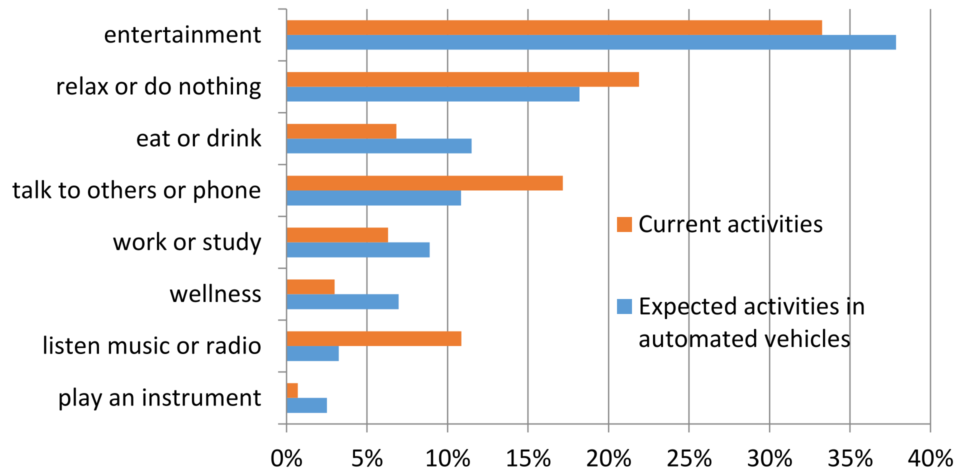


Figure 11 Comparison between the user activities in current journeys and the expected to be performed in autonomous vehicles. The graph is a compilation of several references.

Other studies related to comfort in cars focus motion sickness. Motion sickness is most frequently caused by a conflict between visual and vestibular inputs, loss of control over one's movements and reduced ability to anticipate the direction of movement [20][51][52][65]. Having predicted that users of an autonomous car will be more active compared to travelling in a conventional car, users will increase their risk of being motion sick [35]. Some considerations are that motion sickness can be reduced by the passengers tilting their head toward the centripetal direction (as done by the drivers), the extent of the visual field, restricting the head motion by having fully reclining seats, be positioned in the direction of gaze and being used to this conflict [65]. Also, music, sleep, controlled breathing and the absence of alcohol had positive prevention effects.

Further studies such as Adient [2] and Bengtsson [4], in addition to research projects summarized in the literature review (see Appendix 1), have investigated and created possible interior designs and seat concepts considering the comfort parameters and the most desired side activities just mentioned.

3.3.1.2 OSCCAR User studies

Two user studies were performed within OSCCAR. The overall purpose of the studies was to assess preferred seat rotations, different seating configurations, sitting postures, and activities that people take and execute in a car as passengers, especially against the background of autonomous vehicles. The first study addressed preferences of users regarding different seat rotations, while the second study focused on seat configuration (except rotations), sitting postures, and collected activities. A summary of both studies is provided here. For more details, see Appendix 2.

3.3.1.2.1 Study on seat rotations

The first study was executed in a testing vehicle on the ika test track in Aachen with N = 31 participants. The vehicle was equipped with two rotating seats in a row behind one another in the middle of the rear of the vehicle. These could be turned in steps of 30°, around the entire 360°. Participants were tested in groups of two, ensuring to control for motion sickness prevalence as one person who had experienced motion sickness before and a person who had not were always tested in the same rotations. Each participant started in a different seat rotation and experienced a total of

7 rotations (random sequence, not fully crossed). One group of participants was rotated clockwise between 0° and 180°, the other group counter-clockwise. Therefore, each group was confronted with rotations every 30° but for one side each, e.g. were participants in the first group facing rather to the right, while the second group faced rather to the left. When asked before the test drive on their usual activities when sitting in a car as a passenger, nearly every participant (98%) reported some kind of activity when sitting in the passenger seat; most people of these usually have a conversation (12% of all mentions), followed by reading, listening to music, or being on their phones (10.32% each) The majority of participants indicated that they prefer to face the front while driving (77%), few wish for either lying down or sitting when they were asked to name their preferred choices freely.

After each round on a standardized parkour on the test track featuring one seat rotation, participants' acceptance of each rotation setting was assessed. 100% of participants accepted facing forward (0° rotated), while only 70% accepted the 180° and 270° rotations (clockwise). Overall, left-wing rotations were preferred. Rotations to the right (30°-150° clockwise) were accepted considerably worse than the rotations to the other side. This was supported by the rating for comfort according to the adjusted so-called CP50-scale [57] (see Appendix 2). This low rating could be due to visual cues: Participants experienced higher dizziness and an uncomfortable overall feeling due to fast passing scenery (closer to trees surrounding the test track), whereas they had a higher feeling of control when being able to look into the test track when rotated the other way. However, this result might be different when changing the direction of driving to left hand traffic, but this is subject to further research.

In general, the rotation of the seat makes a difference in the feeling of comfort that was assessed for individual body parts (ergonomic comfort), especially when rating the discomfort for the human back. In both directions of rotating the seat, the equivalent rotations 60° and 300° were perceived as most uncomfortable. Furthermore, participants turned their heads in the direction of travel in forward-facing rotations, indicating 0° to be their preferred seat rotation when just sitting in a car. Ratings of different seat rotations when being engaged in an activity like social interaction, reading or other remain subject to further research. Nevertheless, results indicate that most people prefer a certain feeling of control about where they are going, especially while looking out of the window. Detailed results on this are compiled in Appendix 2.

3.3.1.2.2 Study on seating configurations, sitting postures and activities

The second study was conducted in real traffic (mix of motorways, on rural roads and within the city) with a total of N = 50 participants in 7 use cases. Participants were driven around a specified course around Aachen, Germany, with four participants at once on seats facing each other for 1.5 hours. They were either engaged in activities following leisure or business alone (groups with both, peers and strangers), in groups (peers only), or were not allowed to engage in any visual or social activities except for listening to music in day-time and night-time drives. This resulted in seven use cases, which were tested with two groups each to ensure that each use case was tested sufficiently at least once, except for the *business active* group, which was only tested once. The experiment lasted two hours in total, including instructions, and participants were observed with two cameras per participant, including one frontal and one lateral view. During the data analysis, postures where decoded for head, shoulders, lower back, and buttocks. This was done for the sagittal perspective (contact to backrest, slightly away, further away), for z-rotation (turned left/right, centralized), and the lateral perspective (tilted left/right, centralized). Furthermore, leg positions and activities were tracked independently from this due to reducing the complexity of the overall matrix on sitting postures. Results were analysed overall and individually for each use case.

When looking at overall results for the **lower back**, by far the most popular posture (85.04% of the time) was the one where people had their lower back fully centralized, in lateral, z-rotated, as well as the sagittal position. This posture should therefore be considered for the test case matrix. Even though two more postures for the lower back were obtained the second and third most often, these were taken by far at a lower percentage of time. We therefore advice to not consider these lower back positions for the test case matrix.

Two different **shoulder** postures should be considered for the test case matrix. Again, the most popular posture (65.43% of the time) was the one where people had their shoulders fully centralized, in lateral, z-rotated as well as the sagittal position. This shoulder posture should therefore be considered for the test case matrix. The second most often taken position for the shoulders differs from the previously described position in the sagittal view and shows that participants' shoulders were fully centralized in the lateral and z-rotation view but were slightly away from the backrest (17.41% of the time).

The analysis for the **head** postures included the sagittal perspective only, meaning whether the head had contact to the backrest or not. The lateral and z-rotated view was excluded, as head movement is usually quite fast and therefore hard to determine. Most of the overall time, the participants' heads had contact to the backrest (58.01%). However, the head was also often slightly (24.44%) or further (10.39%) away from the backrest, which is why we advise to include these for the test case matrix if distinct postures of the head will be considered for the test case matrix. As there is usually a large variety of head postures overall and among the use cases, integrating the head postures into the test case matrix can make this quite detailed. This should be considered when choosing the most relevant test cases within WP2.

Three postures of the **legs** were taken most frequently over all participants. The most popular posture (52.49% of the time) were centralized legs with two feet firmly planted on the ground. This position should therefore be considered for the test case matrix. The second most often taken position in this category were legs crossed at the knees (21.90% of the time). The posture for the legs ranging third were two legs/feet underneath the seat (13.93% of the time). This is a considerably lower percentage value than the posture ranging first but is not very far away from the second posture. Therefore, all three leg postures occurring most often should be considered for the test case matrix.

The **activities** participants engaged in varied with the different instructions per user case. The most often occurring activities across all participants are displayed in detail in Appendix 2, along with the percentage of time spent on them, divided by groups. As the activities are highly dependent on the use case, no overall activity distribution was made as this would only have had limited informative value. Participants in the use cases that were engaged in a group activity followed this activity all the time, as instructed. In use cases in which participants were engaged in an activity by themselves, participants mostly listened to music, worked, read something or were on their phones, either texting or on social media. In the visual passive-only conditions, participants followed only the allowed activities, such as listening to music, doing absolutely nothing, looking out of the window or even sleeping. The activities correspond to the sitting postures.

Implications on the Test Case Matrix

Based on the results in the second OSCCAR user studies, a selection of sitting postures (being most frequent), to be considered for the Test Case Matrix are summarized in Table 4.

Table 4 Most frequent sitting postures over all participants in the second user study

Body part	Rank	Position			Percentage of time
		lateral	z-rotation	Sagittal	
Lower back	1st	centralized	Centralized	contact to backrest	85.04%
Shoulders	1st	centralized	Centralized	contact to backrest	65.43%
	2nd	centralized	Centralized	slightly away	17.41%
Head	1st			contact to backrest	58.01%
	2nd			slightly away	24.44%
	3rd			further away	10.39%
Legs	1st	centralized			52.49%
	2nd	crossed at knees			21.90%
	3rd	Legs under the seat			13.93%

The study was able to attain a dataset of verified sitting postures and seating configurations within the setting of this user study, as summarized in Table 4. With these insights, justified statements can be made towards the probability of certain sitting postures in a simulated automated driving situation as carried out in this user study. Nevertheless, future studies should focus on elaborating the learnings further and transfer them to various vehicle concepts, use cases and settings, including a larger sample of participants in order to generalize the results to the upcoming challenges and chances of autonomous vehicles and their users.

3.3.2 Crash Configurations dimension

The Crash Configuration dimension is determined based on real-world data analysis and pre-crash simulations in OSCCAR WP1, i.e. scenario models from accident and traffic data describing the relevant traffic conditions and conflict situations for automated driving functions. The outcome of this activity is a description of the accidents that are expected to persist in mixed traffic, even with onset and increasing market penetration of automated driving. This work is described in detail in the OSCCAR Report D1.1 [44].

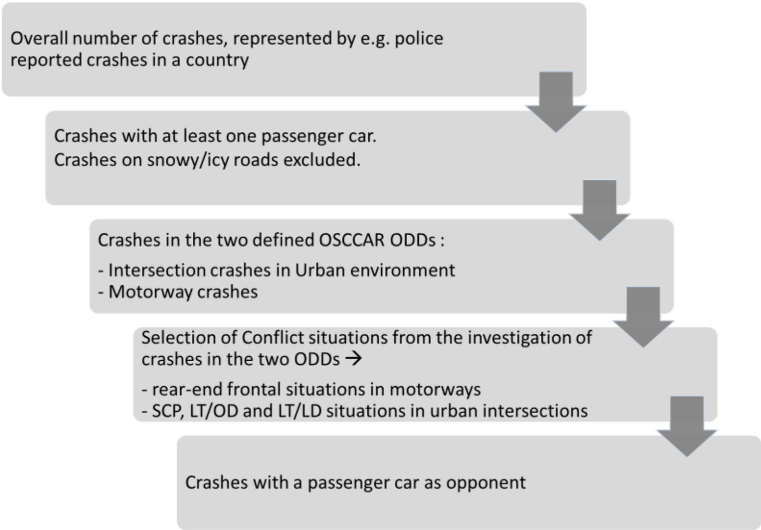


Figure 12 Schematics of the filtering process of the real-world data as input to the Crash Configuration dimension

Figure 12 shows the process used in OSCCAR WP1 for filtering the cases prior to entering the Crash Configurations dimension of the Test Case Matrix. The applicable accident data is selected according to the ODD and crash related contexts as shown in the Figure. Currently, an automated highway driving function and an automated urban driving function are considered. Accident data with detailed pre-crash time series data is available for Germany (GIDAS+PCM) and Sweden (VCTAD) and used in the analysis. The selected cases are simulated with pre-crash simulation models of the considered automation functions to apply the assumed collision avoidance behaviour. The remaining collisions of these simulation studies (geometric configurations and collision speeds) represent future accidents that an automated vehicle would be exposed to in mixed traffic, hence their characteristics serve as “future accident data”. Most relevant crash configurations are identified by clustering of the simulation output data. The cluster size can be used to rank, or grade test cases based on the relevance of the underlying crash configuration.

The pre-crash simulation results of this first study are presented in the OSCCAR Report D1.1 [44], providing results for LT-OD (Left Turn - Opposite Direction), LT-LD (Left Turn – Left Direction) and SCP (Straight Crossing Path) for the German and Swedish data. The results from the two countries are quite heterogeneous. Within the remaining intersection scenarios, there is a large variety of impact directions, overlaps and speeds. Besides selecting two examples from the top frequencies, as presented in Chapter 3.5.2, there is the need to investigate additional Crash Configurations.

Important to note that the filtering process (Figure 12) is applied prior to providing input to the Test Case Matrix. Hence, the starting point prior to the filtering process is the true anchor point of the representativeness of the selected Crash Configurations for the Test Cases.

3.3.3 Individual Human Variations dimension

As outlined in Chapter 3.2., the Individual Human Variations or injury risk evaluation dimension completes the Test Case Matrix and thereby the future safety assessment framework for occupant safety of HAVs. Computational techniques or at least virtual testing and the use of FE (Finite Element) or MBS (Multi Body Systems) HBMs are well addressed in the objectives of OSCCAR. They are the main tools within this Test Case Matrix dimension, allowing the representation of individual human characteristics. Nevertheless, current state-of-the-art HBM still have limitations or drawbacks when used within the above-mentioned framework and new Seating Configurations and Seat Positions.

3.3.3.1 Baseline study

With the purpose to demonstrate the injury prediction capability of today's HBMs within pre-crash and crash applications, a simulation study was performed, called the Baseline study. The results of this study will be used as input data for the conceptual OSCCAR Tasks T2.2, T2.3 and T2.4. Deficits concerning validation status, tissue modelling aspects and finally injury criteria are also formulated as research needs to be addressed by WP3. A complete report is found in Appendix 3 and summarized in this chapter.

Related with the intention to run this Baseline study in the sense of the term state-of-the-art also exemplary load cases and seating postures were proposed and agreed in the OSCCAR WP2 workshop. For the state-of-the-art load case definition, the hypothesis "ADAS operant on the road" was formulated. Especially the findings of the EU project SafeEV [60][67] were reviewed and preliminary results from OSCCAR WP1 ("ADAS effect") were taken into account. Five conflict scenarios were defined and described in more detail. It should explicitly be stated, that these load cases are not a part of the Crash Configuration dimension of the Test Case Matrix - but might be interpreted as "precursors".

To represent the occupant, a selection of THUMS-D models was used. This was due to the fact, that only the OSCCAR Partner Daimler was designated to perform this Baseline study. All these HBM are mainly based on the THUMS FE model (V3 or V4). Literature references are given, if equivalent models (e.g. GHBM) or similar modelling of respective human characteristics (Active HBM) are in place.

The 'Generic Interior' model [24] was used to configure the interior and restraint environment. Within this Baseline study the restraint and interior (seat, dashboard etc.) components of the Generic Interior were modelled in such a way, that they also represent state-of-the-art restraint and current vehicle interior concept.

3.3.3.1.1 Baseline study: Scenario and simulation setups

Case 1 is an oblique frontal impact with a preceding pre-crash manoeuvre, simulating an oncoming vehicle turning into path of the host vehicle, see Figure 13. A midsize male model is placed in the front passenger seat. An Active HBM (A-THUMS-D) is used within the avoidance manoeuvre (1g braking and lane change pulse applied to a vehicle travelling at approx. 50 km/h), by the ADAS function in the host vehicle. A transition is made to the THUMS V4 for in-crash phase simulation of a 40 km/h oblique frontal impact. Standard restraint systems of pre-triggered three-point belt, and passenger airbag are used. The crash pulse was selected from an internal database.

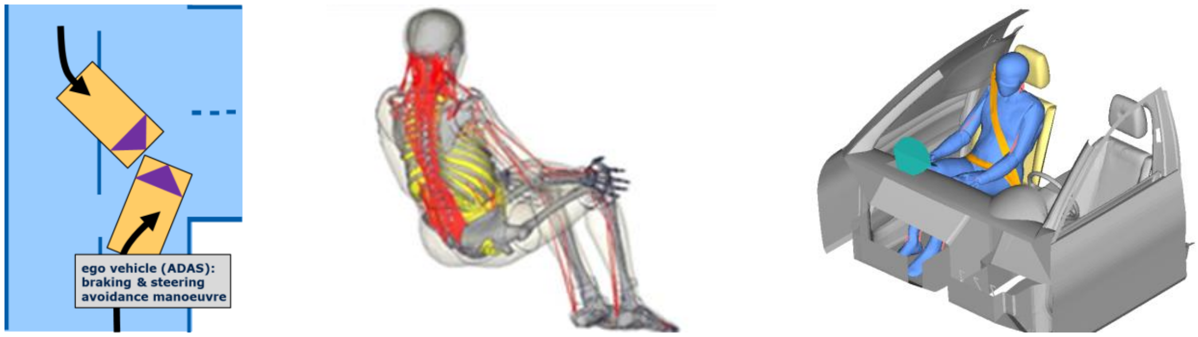


Figure 13 Case 1 - head-on at intersection with avoidance manoeuvre of host vehicle, midsize passenger

Case 2 is a side impact in 40 km/h on the passenger side exposing the midsized male driver (THUMS-TUC (3.01)) to a far-side impact, see Figure 14. It represents an opponent vehicle running into the host vehicle in a crossing situation. No avoidance manoeuvre of the ego vehicle is included due to obstructed view. The driver is restrained by standard three-point belt and driver airbag. The crash pulse was taken from an internal database. This setup also represents an example of a possible rotated Seat Configuration of the Occupant UseCases dimension.

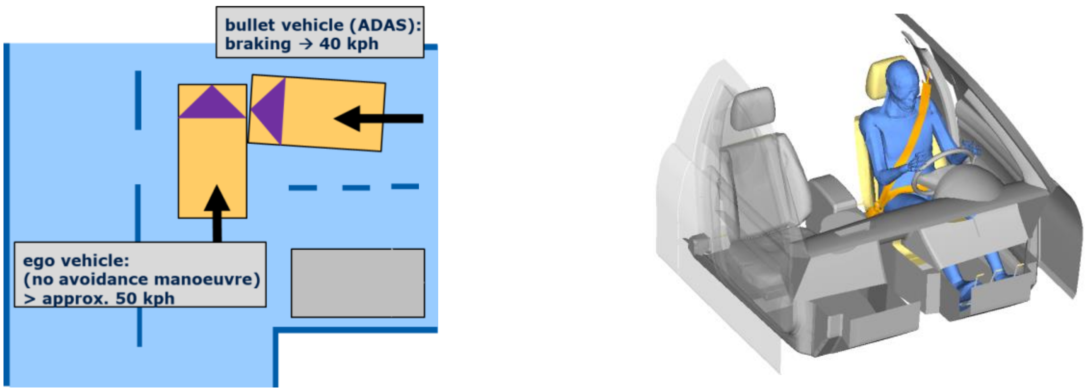


Figure 14 Case 2 – crossing far-side, midsize male driver

In Case 3, an obese (BMI 35) front seat passenger (THUMS-D V4 Obese) placed in a moderate reclined seat is exposed to a frontal impact in 40 km/h, due to an unexpected cut-in manoeuvre causing a rear end collision, see Figure 15. It is assumed that the host vehicle is performing a pre-brake manoeuvre. However, no pre-crash phase is simulated due to the fact that this HBM version currently does not have active muscles implemented. Standard seat belt and passenger airbag are used. The crash pulse was selected from an internal database.

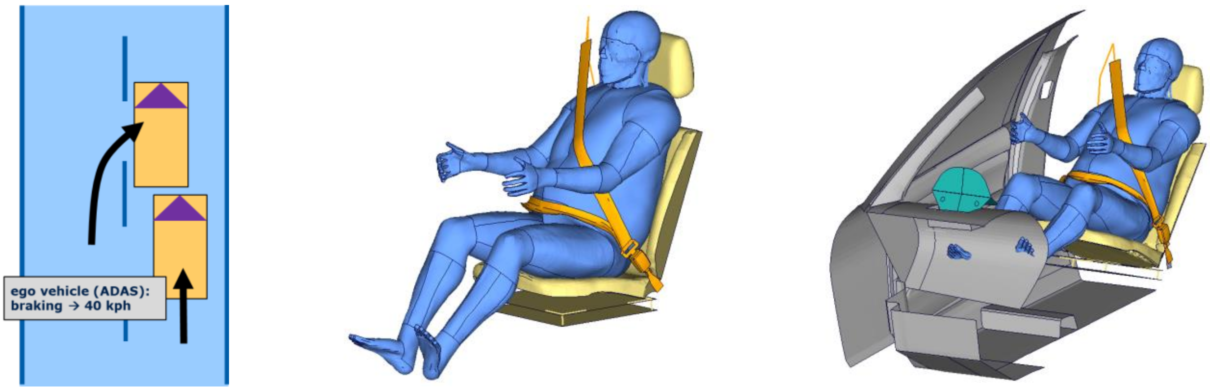


Figure 15 Case 3 – rear-end / head-on ("cut-in" highway scenario), obese passenger

In Case 4, a small female driver (THUMS-D-F05-Asian (5.0)) is exposed to a partial offset frontal impact in 40 km/h due to a head-on collision, e.g. unexpected overtaking manoeuvre, see Figure 16. The applied sitting posture are in accordance with ergonomic seat position and sitting posture for the Asian anthropometry. Standard three-point belt and driver airbag are activated, and an internal crash pulse is used.

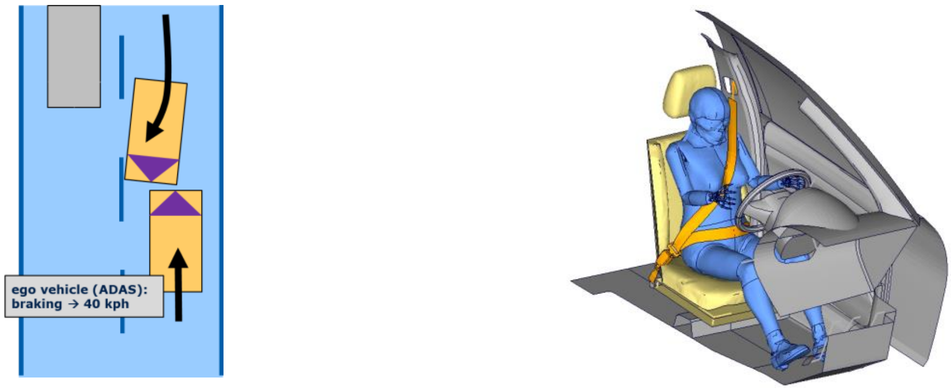


Figure 16 Case 4 – head-on, small female driver

In Case 5, a midsize male driver (THUMS-D-SUFEHN (3.2)) is exposed to a rear end oblique impact in 15 km/h due to a sudden stop of the host vehicle triggered by an autobrake function, whereby the opponent vehicle is running into the host vehicle, see Figure 17. Standard three-point belt is used. No airbag is triggered. The crash pulse was selected from an internal database. The set-up also exemplarily represents a possible rotated Seat Configuration of the Occupant UseCases dimension in the Test Case Matrix.

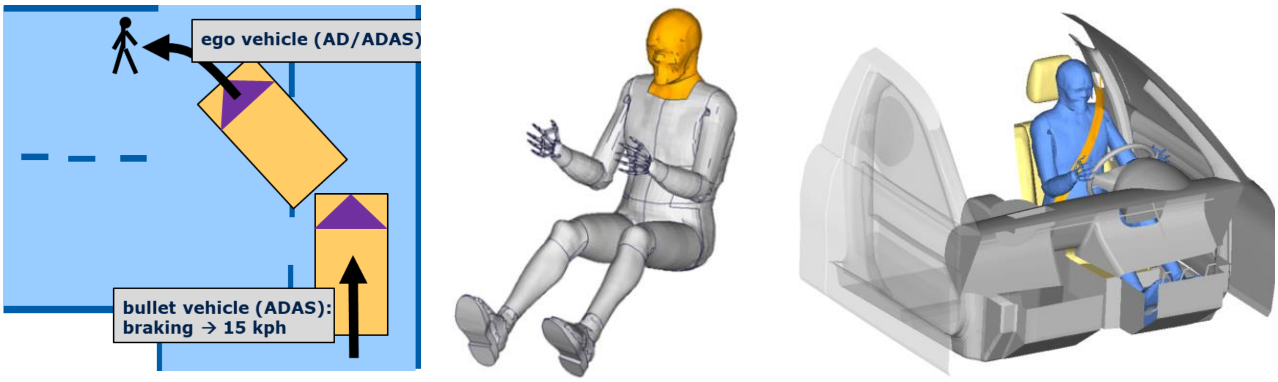


Figure 17 Case 5 – rear-end oblique, midsize male driver

3.3.3.1.2 Baseline study: Status of HBM used, results and observations

Case 1

Status of HBM used:

Within the case 1 scenario, two HBMs are applied, representing also a coupled pre-crash and in-crash simulation approach

A-THUMS-D 50th Male (3.3.5 - Daimler internal release) is used.

This model respectively the methodological approach to develop two model derivatives for dedicated use in a pre-crash phase and in-crash phase including the implementation of a transition method was finally motivated by the fact, that the model should show valid characteristics and be effective

- in a relaxed (w/o muscle activity) state and therefore show valid soft tissues response in low g scenarios
- when implementing active muscles and human behaviour by taking optimisation of calculation time into account in parallel.

The model [56] is based on THUMS-D, which is already a derivative of THUMS V1.2 & V3. A-THUMS-D is currently capable to represent active occupant kinematics in frontal 1g braking pulse & lateral manoeuvres. Macroscopic validation for these application is mainly based on the OM4IS database which was published by Huber at al. [22].

Active characteristics are currently achieved by implementation of a hybrid equilibrium point controller (hybrid controller) coupled with activation dynamics from Hatze [21] interacting with contraction dynamics from MAT_MUSCLE (MAT_156) in LS_DYNA [37].

Similar activities concerning soft tissue material characteristic in terms of valid behaviour under low g and implementation to the THUMS-VW (FE code VPS) are reported by Yigit et al. [69]. Latest validation results and status of the reactive THUMS-VW under moderate lateral loading are reported by Sugiyama et al. [59]. Lambda controller runs in the VPS solver via a user function. 600 muscles (Hill type) with 66 controllers are modelled.

Östh et al. [45] have previously developed a finite element (FE) HBM with proportional integral derivate (PID) controlled Hill-type muscle system model. The neuromuscular feedback control was implemented also for the THUMS AM50 version 3.0 with some enhancements to the model [43]. The so called SAFER A-HBM uses a 1D Hill-type model, as muscle representation, with muscles controlled by PID feedback, via stabilising muscle activation generated in response to external perturbation [53].

Application of the SAFER AHBM including its implementation to the above-mentioned crash/in-crash transition method could be found also in the reporting of SafeEV [67]. It should be mentioned that the SAFER A-HBM also allows “single model” respectively continuously simulation of pre- and in-crash phase. Latest applications are reported by Östh [46].

Same methodological approach is applicable with the latest MBS MADYMO active human model [62]. Several publications on this subject can be found within relevant conference proceedings. Exemplarily and related with this use case the publication from Bosma et al. should be mentioned [5]. Beside the application of the active HBM also the injury evaluation in comparison to latest ATDs (THOR & HIII) is discussed in this paper. The model is currently validated for frontal (forward and rear) and lateral pre-crash manoeuvres.

Another, commercially available FE model with ability to model active behaviour of a human in pre-crash and in-crash situations is the latest version of the THUMS model. This THUMS V5 currently exists in the configuration of an AF05, AM50 and AM95 [27] [63]. Two hundred and sixty-two (262) major skeletal muscles are currently represented by one-dimensional truss elements with Hill-type muscle model in THUMS V5. The active behaviour can be simulated by activating the muscle elements using prescribed parameters and functions. Matsuda et al. presented the results of their study concerning the simulation of occupant posture changes due to evasive manoeuvres and effect on injury risk in vehicle frontal and side collisions at IRCOBI 2018 [38]. This recently published application of an active HBM is also quite close to this exemplary baseline load case. Finally, also THUMS V4 was used in a similar way within the crash phase and for injury risk evaluation.

THUMS V4 was used to evaluate the injury risk in the in-crash phase. An in-house transition method was applied to transfer the physical parameters (posture and velocities) from the source (pre-crash) to the target (in-crash) model. A general description of the method can be found in the SafeEV deliverable D4.2 (see also SAFER A-HBM above) [13]. Further activities on this topic are also foreseen in OSCCAR WP4.

Also, THUMS V4 is commercially available via JSOL coop. and several publications can be found within related literature and relevant conferences [30]. Comparable state-of-the-art FE human body model is represented by the GHBM (Global Human Body Model). Combest recently presented the latest development and project plan at the 7th HBM symposium 2018 in Berlin [9].

Simulation results and observations

Pre-Crash Phase

This section incorporates 1g braking and lane change pulse applied to a vehicle travelling at 50 km/h. Figure 18 illustrates occupant kinematics during the pre-crash avoidance manoeuvre phase. The existing virtual simulation sled model had seatbelts with pre-tensioner & load limiter and a passenger airbag. However, for the pre-crash scenario these systems were de-activated. Under the influence of the pre-crash pulse, the occupant moves away from the original posture & moves closer to the centre console. In the pre-crash phase, no contact with the centre console is observed.

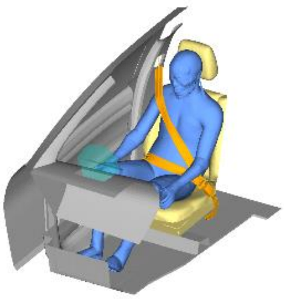

0 ms 300 ms


600 ms 1000 ms

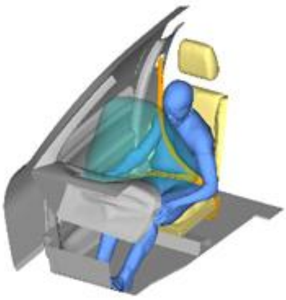
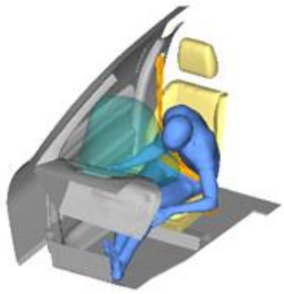
Figure 18 Case 1 - Occupant kinematics in pre-crash phase using ATHUMSD active occupant model

<u>In-Crash Phase</u>

Figure 19 shows the overall kinematics of the occupant in the in-crash phase. The same triggering time of the pre-tensioning and airbag system as used in a standard frontal load case have been considered. No real interaction with the passenger airbag is seen. Belt interaction loads the pelvis & rib cage both due to the oblique movement of the occupant.




0 ms 60 ms

90 ms 130 ms

Figure 19 Case 1 - occupant kinematics in in-crash phase using THUMS V4 50th male occupant model

Figure 20 illustrates the risk of head injury which is computed through the Cumulative Strain Damage Measure (CSDM) criterion. No risk of injury is predicted for the occupant head in this conflict scenario (no hard contacts and extreme head kinematic is observed).

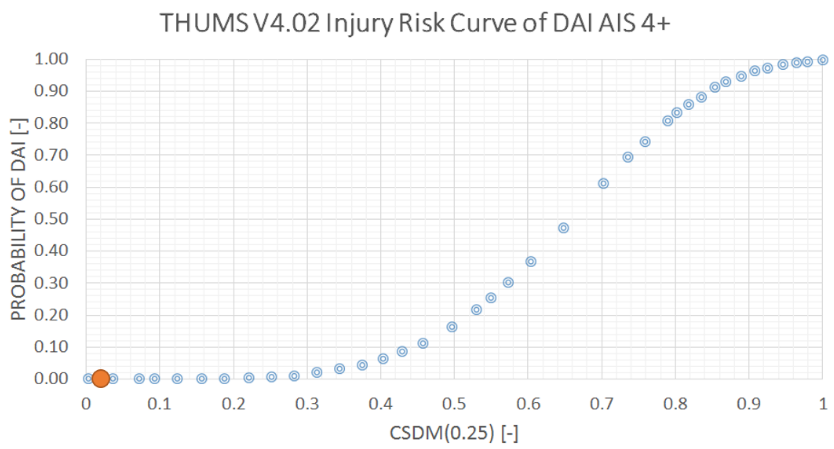


Figure 20 Case 1 - head Injury risk (CSDM) (Source IRC: TOYOTA)

Injury risk for the pelvis using the probabilistic injury criterion currently developed for THUMS V4 and based on max. principle strain by Peres et al. [48] is shown in Figure 21. Local effects might cause this notable risk indicated. More details of the injury evaluation and use of further injury indicators are reported and discussed in Appendix 2.

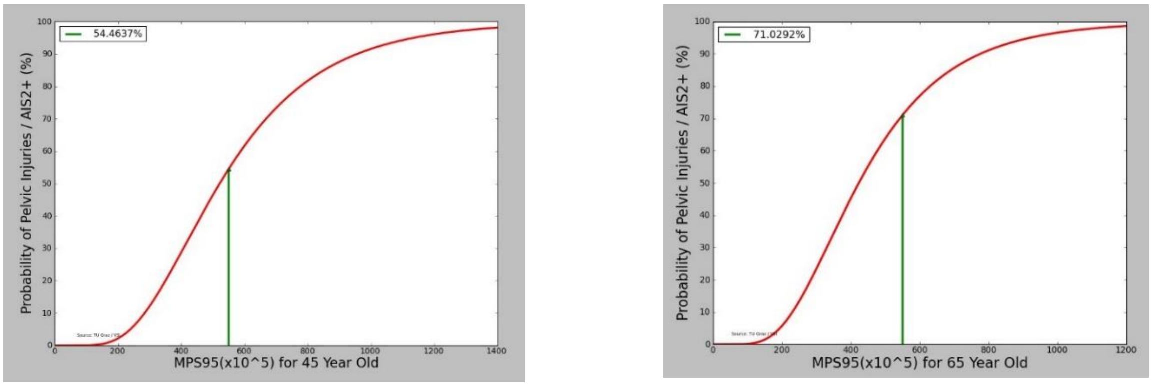


Figure 21 Case 1 - probability of pelvis injury based on IRC developed by Peres et al. [48].

<u>Case 2</u>

Status of HBM used:

Within the case 2 scenario the latest version of the THUMS-TUC was used. This model is mainly based on THUMS V3 and was further developed within a collaborative activity of the THUMS User Community [64]. The status of the model was recently presented by Peldschus et al. (2018) [47]. Modifications were mainly made in the shoulder, thorax and leg region. In general, also the robustness was improved by remeshing and revision of contacts etc. Finally, the probabilistic analysis method concerning evaluation of rib fracture risk, proposed and developed by Forman at al. [15] was specifically adapted and implemented to this model. This method will be used within the post processing. Latest applications of the THUMS-TUC are reported with reference to the SENIORS project. Here the model was also used as basis for further modifications to represent age-related (elderly) changes of rib cage anthropometry and rib fracture risk [50]. A detailed description of the THUMS-TUC model and its further improvement in terms of implementation also of active muscles can be found in the publication of Yigit [70].

Simulation results and observations

Figure 22 illustrates the overall kinematics of the occupant in the far-side conflict scenario (Case 2).

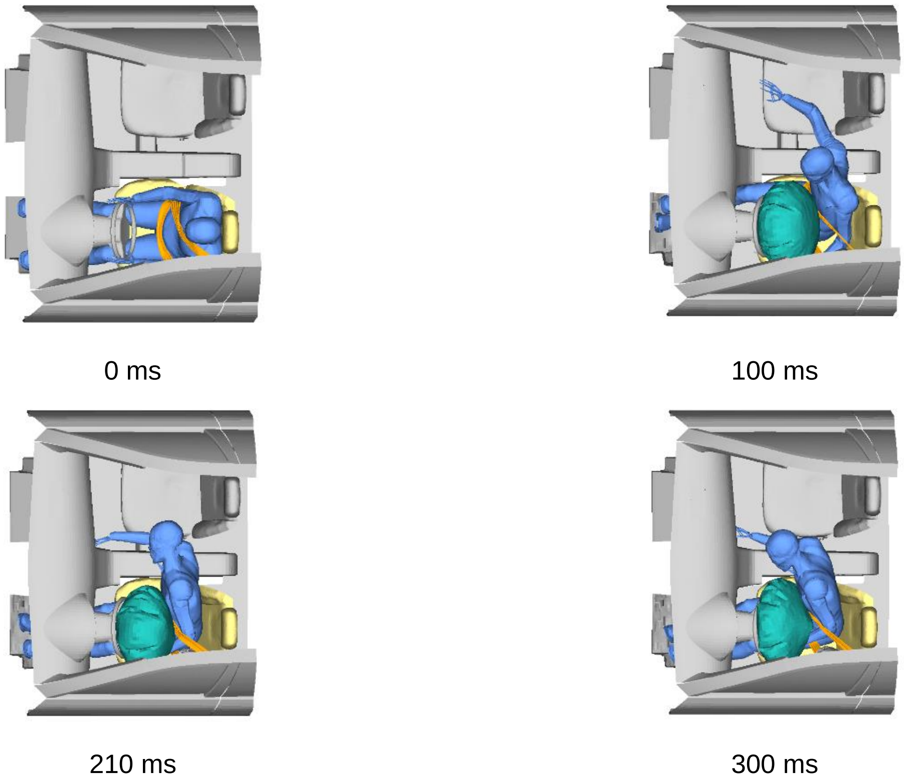


Figure 22 Case 2 - occupant kinematics in far-side scenario using THUMS-TUC 50th male occupant

Risk of rib fractures is predicted using the Forman criterion. The Forman criterion and method has been implemented in a tool from University of Virginia and the injury is predicted in the format below (Figure 23- left) with multiple rib fractures and age being considered [15]. The method was explicitly adapted and implemented to the THUMS-TUC model. Single rib fracture risk > 90% is observed for both age groups of 45 and 75 years. However, the tool needs to be further developed for incorporating the actual location of rib fracture risk (as shown in additional max. strain plot and post-processed with Burstein criteria [7] computed in the model. Furthermore, a verification concerning computed strain processed in the rib fracture risk predictor of the tool is needed (will be addressed in OSCCAR WP 3).

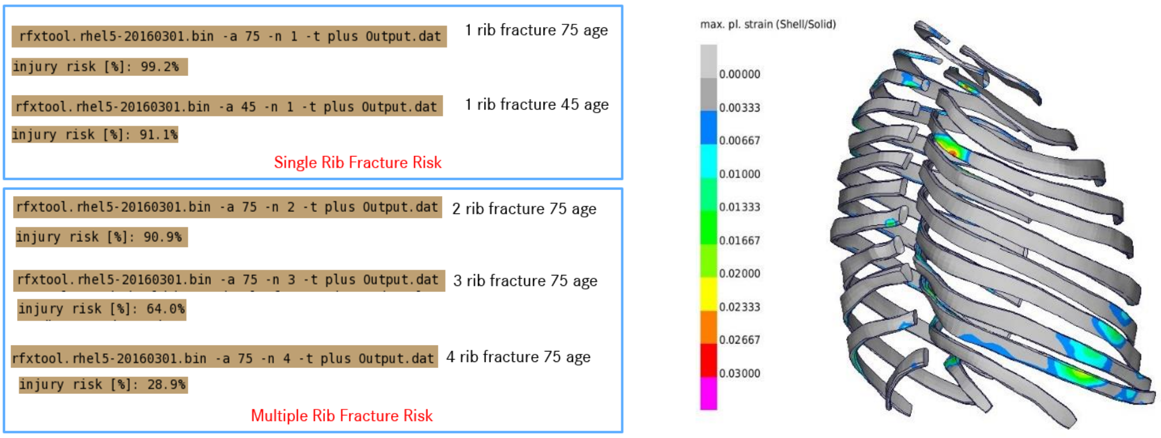


Figure 23 Case 2 - rib fracture risk given by Forman criterion (left) [15]; rib fractures predicted by max. principle strain, and Burstein injury indicator (3% plastic strain) (right) [7].

<u>Case 3</u>

Status of HBM used:

A Daimler in-house created derivative of THUMS V4 was used within case 3 of the Baseline study. THUMS V4 male AM50 was morphed to represent a corpulent person. The target anthropometry of this model was based on the corresponding RAMSIS obese manikin (121 kg, BMI 38.2; Database SizeGermany). The target anthropometry from RAMSIS showed also good consistency with UMTRI database surface model representing an occupant of 125 kg. Modelling and distribution of visceral and subcutaneous fat were done in accordance with published data and related literature. It has to be stated that this model is still under development and was not extensively validated prior to this study. The status concerning the validation set-up of by Forman et al. [16] and Foster et al. [17] are described in Appendix 3. A brief description of the creation process and an application of the model within a reconstruction of a real accident can be found in the publication by Mayer et al. [40].

Comparable development of a THUMS V4 AM50 representing an obese occupant (BMI 35) was presented by Kitagawa et al. [32]. In the study, the validation of the model against PMHS data was discussed and different methods for post-processing and injury risk evaluation were shown comparing non-obese and obese occupant. The HBM models were applied in a frontal collision and a pole side impact scenario.

A similar approach for an obese model development is also reported by GHBMC [9].

Simulation results and observations

Figure 24 illustrates the overall kinematics of the occupant in the unexpected cut-in manoeuvre leading to a frontal collision.

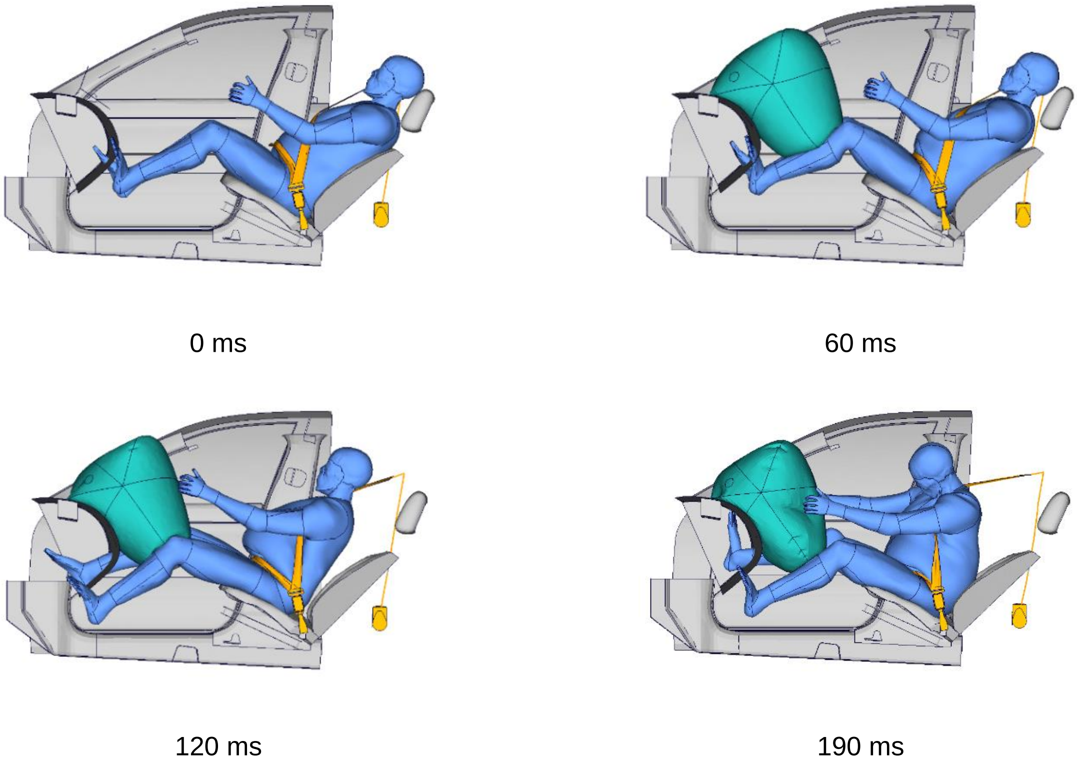


Figure 24 Case 3 - kinematic of obese occupant in frontal load case and moderate resting position

No interaction with the passenger airbag is seen or any head contact is observed. Also, no remarkable risk for rib fractures were seen in the post-processing. On the other hand, high seatbelt contact forces (10.68 kN) are experienced by the occupant at ~130 ms which typically indicates potential rib fracture risks and risk of abdominal and pelvic injuries. It seems that obesity, comparable to similar implications in side collisions, has some kind of beneficial effect in this specific configuration. However, no detailed analysis concerning injury risk in the abdominal region was made due to unanswered questions related to a valid modelling of fat and its characteristics. Further details concerning the validation status of this obese model are reported in the appendix as well.

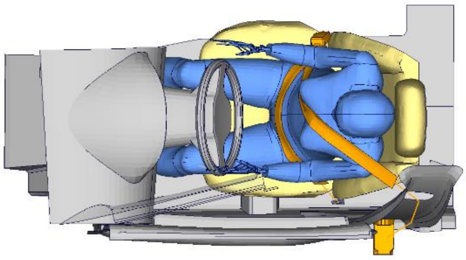
It should also be stated that current simulations consider that the seat structure below the pan as rigid. However, considering weight of the obese passenger the seat structure design would be a challenge and would influence the overall kinematics

Case 4

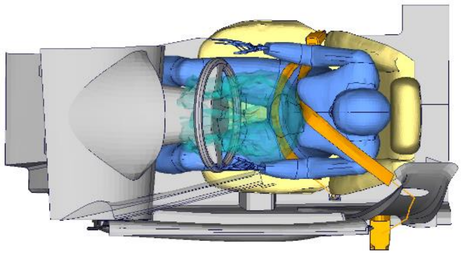
Status of HBM used:

In case 4 another derivative of THUMS-D was used to represent a 5% female with Asian anthropometry. This 5th percentile female of Asian population was developed based on the THUMSD-F05 model using an appropriate geometry scaling method. To ensure the two HBMs have comparable biofidelity, the Asian 5th percentile female HBM was validated against frontal as well as lateral load cases. Scaling factors for the HBM were calculated using the dimensions of the THUMSD-F05 model and that of the Asian 5th percentile female derived from latest China National Institute of Standardization (CNIS) database. Scaling process and a first use case including post-processing and injury risk metric applied was reported by Yang et al. at IRCOBI Asia in 2016 [68].

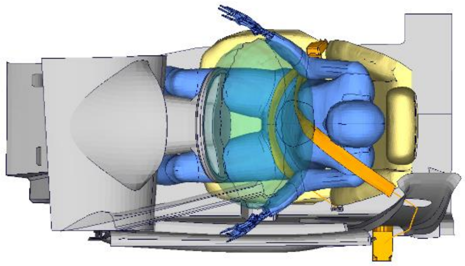
Simulation results and observations



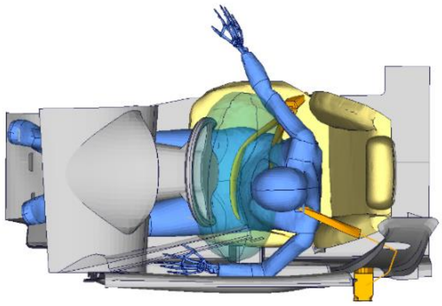
0 ms



20 ms



60 ms



85 ms

Figure 25 Case 4 - kinematic of 5% female with Asian anthropometry in frontal load case

Low head injury risk exists for the Asian female. Risk for rib fractures are observed in the left side (9th & 11th ribs) for the Asian female. No injury risk curve respectively probabilistic method is available for the current model. Hence, also an injury indicator based on max. plastic strain is used for computing the risk. It should be stated that the current Asian female model is well conforming to the anthropometric requirements of the Asian population. However, the material properties are taken from original “Western” model and should be considered for further research and updates to represent also Asian population characteristics. More details related to these body regions can be found in the Appendix 2.

Analysis of injury risk for pelvis and femur are illustrated in Figure 25. This body region was specifically examined due to the fact that the female is sitting closer to the steering wheel and instrument panel. However, in this generic environment no severe contact with the instrument panel was observed. So, no risk of pelvic fracture is predicted in this load case. Plastic strains of approximately 1.7% are observed in the iliac crest which is driven mainly by loading from the seat belt system. Also, no risk of femur fracture is predicted in this load case. As injury indicator for predicting the fracture the Burstein injury indicator of 3% plastic strain is used.

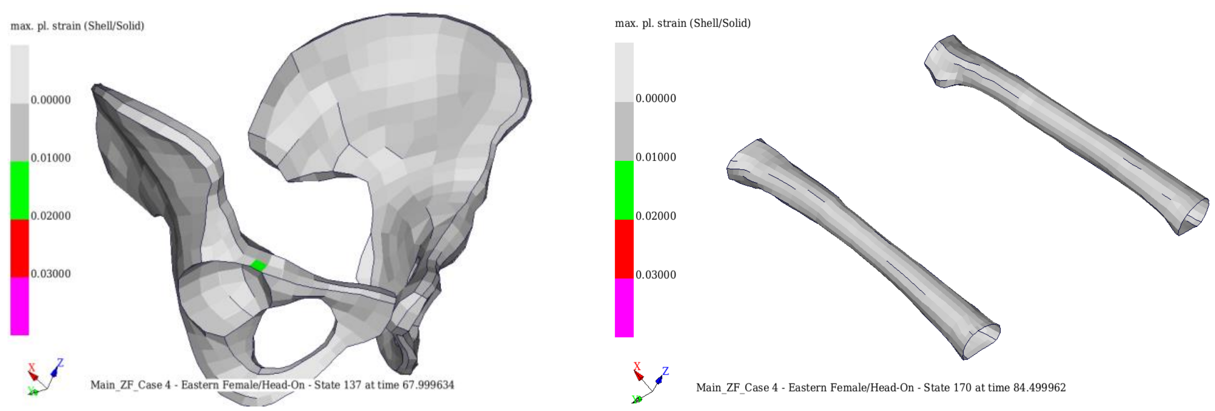


Figure 26 Case 4 - pelvic fracture prediction for Asian female (Burstein Injury predictor, 3% pl. strain) (left); femur fracture prediction for Asian female (Burstein injury predictor, 3% pl. strain) (right)

<u>Case 5</u>

Status of HBM used:

THUMS-D V3.2 was also the basis for the implementation of the SUFEHM and also the SUFEHN. This modified THUMS was now applied within this baseline case 5. The coupling of the Strasbourg University Head Model (SUFEHM) to THUMS-D and its validation was already published in 2009 [23].

This Strasbourg University Finite Element Head Model (SUFEHM), which is a 50th percentile FE model of the adult human head, was developed under Radioss software (Kang et al., 1997) [29] and transferred to LS-DYNA (Deck and Willinger, 2008) [11].

It has to be stated that the SUFEHM is available under three different codes (PAMCRASH/VPS, RADIOSS and LS-DYNA) and that it has been validated against existing experimental head impact data available in the literature in terms of brain pressure, brain deformation and skull fracture under the three codes. The model has been used for extensive real-world head trauma simulation in order to derive model-based head injury criteria for three different injury mechanisms, neurological injuries, subdural hematomas and skull fracture. In order to ensure an easy use of the model, a SUFEHM dedicated IRA-tool (Injury Risk Assessment tool) has been developed. This post-processing tool permits an automatic analysis and risk assessment.

In 2004, Meyer et al. [41] presented a finite element neck model and its original validation and coupled it in 2012 with the existing Strasbourg University Finite Element Head Model and which is referred to as SUFEHN now. Latest development was presented by Meyer et al., 2018 [42].

Several FE Head Models exist and were published in recent years which have some tolerance limits to specific injury criteria: SIMon models developed by NHTSA and Takhounts et al. [61], KTH model developed by Kleiven [33] and WSU model developed by Zhang et al. [71].

Latest applications of the THUMS-D with SUFEHM and as well THUMS-VW with SUFEHM in VPS are also extensively reported in the EU research project SafeEV [13][39][67].

Simulation results and observations

The existing virtual simulation sled model had seatbelts with pre-tensioner and load limiter, and a driver steering wheel airbag. However, for the rear end collision scenario these systems were de-activated. Figure 27 illustrates occupant kinematics during the impact. In the baseline simulation the contact between the head and the b-pillar was de-activated as structural contacts were not in focus. This was also primarily done to capture the complete kinematics of the head neck complex.

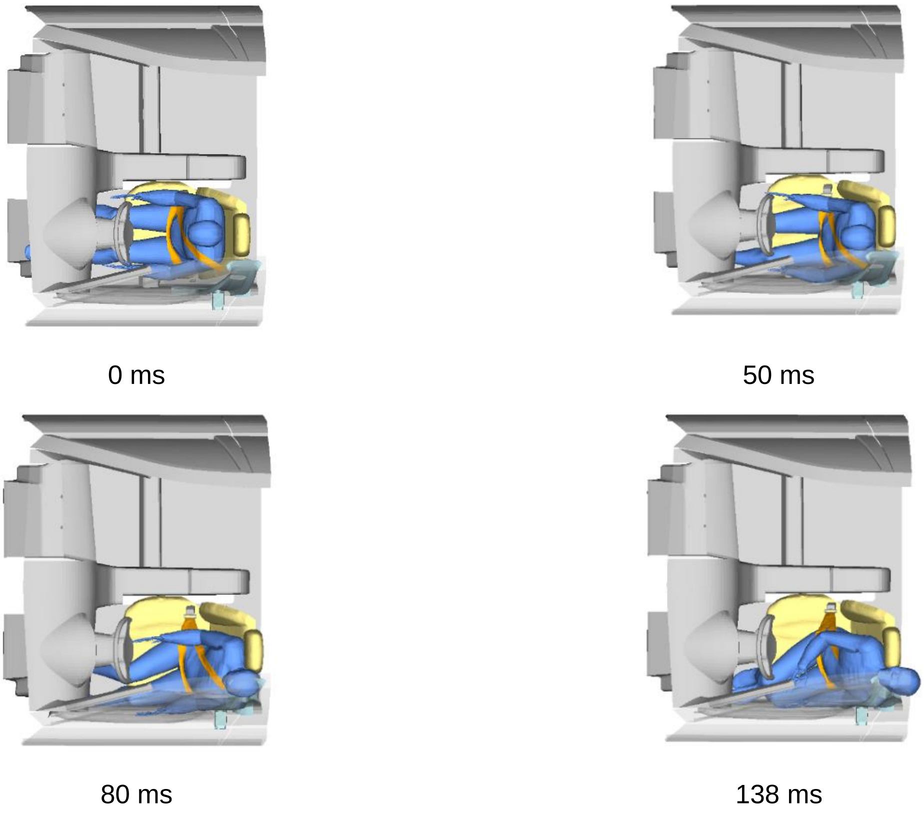


Figure 27 Case 5 - occupant kinematics using THUMS-D-SUFEHN in rear end collision scenario

Head injury assessment is done based on SUFEHM IRA tool. Figure 28 shows the injury risk curves for head. Risk of DAI (neurological injury) is 9.3 % / is low. The injury risk for the head in general is low because of limited interaction with any of the structural components.

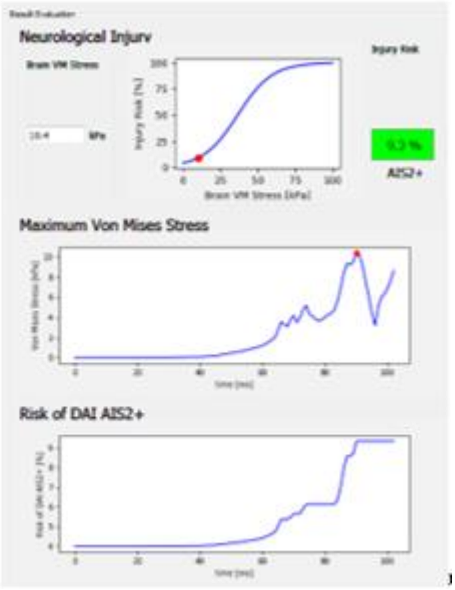
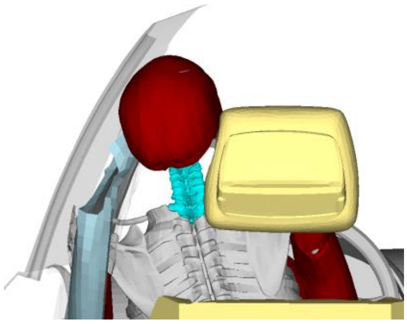
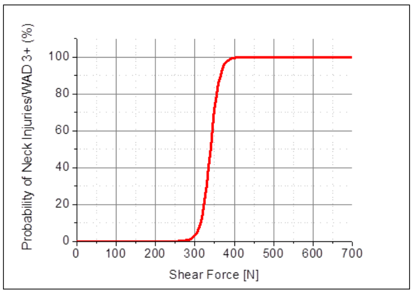


Figure 28 Case 5 - Injury risk evaluation and IRC for head using SUFEHM IRA tool

A risk of neck injury, primarily whiplash injury, was observed in this configuration. This evaluation is based on a peak sheer force of 1.06 kN experienced at Occipital Condyle. Figure 29 illustrates the neck injury evaluation for the occupant. The reason foreseen for the whiplash risk is the absence of head restraint support due to lateral component of the pulse. However, kinematic evaluations also provide further insights that lateral guidance of the seat i.e. the depth of the seat bolsters and belt interaction with the occupant are areas which are influencing occupant kinematics.





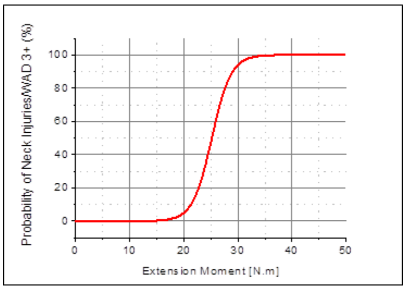


Figure 29 Case 5 - Head-Neck kinematic at 138 ms (left); Injury risk curve for neck shear force and extension moment (right)

3.4 Complete Test Case Matrix

This chapter presents the complete content of the Test Case Matrix. The design of the Test Case Matrix is described in Chapter 3.2, including details on the content of the different dimensions (Chapter 3.2.3). Before providing an example of application, it is deemed valuable to gain an understanding of the amount of combinations possible. This is essential in order to substantiate the need of the Test Case Matrix as the foundation and basis for total representativeness for the selected Test Cases for further studies.

For space reasons, a complete Test Case Matrix cannot be included in this report. Instead, an excel document is available as a project result, and details are provided below enabling creation of a copy. At this stage the Occupant UseCases dimension and the Crash Configurations dimension are included in the Test Case Matrix and represent one axis each in the 2D matrix. Figure 30 shows the sub-headings and the first 12 rows of the Occupant UseCases dimension/axis in the Test Case Matrix. The heading consists of the six different sub-headings as presented in Chapter 3.2.3.1. In the same way, the Crash Configuration consists of combinations of the five sub-headings presented in Chapter 3.2.3.2. In the excel document, each horizontal row of the Occupant UseCases crosses each vertical column of the Crash Configurations.

Seating configuration	Interior feature	Seat position	Sitting posture lateral	Sitting posture z-rotation	Sitting posture sagittal
Traditional seating configuration, single : Pos1	1a) steering wheel	Nominal upright	centralized lateral	centralized rotation	contact to seatback
Traditional seating configuration, single : Pos1	1a) steering wheel	Nominal upright	centralized lateral	centralized rotation	slightly forward
Traditional seating configuration, single : Pos1	1a) steering wheel	Nominal upright	centralized lateral	centralized rotation	further forward
Traditional seating configuration, single : Pos1	1a) steering wheel	Nominal upright	centralized lateral	turned right	contact to seatback
Traditional seating configuration, single : Pos1	1a) steering wheel	Nominal upright	centralized lateral	turned right	slightly forward
Traditional seating configuration, single : Pos1	1a) steering wheel	Nominal upright	centralized lateral	turned right	further forward
Traditional seating configuration, single : Pos1	1a) steering wheel	Nominal upright	centralized lateral	turned left	contact to seatback
Traditional seating configuration, single : Pos1	1a) steering wheel	Nominal upright	centralized lateral	turned left	slightly forward
Traditional seating configuration, single : Pos1	1a) steering wheel	Nominal upright	centralized lateral	turned left	further forward
Traditional seating configuration, single : Pos1	1a) steering wheel	Nominal upright	tilted right	centralized rotation	contact to seatback
Traditional seating configuration, single : Pos1	1a) steering wheel	Nominal upright	tilted right	centralized rotation	slightly forward
Traditional seating configuration, single : Pos1	1a) steering wheel	Nominal upright	tilted right	centralized rotation	further forward

Figure 30 Headings and the first 12 rows of the Occupant UseCases dimension in the Test Case Matrix

The dimension of Occupant UseCases, as presented in this study (Chapter 3.2.3.1), consists of the:

- 26 combinations of individual Seating Configurations, in eight different configurations (Figure 3)
- Five aspects of Interior Features (Table 1)
- Five different Seat Positions (Figure 4)
- Three variants of three variables on Sitting Posture (Figure 5)

Not all combinations are relevant, as exemplified by rear seat position and steering wheel. Figure 31 and Figure 32 provide information on which combinations that are included in the Test Case Matrix for the combinations of seating configuration, interior feature and seat position. All variations of sitting postures are included for all combinations. When combining all the variables in the relevant combinations, it adds up to a total of 7,830 rows.

When using the Test Case Matrix, the Pre-processes, as described in Chapter 3.2.3, form the basis for the applying the filtering of the relevant content of the Matrix. Complete rows of Occupant UseCases can be selected or deleted, applying the Test Case Matrix for the purpose and making it more limited in size.

Seating configuration / Interior Feature	1a) steering wheel	1b) knee support	1c) table	2) lateral structure	3) loose objects
Traditional seating configuration, single : Pos1	x	x	x	x	x
Traditional seating configuration, single : Pos2		x	x	x	x
Traditional seating configuration, single : Pos3		x	x	x	x
Traditional seating configuration, single : Pos4		x	x	x	x
Swivel front seats, single: Pos1	x	x	x	x	x
Swivel front seats, single: Pos2		x	x	x	x
Lateral, single : Pos1				x	x
Lateral, single : Pos2				x	x
Lateral, single : Pos3				x	x
Lateral, single : Pos4				x	x
Lateral, double : Pos1				x	x
Lateral, double : Pos2				x	x
Lateral, double : Pos3				x	x
Lateral, double : Pos4				x	x
Face-2-Face, forward single : Pos3			x	x	x
Face-2-Face, forward single : Pos4			x	x	x
Face-2-Face, rearward single : Pos1			x	x	x
Face-2-Face, rearward single : Pos2			x	x	x
Face-2-Face, double : Pos1			x	x	x
Face-2-Face, double : Pos3			x	x	x
Face-2-Face, double : Pos2			x	x	x
Face-2-Face, double : Pos4			x	x	x
Face-2-Face, swivel, double : Pos1			x	x	x
Face-2-Face, swivel, double : Pos3			x	x	x
Face-2-Face, swivel, double : Pos2			x	x	x
Face-2-Face, swivel, double : Pos4			x	x	x

Figure 31 Combinations of Seating Configurations and Interior Features. "x" indicates inclusion in the Test Case Matrix

Seating Configuration / Seat Position	Nominal upright	Relaxed - seatback only	Relaxed - seatback & seat pan	Relaxed - articulated seatback	Relaxed - seatback, seat pan & legsupport
Traditional seating configuration, single : Pos1	x	x	x	x	x
Traditional seating configuration, single : Pos2	x	x	x	x	x
Traditional seating configuration, single : Pos3	x	x	x	x	x
Traditional seating configuration, single : Pos4	x	x	x	x	x
Swivel front seats, single: Pos1	x	x	x	x	x
Swivel front seats, single: Pos2	x	x	x	x	x
Lateral, single : Pos1	x				
Lateral, single : Pos2	x				
Lateral, single : Pos3	x				
Lateral, single : Pos4	x				
Lateral, double : Pos1	x				
Lateral, double : Pos2	x				
Lateral, double : Pos3	x				
Lateral, double : Pos4	x				
Face-2-Face, forward single : Pos3	x	x	x	x	
Face-2-Face, forward single : Pos4	x	x	x	x	
Face-2-Face, rearward single : Pos1	x	x	x	x	
Face-2-Face, rearward single : Pos2	x	x	x	x	
Face-2-Face, double : Pos1	x	x	x	x	
Face-2-Face, double : Pos3	x	x	x	x	
Face-2-Face, double : Pos2	x	x	x	x	
Face-2-Face, double : Pos4	x	x	x	x	
Face-2-Face, swivel, double : Pos1	x	x	x	x	
Face-2-Face, swivel, double : Pos3	x	x	x	x	
Face-2-Face, swivel, double : Pos2	x	x	x	x	
Face-2-Face, swivel, double : Pos4	x	x	x	x	

Figure 32 Combinations of Seating Configurations and Seat Positions. "x" indicates inclusion in the Test Case Matrix

The dimension of Crash Configurations, as presented in this study (Chapter 3.2.3.2), consists of the:

- Twelve groups of angles for CA_AD (Collision Point Angle of the host), see Table 2
- Twelve groups of angles for CA_opp (Collision Point Angle of the opponent), see Table 2
- Twelve groups of angles for yaw (collision yaw angle), see Table 2
- Three groups of velocities for V_AD (collision Velocities of the host); low, medium and high
- Three groups of velocities for V_opp (collision Velocities of the opponent), low, medium and high

No combination is needed to be excluded in the Test Case Matrix, hence the columns adds up to a total of 15,552. However, when applying the methodology, the numbers are reduced through the methodology OSCCAR WP1 has developed, using real world data to filter out remaining crash configurations. The complete Test Case Matrix then mainly serves as a reference for the total possible content in the Crash Configuration dimension.

Results derived from the work in OSCCAR WP1 or other studies can provide input on frequencies or relative importance. This can be used to grade the different combinations of Test Cases, when applying the Process of Grading, as described in 3.2.4. An example of applying the selection process is presented in Chapter 3.5. The process of identifying/selecting relevant cases differs between the two dimensions. This is mainly because of availability of representative databases for the Crash Configurations dimension input, while other challenges apply for the Occupant UseCases dimension.

For both dimensions, the specific details on e.g. seat recline angle and collision point angles, need to be chosen within the range of the specified grouping. In addition, a crash pulse as well as a pre-crash vehicle kinematics information need to be developed in order to execute the simulations or testing for the Demonstrator Test Cases.

3.5 Applying the Test Case selection and Process of Grading– an example

This chapter contains an example of using the Test Case Matrix together with the Process of Grading. It is important to emphasize that this chapter serves the purpose to provide an example on how to apply the methodology as presented in this report. It does not serve the purpose of identifying all Demonstrator Test Cases that will be addressed in the OSCCAR project. This is still work to be done. One Demonstrator Test Case will be briefly described in 3.5.5.1 and discussed in relation to the grading. This specific example has been selected to be used within the project. An important aspect for that specific Demonstrator Test Case is the feasibility to execute it as physical crash testing, especially important for OSCCAR WP4 and WP5.

The chapter will exemplify the process of using the Test Case Matrix, including the Pre-pre- and Pre-processes (as presented in Chapter 3.2.3.) and the Process of Grading (Chapter 3.2.4.), referring to some available input data (Chapter 3.3.) to derive an example of a Demonstrator Test Cases.

First, the context of the car and the environment needs to be defined; including ODD. The context is defining the Pre-processes, whereby the Test Case Matrix can be reduced in size before identifying combinations to be used addressing the research questions in demand.

For this example, a fully autonomous vehicle with a Seating Configuration “Face-2-Face”, as illustrated in Figure 33 was chosen. Typically, it will take passengers for a shorter ride within urban areas such as large cities but also going back and forth to the airport, or similar. Hence, it will operate in mixed traffic in cities and on highways. The car is equipped with four seats; two facing the rear and two facing the front. The forward-facing seats allow for some adjustments in seat back angle, while the rearward facing seats do not. None of the seats can be rotated, nor are equipped with leg supports. There is no table between the passengers and the use of carry-on devices is likely limited to small hand held devices (e.g. phones). This description encompasses the Pre-pre and the Pre-processes. If the research question or study requires, this can be made in a more detailed and structured matter, enabling a precise and quantifiable description of the limitations of the specific study.

Figure 33 Illustration of the vehicle for applying the Test Case selection process

3.5.1 Occupant UseCases dimension

For the content of the Occupant UseCases dimension, the four areas of the structure are affected as follows:

Three of the eight Seating Configurations shown in Figure 3 are applicable. Hence, all of the lines in the Test Case Matrix dimension of Occupant UseCases related to the ‘Traditional seating configuration’, ‘Lateral’, ‘Face-2-Face, swivel’ and ‘Swivel front seat configuration’ can be excluded.

Among the Interior Features, ‘Restriction in front of occupant’ are excluded, except for Table (1c). ‘Restriction on the side of the occupant’ depends on the combination of the other Occupant UseCases and the Crash Configurations. ‘Loose objects’ are limited to small objects only.

Two of the five Seat Positions, shown in Figure 4 are applicable. ‘Nominal upright’ seat position is valid together with all combinations of the applicable seating configurations, while ‘relaxed – seat back’ in the three combinations of ‘seatback only’, ‘seatback & seat pan’ and ‘articulated seatback’ are only applicable for the front facing seats.

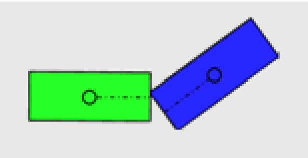
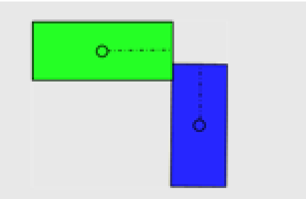
All Sitting Postures, as illustrated in Figure 5, are applicable although the range of variations are likely relatively low in this type of application.

When excluding the non-applicable rows for the context of this example, the rows in the Occupant UseCases dimension reduce from 7,830 to 2,430.

3.5.2 Crash Configurations dimension

As the car will operate mainly in mixed traffic in urban areas, two relevant crash configurations are selected from the remaining intersection crash scenarios, as presented in the OSCCAR Report D1.1 [44]. The two selected crash configuration example cases are described below and summarized in Table 5.

Table 5 Two selected crash configuration example cases. Host vehicle to the left (green)

Case No.	Visualization	CA_AD (°)	CA_opp (°)	yaw (°)	Cluster share	V_AD (km/h)	V_opp (km/h)
1		5	-20	-144	25%	46	19
2		-19	29	89	13%	53	29

Case 1 is a frontal oblique impact. The intersection simulation study for the German data includes a high number of opponent vehicle turning into the vehicle path, so called left-turn across path opposite direction (LT-OD) accidents. When the host vehicle is simulated to brake, it results in an about 35° oblique impact condition. The collision velocities for the host vehicle and the opponent are 46 km/h and 19 km/h, respectively. The overall cluster size is rather large with a representation of 25% among all LT-OD cases.

Case 2 is a frontal edge impact. The second example targets to select a crash configuration that appears with high relevance in the intersection simulation studies in both German and Swedish data and to select a complement to case 1, providing an additional relevant example for applying the process of grading. The selected crash configuration is an edge collision at the right front corner, very close to the vehicle front edge of the host vehicle. This case includes higher speed values as compared to case 1.

3.5.3 Individual Occupant Variations dimension

As stated previously in the report, the structure of the dimension of Individual Occupant Variations is less defined as compared the other two dimensions. It is very much dependent on the availability and capabilities of the human tools, whereby it also will change over time. No Pre-process was applied to this dimension in this example.

3.5.4 Grading of selected Test Cases

To illustrate the Process of Grading, some examples of Test Cases are selected based on the matrix content remaining after applying the Pre-process on the Occupant UseCases as described in Chapter 3.5.1., and using the selected Crash Configurations example cases as described in Chapter 3.5.2. The examples ae only chosen with the purpose of illustrating a span of differences within the scope of the example. No effort is made to justify the choice in any other way.

Table 6 High-level description of the ten selected Test Cases in the example of applying the Process of Grading

Case	Occupant UseCase				Crash Configuration		
	Seating configuration	Seat position	Sitting posture	Interior feature	Type	Severity	Pre-crash manoeuvre
A	F2F, **forward** facing, alone	upright	upright	no	Front-oblique	moderate	No
B	F2F, **forward** facing, alone	reclined	upright	no	Front-oblique	moderate	No
C	F2F, **forward** facing, alone	upright	upright	table	Front-oblique	moderate	No
D	F2F, **forward** facing, **facing other occupant**	upright	upright	no	Front-oblique	moderate	No
E	F2F, **rear** facing, alone	upright	upright	no	Front-oblique	moderate	No
F	F2F, **rear** facing, alone	upright	bending forward	no	Front-oblique	moderate	No
G	F2F, **rear** facing, **facing other occupant**	upright	upright	Devices in laps (both)	Front-oblique	moderate	No
H	F2F, **forward** facing, alone	upright	upright	no	Front edge	high	No
I	F2F, **forward** facing, **facing other occupant**	upright	upright	no	Front edge	high	No
J	F2F, **rear** facing, alone	upright	upright	no	Front edge	high	No

A total of ten Test Cases were chosen for applying the Process of Grading, being a reasonable number with the purpose of this report on demonstrating the process. There are no limitations in the methodology in the numbers of cases. No specific methodology was used when selecting these cases; rather changing some parameters staying within the overall context of the car and the described scenario. The ten selected Test Cases are summarized in Table 6, and the grading of the cases are shown in Table 7 and

Table 8. The Occupant UseCases and Crash Configurations are scored separately, as well as provided a total scoring, in which also the weight factors per Evaluation Criteria, as presented in

Table 3, is included. The scoring was done solely from an illustrational purpose. No emphasize should be put on the absolute scorings in this example.

Table 7 Grading of the selected Test Cases A-E in the example of applying the Process of Grading. UC=Occupant UseCases, CC= Crash Configurations

Evaluation Criteria	A			B			C			D			E		
	UC	CC	Tot	UC	CC	Tot	UC	CC	Tot	UC	CC	Tot	UC	CC	Tot
1. Novelty	5	5	1.0	10	5	1.5	5	5	1.0	5	5	1.0	0	5	0.5
2. Severity / Challenging	5	10	4.5	10	10	6.0	5	10	4.5	10	10	6.0	5	10	4.5
3. Relevance / expected by end user	10	10	6.0	5	10	4.5	5	10	4.5	5	10	4.5	5	10	4.5
4. Urgency	5	5	1.0	5	5	1.0	5	5	1.0	5	5	1.0	5	5	1.0
5. Highlight benefit of OSCCAR approach	5	5	2.0	10	5	3.0	10	5	3.0	10	5	3.0	5	5	3.0
Total			**14.5**			**16.0**			**14.0**			**15.5**			**13.5**
Readiness			y			y			y			y			y

Table 8 Grading of the selected Test Cases F-J in the example of applying the Process of Grading. UC=Occupant UseCases, CC= Crash Configurations

Evaluation Criteria	F			G			H			I			J		
	UC	CC	Tot	UC	CC	Tot	UC	CC	Tot	UC	CC	Tot	UC	CC	Tot
1. Novelty	5	5	1.0	10	5	1.5	5	0	0.0	5	0	0.0	0	0	0.0
2. Severity / Challenging	10	10	6.0	10	10	6.0	5	10	4.5	10	10	4.5	5	10	4.5
3. Relevance / expected by end user	5	10	4.5	5	10	4.5	10	10	6.0	5	10	6.0	5	10	6.0
4. Urgency	5	5	1.0	5	5	1.0	5	5	1.0	5	5	1.0	5	5	1.0
5. Highlight benefit of OSCCAR approach	10	5	3.0	10	5	3.0	5	0	0.0	10	0	0.0	5	0	0.0
Total			**15.5**			**16.0**			**11.5**			**11.5**			**11.5**
Readiness			n			y			y			y			y

In Table 7 and Table 8 it can be seen that within the same crash configuration (cases A-G) the grading is rather similar. This is likely due to that the selected context is quite restricted with respect to variations in Occupant UseCases related aspects. Reclined seat (case B), facing other occupant (case D) and loose-objects (case G) increased scoring, while a table (case C) lowered somewhat. Compared to the forward facing, the rear facing cases were judged relatively lower, mainly due to lower scores in Novelty and Complexity. Although the forward bended rear facing occupant was the only one disqualified due to Readiness, several of the other cases are likely on the border line, especially considering the Crash Configuration being oblique.

3.5.5 Demonstrator Test Cases

Demonstrator Test Cases are the platform for which research questions can be tested. Research questions could include; e.g. investigating the human body models' capability of distinguishing changes in protection principles, identifying gaps in the human body models used, including the validation data or injury mechanism and criteria research, in addition to investigating the capabilities of the existing hardware tools. This report supports the creation of this, by providing a structured process of identifying, selecting and motivating the choice of Test Cases to serve as Demonstrator Test Cases within the project.

For the OSCCAR project, the Demonstrator Test Cases serve several purposes. One of the purposes is to investigate whether a Test Case can be used by several tools and methods, such as hardware testing versus virtual simulations, as well as applied by different partners using different versions and programs for virtual testing. The overall purpose of this is to understand a whole tool chain evaluation. The Demonstrator Test Case presented in Chapter 3.5.5.1. serves this purpose. It was chosen to include this specific Demonstrator Test Case in the report as the example, because it was the only one decided on at the time of the report to be finalized. Additional Demonstrator Test Cases are to be included during the course of the project.

Another purpose within OSCCAR is to investigate new protection principles in selected Demonstrator Test Cases, i.e. new Occupant UseCases in combination with relevant Crash Configurations. The research questions address mainly the understanding whether the tools available are capable, and what refinements are needed in order to capture important interactions enabling development of protection. The development of protection systems is not in the scope of OSCCAR, hence the focus is on recreating humanlike kinematics, interactions, in addition to capabilities of injury prediction of relevant potential injury mechanisms. The Demonstrator Test Case as described in Chapter 3.5.5.1. is an example chosen based on the context illustrated in Figure 33. One of the main reasons for selecting it was to assume the challenge with respect to investigation of protection principles.

Within a Demonstrator Test Case, variations of several parameters will be made, targeting the purpose of investigating protection principles. Through the project, additional Demonstrator Test Cases, based on a variety of contexts, will be added for this purpose.

3.5.5.1 An example of a Demonstrator Test Case

As an example, one Demonstrator Test Case is presented briefly below. The choice of this Demonstrator Test Case was partly restricted by the need to be possible to be recreated in a physical test environment. The reason for this is to contribute to the 'whole chain evaluation', including multiple modes of simulation and testing.

The key research question addressed in this example of Demonstrator Test Case is: *"How to capture and evaluate the challenges when restraining an occupant sitting forward facing in the 'Face-2-Face' position in a frontal oblique crash?"*

The purpose is to address this research question using the defined Demonstrator Test Case applied in different methods, including physical testing and virtual testing in different codes and by different project partners. The expected results are identified gaps regarding tools and methods, in addition to demonstrating the feasibility of a whole tool chain approach. Within the research question, parameters could be varied to provide enhanced insights. Examples of such variations are: crash pulse variations, seat belt designs (geometries and characteristics), seat characteristics, seat back angles, leg, feet and/or knee supports. When using simulations, variations on occupant characteristics should preferably be included, referring to the third axis of the Test Case Matrix, namely the Individual Human Variations dimension.

This Demonstrator Test Case is the Case A as presented in Table 6 and graded in Table 7. In the scoring it was given a total of 14.5, which in comparison to the other graded cases is relatively low. Still it is judged as complex compared to current legal and consumer rating test cases. Being able to recreate in physical testing is a prerequisite for this Demonstrator Test Case, while it influences the Evaluation Criteria of ‘Related to OSCCAR goal’ negatively.

The overall context of this selected Demonstrator Test Case is ODD of L4/L5 vehicle types in urban crossings. The crash configuration is taken from urban crossings scenarios. The selected crash configuration is frontal oblique. The occupant in focus is the rear passenger facing forward, see illustrations in Figure 34.

Figure 34 Illustrations for the Demonstrator Test Case for whole tool chain evaluation

Before physical testing can be performed, additional details are needed to be decided on, including crash pulse, potential pre-crash kinematics, seat design, vehicle interior geometries, restraint systems used during testing etc. This will be sorted out in OSCCAR Task T2.4. For the virtual simulations, the varieties will be defined in OSCCAR Task T2.3.

3.6 Discussions

Demonstrator Test Cases are the platform for which research questions can be tested. Research questions could include: understanding evaluation of protection principles, identifying gaps in the HBMs used, including the validation data or injury mechanism and criteria research, and investigating the capabilities of the existing hardware tools. This report supports the creation of this, by providing a structured methodology of identifying, selecting, visualising and motivating the choice of Demonstrator Test Cases.

In the OSCCAR project, the Demonstrator Test Cases serve two main purposes; understanding the whole tool chain and investigating evaluation of protection principles. The focus is on the tools and methods. For the whole tool chain purpose, hardware testing is combined with virtual simulations. In addition, the understanding of whether the tools available are capable is included, in addition to what refinements are needed to capture important interactions enabling evaluation of protection. The Demonstrator Test Case presented in Chapter 3.5.5.1. serves both purposes. In the OSCCAR project, it will be used in a sled test rig using ATDs in Task T2.4, and in simulations using different types of HBMs in Task T2.3. Other Demonstrator Test Cases will be chosen during the project's progress, both within the context as explored in the example in Chapter 3.5., as well as other context of ODD etc.

The methodology developed in this study is designed to work in a large context. It is not limited to any level of automation or type of vehicle but made as generic as possible to allow for a large range of future contexts, as well as applicable for today's context. The Pre-pre- and Pre-processes will help to limit the Test Case Matrix, making it more efficient to use, although still providing clear track on how the selected sub-set relates to the whole context. This is likely one of the main benefits of the overall methodology. Another one is that even if a selection of content and categories for the Occupant UseCases and Crash configurations dimensions is made in this report, this can easily be changed to accommodate the needs in future developments.

Describing the combinations of the three dimensions of the Test Case Matrix is a challenge. The main outcome of this report is a proposal for a structured way of classifying, structuring, prioritising and matching these inherently independent but interacting dimensions. This serves several purposes: providing an overview and setting chosen Test Cases into a larger context, in addition to helping in selection of specific Test Cases to be further investigated. The Pre-pre- and Pre-processes enabling exclusions of some combinations, is likely helpful to keep the Test Case Matrix feasible to work with, still keeping the larger context.

The primary purpose for the Process for Grading is to help motivate the different Demonstrator Test Cases that will be further investigated within the OSCCAR project. The grading as presented in this report was only to demonstrate this part of the methodology. In the example provided in this report, no quality assured method determining the rating was used, hence the rating assigned should not be used as reference. When applying the Process of Grading, an agreed method using a well-defined and agreed rating scheme is encouraged.

The methodology contains detailed specification on the Occupant UseCases and the Crash Configurations dimensions, while less details on the dimension of Individual Human Variations. For the scope of this report and the next steps in the OSCCAR project, this was deemed sufficient. The input on Crash Configurations provided to this report, was early results from WP1, which in parallel is creating methods for predicting future accident scenarios. This work is further described in the OSCCAR report D1.1 [44]. In this early project phase (up until milestone 4, for D1.1), this activity is done with focus on timing rather than on methodological refinement with regard to weighting, sampling or statistical tests that have been proposed to account for e.g. modelling assumptions, simulation differences or data weaknesses. The OSCCAR project takes this into account by continuing the work on the Test Case selecting method and its components by updating the Test Case Matrix based on improved scenario models.

Refinement of the dimension of Individual Human Variations could be a next step, also following the advancement of the HBMs. Nevertheless, the Baseline study has given a first insight into this dimension. The main purpose of the Baseline study is to further qualify virtual testing and related tools, namely HBMs. The aspect of individual human variation, or in other words population heterogeneity, is essential in the future and might also deem different needs in different parts of the world. Hence, the Individual Human Variation dimension should be understood as flexible in the perspective when defining human use cases but be as precise as possible when formulating prerequisites and evaluation criteria. The baseline simulation study consequently gave an overview of some existing state-of-the-art (FE) HBM and of today’s pre- and post-processing including evaluation criteria. It became obvious, even though models from one partner were used only, that harmonization and development of model independent criteria for injury risk evaluation are crucial. The Baseline study simulation setups also already tried to address moderate non-standard occupant configurations and demonstrated a kind of intermediate step (e.g. ADAS effect to define the conflict scenarios) towards the projected OSCCAR HAV use cases. It became clear, especially with the use of HBMs, that when leaving “standard” configurations occupant kinematics might be “outside” the restraint capability of state-of-the-art safety systems (please keep in mind, that generic not optimized systems were applied) and also new body regions have to be considered in terms of injury risk evaluation.

Although a grouping process was pre-applied, the Test Case Matrix resulted in a numerous combinations of Occupant UseCases. Especially, restrictions were made in the area of the Sitting Posture, excluding e.g. details on leg and arm positions. In addition, further combinations of Seating Configurations, and the occupancies including more combinations of occupants potentially interacting with each other during a crash, could be included. Even though these restrictions, the proposed content of the Occupant UseCases dimension adds up to a total of 7,830 combination in this report. It is important to emphasize that the Test Case Matrix is primarily a methodology and should be adjusted for the specific needs when applying it. For the same reason, the Pre-pre- and Pre-processes form important parts of the methodology, providing a structured way of dealing with the data. Noteworthy, the process of reducing number of combinations is different for the Crash Configurations. The process shown in Figure 12 is used for that reduction and needs to be referred to when putting the Crash Configurations into a total context.

Occupant UseCases to be further investigated were identified by reviewing the literature, in addition to new user studies. Two user studies were performed within the project, addressing participants’ attitudes regarding different seat rotations on the one hand and seat positions, especially regarding the backrest angle, sitting postures and activities on the other hand. The studies provided information on, firstly, users’ preferences of different seat rotations in a setting limited to the perception of the vehicle’s dynamics, indicating that people under the given testing specifications preferred left-hand rotations over right-hand rotations when seated on the right side of the vehicle. Secondly, the user study on sitting postures was able to limit the set of different sitting postures and activities in various use cases. With these insights, justified statements can be made towards the probability of certain sitting postures in a simulated automated driving situation as carried out in this user study and therefore facilitates limiting the relevant Test Cases for further research. Next steps will assess, on the one hand, the influence of different settings such as social interaction on the acceptance and perception of different seat rotations. On the other hand, additional research regarding sitting postures and activities includes verifying the obtained results and transferring them to various vehicle concepts, including e.g. different seat configurations, use cases and settings.

4 DISSEMINATION, EXPLOITATION AND STANDARDISATION

The work presented in this report is intended to be shared through all possible dissemination channels, including publications and presentations on the project in general, workshops and training courses. Specifically, the user studies performed within this task are planned to be presented at conferences, in journal publications and part of a PhD thesis.

Further, the methodology of the Test Case Matrix and the process of grading has already been investigated by the industrial partners in the project, to understand how it can help in the product development and enabling to bring potential products to the market as well as potential patents.

Being novel of its kind, it will also be encouraged to be used by a wider community and contributing to future standards and guideline developments.

5 CONCLUSIONS

A methodology was developed, combining specifications on Crash Configurations, Occupant UseCases and Individual Human Variations, which can be used for selecting and motivating a Demonstrator Test Case for investigating occupant protection principles. A Process of Grading was developed and applied to a selected context of Operational Design Domain. The purpose of the example was to present hands-on work with the developed methodology. In addition, one Demonstrator Test Case, which is selected to be used within OSCCAR for whole tool chain evaluation for investigating protection principles, is briefly presented. Other Demonstrator Test Cases will follow through the project.

Available information from published studies, in addition to studies performed within the project, is summarized. Two user studies were performed to investigate aspects of new seating configurations and seat positions in future cars. In addition, a Baseline simulation study on the performance of state-of-the art HBMs was executed, providing information on the current limits of HBMs in five different test set-ups.

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APPENDIX 1 – LITERATURE REVIEW

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The objective of this document is to summarize the previous projects and studies that will be used as a literature review within the **OSCCAR T2.1 Definition of test cases.**

The focus of the literature review is on:

- Use cases
- Driving mode
- Occupant :
    - Seating position
    - Comfort
    - Behaviour
    - Tasks and side tasks
    - Carry-on devices
    - Safety systems
- Workshop organization

In the following sections many studies and publications about different aspects of vehicle occupant's behaviour and necessities are summarized and organized.

The aim is to understand and finally define the most relevant use cases of autonomous vehicles regarding the inside seating configurations.

1 PAPERS AND PUBLICATIONS LITERATURE REVIEW

Following the ideas of how user cases should be described, different papers, publications and projects regarding the different key topics have been read. The papers and publications literature studied are presented in the following pages.

1.1 Use cases

A use case is a written description of how users will perform tasks, in this case regarding the occupants of autonomous vehicles. Meanwhile, the autonomous vehicles have been classified in different levels of autonomy or use cases according to their driving characteristics. These characteristics substantially determine the vehicle users' behaviour and side activities to be engaged while riding. Therefore, it is crucial to take them into account when defining the occupants' user needs, activities and behaviours during automated driving and to define the use cases of the occupants of the autonomous vehicles.

Five levels of automation were described by ERTRAC [10] some time ago. Levels 0, 1 and 2 are manual driving vehicles with some devices that help the driving experience in level 1 and that allow to be not constantly engaged in driver actions but monitoring the driving environment in level 2. Levels 3, 4 and 5, described below, are considered autonomous vehicles:

- **SAE Level 3:** The driver's task is to determine when activation of the automated driving system is appropriate and to take over upon request within a limited period of time. The driver may also request deactivation of the automated driving system.

The system monitors the driving environment when activated; permits activation only under conditions (use cases and operational design domain) for which it was designed; executes longitudinal (accelerating/braking) and lateral (steering) portions of the dynamic driving task when activated; deactivates only after requesting the driver to take-over with a sufficient lead time; may − under certain, limited circumstances − transition to minimal risk condition if the human driver does not take over; and may momentarily delay deactivation when immediate human takeover could compromise safety

  - <u>Remark 1</u>: For Level 3 systems, with the driver providing the ultimate fallback performance, he/she must be in position to resume control within a short period of time when a takeover request occurs. This may happen with an increased lead time, but the driver must react. Therefore, only secondary tasks with appropriate reaction time are allowed. This would in an extreme case exclude e.g. sleeping. Driver activation monitoring might be used to avoid such unintended use. Potential technical solutions range from detecting the driver's manual operations to monitoring cameras to detecting the driver's head position and eyelid movement.
  - <u>Remark 2:</u> To enable predictable and reproducible takeover scenarios it would be beneficial if vehicle displays that are controlled by the automation system were used for secondary tasks (e.g. texting, internet surfing, video-telephony). If a takeover request occurs the secondary task content on the display is faded out and the takeover request is displayed instead.
  - <u>Remark 3:</u> The driver is not capable of reacting to emergency braking manoeuvres of the vehicle in front of the driver due to secondary tasks. Such scenarios must be accomplished by the system.

- **SAE Level 4: The driver's task is to determine when activation of the automated driving** system is appropriate, and to take over upon request within lead time. The driver may also request deactivation of automated driving system

  The system monitors the driving environment when activated, permits activation only under conditions (use cases and operational design domain) for which it was designed, and executes longitudinal (accelerating, braking) and lateral (steering) portions of the dynamic driving task as well as OEDR when activated.

  It also initiates deactivation when design conditions are no longer met e.g. requests driver to take over and initiates deactivation to reach a minimal risk condition if driver does not respond to the takeover request fully deactivates only after human driver takes over or minimal risk condition is achieved; transitions to minimal risk condition if human driver does not take over, and may momentarily delay deactivation when immediate human takeover could compromise safety

  - Remark: Level 4 systems do not require the driver to provide fallback performance. Therefore, the system must be capable of transferring the vehicle to a minimal risk condition within the operational design domain. This might increase technical effort.

- **SAE Level 5**: The driver may activate the automated driving system and may request deactivation of the automated driving system.

  When activated, the system monitors the driving environment, executes longitudinal (accelerating/ braking) and lateral (steering) as well as the OEDR subtasks of the dynamic driving task, deactivates only after the human driver takes over or vehicle reaches its destination, transitions to a minimal risk condition as necessary if failure in the automated driving system occurs, and may momentarily delay deactivation when immediate human driver takeover could compromise safety

  - Remark 1: Level 5 systems can complete any on-road journey from origin to destination without the help of a human driver. Consequently, typical driver controls are not required in an extreme scenario (no steering wheel, pedals or instrument cluster). Completely new vehicle designs or even completely new classes of vehicles are possible.
  - Remark 2: In a theoretical analysis of vehicle automation, Level 5 systems must be considered because they complete the automation scale. Such systems are not in the focus of AdaptIVe because it is unlikely that they will be available as a product in the foreseeable future

Beside of the vehicle's automation levels, Fraedrich [12] defined different uses cases.

- **Use case 1: Highway Pilot**

  On interstates or interstate-like expressways the driving task can be transferred to the vehicle. During that time, the driver does not have to monitor traffic or driving and can pursue other activities.

  The main benefits for users is supposed to be the relief of tasks that are often regarded as stressful (monotonous driving over longer time periods, traffic jams or road work scenarios with exhausting braking and acceleration tasks) [7] and the possibility of spending time in a different way – one that is potentially perceived as more worthwhile. In view of its immediate technical feasibility, Highway Pilot will in all likelihood be the "inevitable" next step on the path to autonomous driving. In its foreseen application – journeys lengthy in both time and distance.

- **Use case 2: Parking Pilot**

  After all passengers get out, the vehicle can drive autonomously to a pre-defined parking spot and return from there too

  The possibility to get out of the vehicle at a desired destination and let the vehicle park itself could significantly help to ease time and parking pressure that especially occur in areas where space for private parking is limited, cost-intensive and also frequently combined with long walking-distances to and from parking locations. The function would facilitate transporting children and cargo and make the use of cars easier for people with mobility constraints. Parking search traffic could be minimized substantially with positive effects on inner-city traffic and reduction of travel-time. Then again, additional trips could originate from empty routes of vehicles, thus leading to more traffic and potentially counterbalancing the before-mentioned effect. This use case could also lead to significant changes in car ownership rates as such vehicles could be privately owned but might also be owned by a carsharing provider or similar business model [41].

- **Use case 3: Fully Automated Vehicle**

  On demand, the driving can be transferred to the vehicle. During that time, the driver does not have to monitor traffic or driving and can pursue other activities

  From an individual perspective, increased safety, and travel-time spent in worthwhile ways might be perceived benefits of this use case. This could especially apply for commuters, who could spend their on-board time more productively or more meaningfully. Impacts on the transport system and on land use could be tremendous. If travel-time is perceived more positively, people could tend to accept longer commuting distances, live in the suburbs, or in more remote, rural areas, while working in the city [8] [17]. Moreover, decreasing inhibition thresholds for inexperienced, insecure or elderly drivers could lead to an increase in car use and ownership rates as well as to a decline in the use of public transport modes [5] [11] depending, however, on regulations on requirements for drivers' licenses, which makes it difficult overall to predict the developments.

- **Use case 4: Vehicle on Demand**

  A Vehicle on Demand is a motor vehicle that can transport its passengers without any driver. Humans cannot drive manually; therefore, such a vehicle does not have a steering wheel or pedals anymore

  Vehicle on Demand could provide seamless use of transport means, therefore likely increasing multimodal travel behaviour. At the same time, however, it could serve as a rival to public transport, increasing VMT and car use dramatically [11] [43]. This use case implies large-scale changes in the user experience as well as in travel behaviour and in the overall transport system as it allows for individual and flexible mobility. Vehicle on Demand is expected to bring car ownership rates down drastically and lead to a tremendous increase in carsharing with significant impacts on land use, e.g. in inner-city areas, where parking space could be freed for alternative use as well as to transform individual and public transport systems as we currently know them [12] [30] [38].

1.2 Requests and user activities

Besides of the impact and importance of the level of automation and the automation use case described above, is necessary to understand the user requirements, necessities and behaviours to define the most likely occupants use cases. To do so, several studies and surveys have been analysed.

An open survey was performed [13] to explore how people associate the technology of an automated vehicle and a vehicle on demand. The top 5 positive values for an autonomous vehicle were: comfortable, good safe relaxing and modern, which describes how people hope or expect it will be. The top five positive values of a vehicle on demand were useful comfortable, relaxing, modern and safe. However, the number of “no idea” answers for the vehicle on demand was 51% which indicates that most of the interviewed population cannot imagine this concept nor know what to expect.

According to this study, assessments and evaluation rating of autonomous driving were not overwhelmingly positive. Figure 1 shows the results for questions addressing the perception of autonomous vehicles. Their summed percentage values lie in a range between 15 and 45.

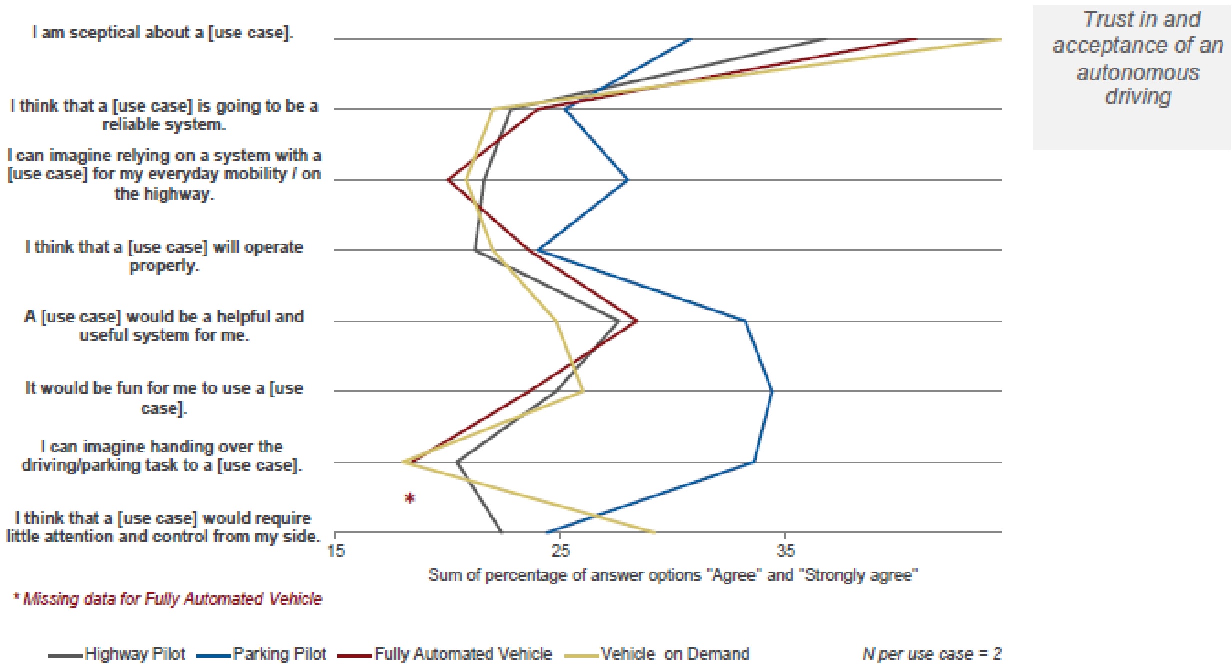


Figure 1 Attitude towards different use cases of autonomous driving [13].

They saw that Parking Pilot is widely accepted. This rests largely on the particular benefit seen as coming with this vehicle-automation function: less stress, less time spent parking, more comfort.

Highway Pilot is actually seen as helpful by a large share of the respondents. Expectations of filling time gained via automation with alternative activities, even merely conversing with others in the vehicle, are particularly low compared to other use cases, however. It is possibly understood as more of a support than an autonomous system, an assumption backed up by the rather limited trust Highway Pilot enjoys. Its acceptance thus only increases when it comes to particular usage scenarios. There is a notably high level of willingness to replace currently preferred transport modes among respondents who have high demands for time-saving. Respondents who already use driver-assist systems are also noticeably willing to use Highway Pilot.

The respondents view Fully-Automated Vehicle and Vehicle on Demand as being very similar in many respects. That the idea of being on the road in a self-driving car is actually catching on can be seen in the high degree of approval of filling freed-up time with alternative activities. Fully Automated Vehicle is seen as particularly useful for longer trips, even more so than Highway Pilot.

The user evaluations of Vehicle on Demand are accompanied with pronounced doubts as to the safety of such a vehicle, even when its comfort, usefulness and potential cost benefits are stressed.

Vehicle on Demand is the use case in which direct, driver-initiated "steering" is no longer an option and the difficulty of actually imagining oneself using this system is apparently connected with fears of the new technology, ultimately leading to a comparably high level of rejection

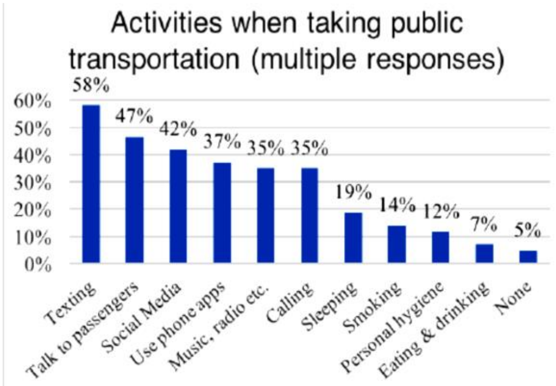
Also, the study of [40] agrees with the previous statement that autonomous driving is not very well evaluated. The study included responses from 3,255 adults in the U.S. and five other countries (China, India, Japan, the U.K., and Australia) and the observed results said that between a 3% (China) and a 33% (Japan) of the population would not ride an autonomous vehicle.

To address user activities in autonomous driving, first of all it is interesting to know how they spend their mobility time nowadays in different situations.

In [13] it can be seen that when contemplating the potential for productive time use, the low share of people that actually currently work while riding on trains or in public transport is remarkable: 77 % of respondents say they never work during public transport trips. On long-distance train trips, this share is down to 69 %, contrasted by 6 % of the interviewees often or always working on the go. Sociodemographic factors had a statistically significant effect on the answers – especially the variables gender, income, education level, household size, and the presence of children in the household [8]. These findings correspond well with the work of Gardner and Abraham, who reported that "[…] participants tended to neglect the potential for journey time to be used productively […]" on commuting activities [14].

Another survey was performed [34] and studied the subway (U-Bahn in and around Munich) passenger activities under observation, and the suburban trains (S-Bahn in and around Munich) passenger activities by an in-situ survey (43 people). Both transport modes are very similar, having both outside and subway route parts and usually both used for short and middle distances. In the in-situ survey (multiple choices) the passengers said that their activities were basically using the phone texting (58%), social media use (42%) phone apps (37%); calling (35%) and music or radio listening (35%). Other activities are talking with other passengers, sleeping, smoking, personal hygiene and eating. However, when observing the subway passenger, the most frequent activity (18,5%) is "do nothing" followed by reading, talking with passengers, looking out of the window, phone activities, eating, playing, watching videos and sleeping, see Figure 2 and Figure 3.

If we consider comparable both transport modes, which in fact are very similar, the differences observed in the results may be due to the way the information was obtained (observed or interview). It can be observed that people interviewed said that they usually were interacting with the phone or talking, however it was observed that most people were doing nothing while travelling. Therefore, it can be concluded that people usually say that they are more active than they really are.



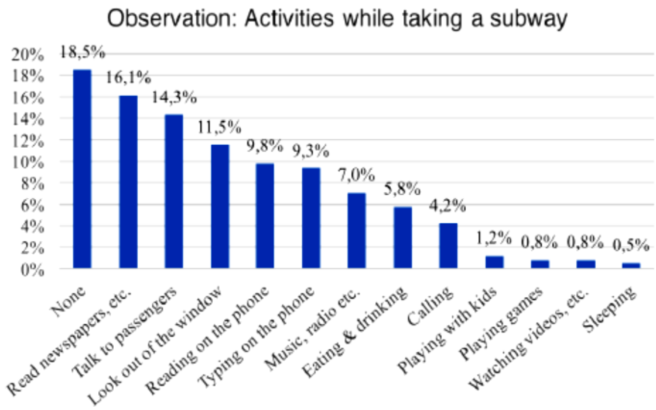


Figure 2 Interviews in suburban trains: activities the participants perform in public transport, from Pleging et al. 2016 [34]

Figure 3 Contextual observations: passenger activities subway rides, from Pleging et al. 2016 [34]

Within the study [3] user activities in public transport while travelling were studied by observation. First, on two different bus trips in Gothenburg (around 10min trip), 99 people were observed. Most of them were looking through the window (60%), and the others were interacting with the phone (20%), using headphones, talking with others or other activities. Secondly people were observed while travelling by train. There people usually were interacting with the phone (around 35%), drinking, wearing headphones, interacting with others, using the computer, eating or knitting. It is clear that interacting with the phone is a very important activity while travelling. It can also be seen that on train trip (a long and high-speed trip of 3h from Gothenburg to Stockholm) nearly everybody was seated while on the bus trip (short trip of 10min.) only around 70% of the people was seated even if there were a 60% of spare seats. The differences observed are manly linked with the trip and the transport mode characteristics. On long trips people are more likely to be seated, but carrying out an activity (interacting with phone, with others or with a computer or eating and drinking) while on short trips, most of the people were looking out of the window and many of them are not taking a seat, see Figures 4 and 5.

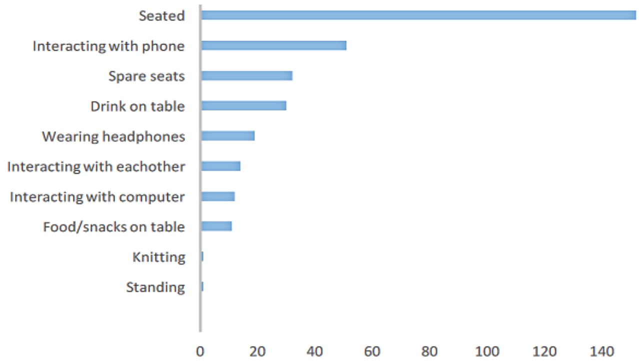


Figure 4 Bus passenger activities (10 minutes), from Bengtsson 2017 [3]

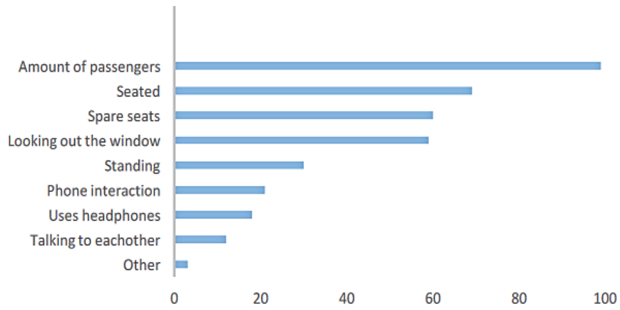


Figure 5 Train traveller activities (3h), from Bengtsson 2017 [3]

Fraedrich et al. (2016) address various aspects of how people spend 'mobility time' analysing several survey results to different transport modes users [13]. First, the respondents were asked in which activities they were generally engaged while traveling by car, local public transport, or train. Activities conducted by car users naturally and not surprisingly, focusing on the ride and the route is the main activity reported while driving a car. Driving is often accompanied by listening to music or chatting with other passengers: around 80 % of car drivers stated they often or always listen to music and the corresponding shares for chatting are about two-thirds (62 %). Also, more than half (56 %) of the respondents reported always or often enjoying the ride and the scenery. Already now, the car is used at least sometimes as a mobile office by 7 % of the car drivers – potentially by means of making phone calls. However, over 90 % stated never working while driving a car. Social networking, such as using the phone, mailing or sending text messages, was similarly uncommon with over 80 % of the survey participants reporting never doing it. By far the most mentioned activity pursued often or always in public transport and long-distance trains is enjoying the landscape and the journey (50 % for public transport, 66 % on trains), closely followed by conversations with fellow travellers (43 % and 49 %). Two-thirds of the train users report frequently or always enjoying the view, for public transport users this share is down to 50 %. Almost half of the train users reported always or often conversing. Generally, their findings seem very in line with those reported by Lyons et al. (2007) [31]. In their study on the activities conducted by British rail users, window gazing was also – especially on short trips – the most mentioned activity on train trips. Listening to music, reading or relaxing is another oft-mentioned activity, especially on train trips. Interestingly high are the shares of people stating they often or always concentrate on the trip – in both variants of mass transportation by almost 40 %. The low share of our survey respondents stating that they use the time for social networking purposes is also noticeable (Figure 6).

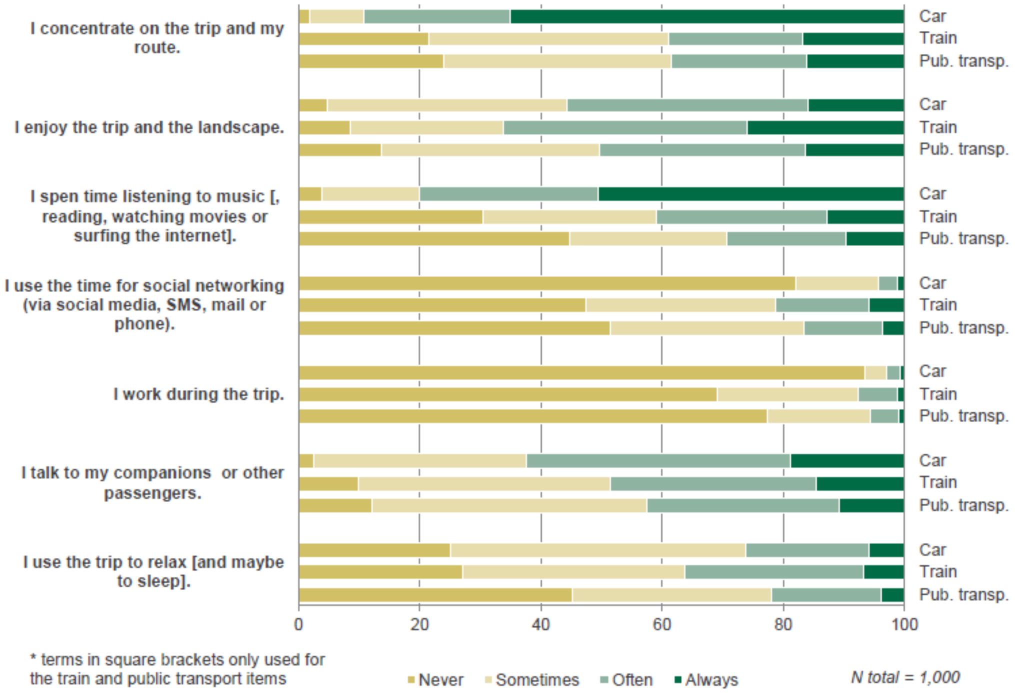


Figure 6 Survey about the activities performed by travellers in cars, trains, or public transport, from Fraedrich et al. 2016 [13].

Observing this survey graph and comparing those three trip modes. As we could see in the previous graph, in public transport - usually short trips - people are less often engaged in activities. In train - usually long trips - people are looking out the window, relaxed and use the time for social network but also, they use to work more often than in the other transport modes. In the car, people are more often concentrate in the route and talking or listening music, which can be done while driving, many say that they relax and sleep they are less involved in social media or working than in the other transport modes, which could be because they are the driver. Analysing the characteristics of those transport modes it could be said that:

- Public transport travellers don't have time, space or don't feel comfortable to carry out many activities.
- Train travellers are calmer and more relaxed, probably because it is an outside route (not subway), they have more space, and they are also influenced by a more stable journey (less accelerations and decelerations) and because they are usually longer trips.
- On car trips travellers are relaxed and enjoying the trip, which may be because they feel comfortable but also due to route characteristics such as longitude and stability.

It is difficult to summarize and put together all the information obtained in these studies, since they have been performed under very different conditions, methods and objectives. However, it is interesting to realize which activities have been asked the most and which are usually the most likely carried out. To evaluate this, we have defined a list of common activities and we have rated each of them regarding their ranking in each of the previously commented surveys. We can see in the following graph the importance of each activity currently carried out by travellers (Figure 7).

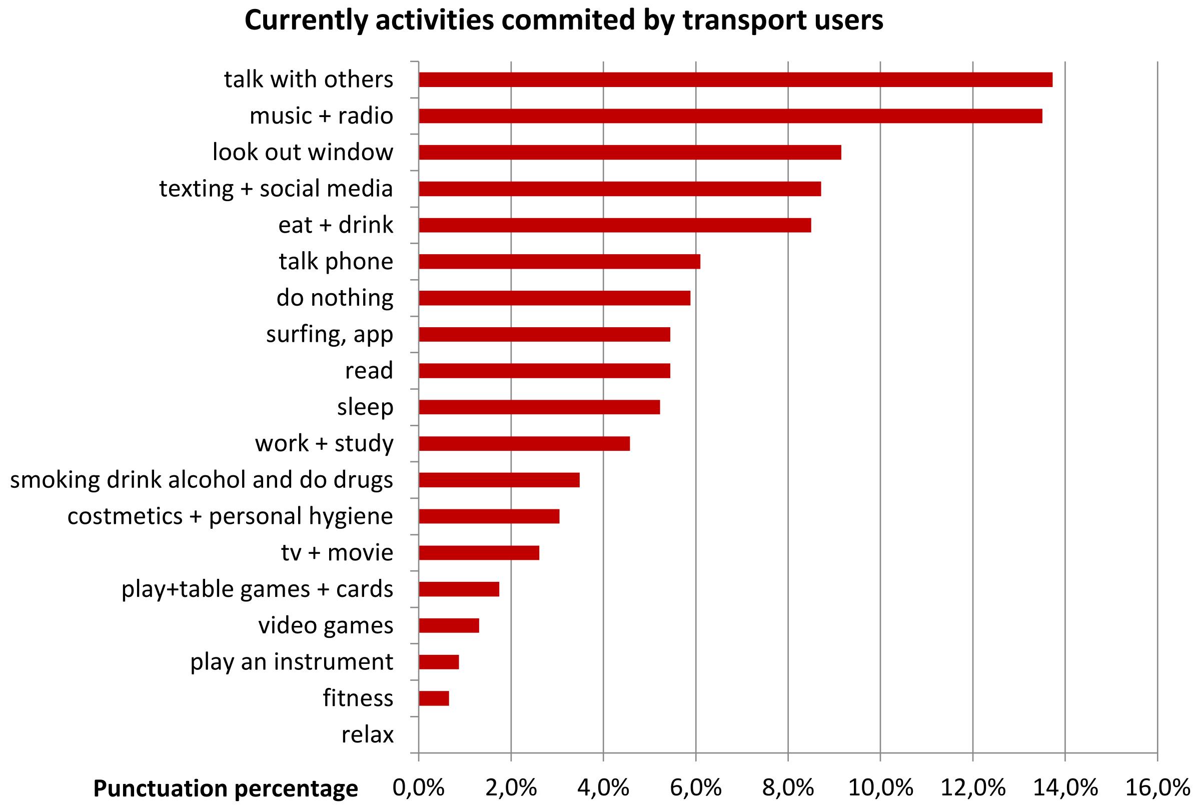


Figure 7 The most usual activities performed by people while travelling

Activities rating: First, the activities of each of the previous survey studies have been associated with one of the listed activities (Figure 8). Secondly, we rated each activity regarding its ranking in the original surveys –for each survey, the activity that has been the most carried out by transport users received 15 points, the second activity most carried out received 14 points and so on. Thirdly, we have added up all the points received for each activity and calculated a rating percentage. Finally, we have created a new activity ranking.

When we analyse the literature, it is important to understand the effect on the results of the way the information has been obtained – survey or observation. This point would indicate the differences between what people wish to carry out during their travel time and what they are actually do. Following the same method of activities rating as in the previous graph, we have compared the studies about the most common activities currently carried out, regarding whether they were a survey or an observation (following graph). The conclusion is that in general people answer with more active activities than can be observed.

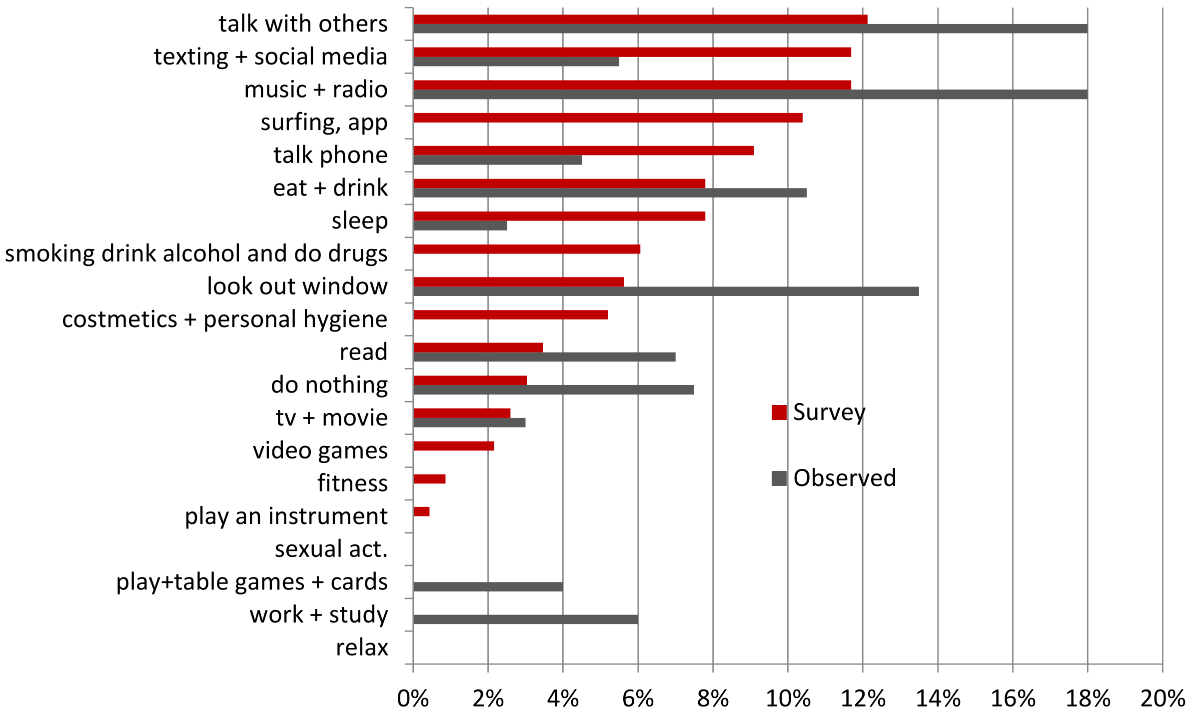


Figure 8 Comparison between the observed and answered in survey of the most currently most usual activities performed on journeys.

Also, it is interesting to understand the effect of the transport mode characteristics on the activities performed. These characteristics, which can be summarized in time and comfort characteristics, are:

- Length of the journey
- Sharing space or living space
- Seating places, seating position, seat characteristics
- Noise
- Exterior or subway journey
- Stability or speed, accelerations and brakes

The above surveys suggested that long journeys, calm and comfort motivate people to focus on longer and more complex activities.

Thereafter, literature studies about the most likely activities that users would carry out in an automated driving car have been analysed. This is a combination of their wishes and hopes for a future situation based on their expectations on future autonomous vehicles' characteristics.

The study presented by Sivak and Schoettle (2015) which included responses from 3,255 adults in the U.S. and five other countries (China, India, Japan, the U.K., and Australia) show that the activities most likely to be performed - for those who would ride in an autonomous car - are: watching the road (between 33% and a 47%) followed by reading texting or talking, sleeping, watching TV or movies, working, playing games and others [40]

961 US drivers were asked regarding the more likely activities that they would conduct in self-driving vehicles in the study [6]. Many of the responders answered that they would be more likely to eat (48%) followed by read messages (45%), write messages (43%), access the internet (36%), take pictures (36%), record videos (26%) watch a movie (21%) and finally read a book (19%)

An internet survey [2] of 2.000 drivers about the most likely activities done in a self-driving car. Drivers rated with a 5 the most likely activity and with a 1 the less likely ones. The most likely activity (rated with a 2.9) of this survey was read a book followed (with a 2.8) by talk by phone with family and friends. This survey asked about less usual question in this kind of surveys like: engage in sexual activities, pry or do drugs which were rated with a 1.6, 1.5 and 1.2 respectively.

Within the project by Bengtsson (2017) a survey on the preferred activities that passengers would do in an autonomous vehicle was performed [3]. One survey was performed to a target group which is the first people willing to buy an autonomous vehicle - usually risk taken, educated, independent and innovation people - in Stena Centre a hub for creative entrepreneurs located in Gothenburg, Sweden. For them, the most preferred activity would be work (15 out of 18 people in a multiple choice) followed by listening to music, watching TV or movies, reading, sleeping or relaxing, eating, surfing or playing videogames. Another survey done at Creative Loops also in Gothenburg, asked how people would spend their time in an autonomous vehicle if they travelled 2h a day. Most of the people answered work/study in the first place, followed by surf the web, eat and sleep/relax. Other selected activities were productive home activities (such as cooking or laundry), listening to music, playing music, reading, watching TV, looking through the window putting on makeup, socializing or working out (Figures 9 and 10).

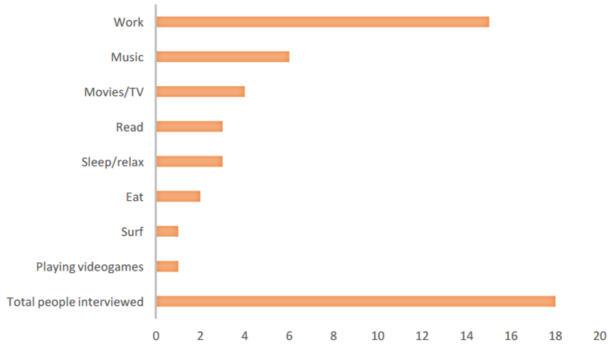


Figure 9 preferred commuting activities in an autonomous vehicle according to target group, from Bengtsson 2017 [3].

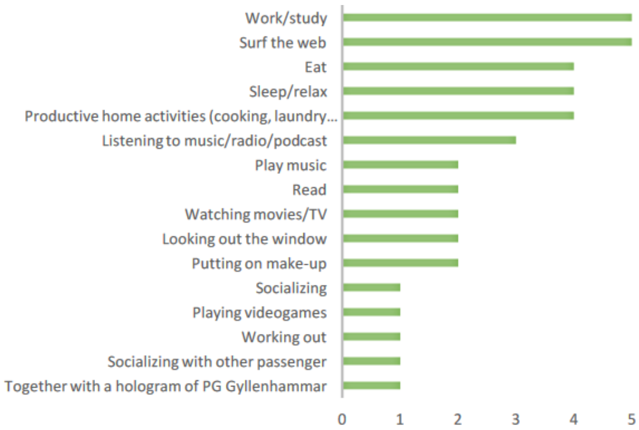


Figure 10 "How would you spend your time in an autonomous car if you spent 2 hours every day commuting to your job?", from Bengtsson 2017 [3].

Jorlöv et al. (2017) asked 52 vehicle users, between 11 to 63 years old, what would they do in an autonomous vehicle in a long and a short trip [19]. The answer for the long trip were: watch a movie, play board games and videogames, socializing, eat, read, look out through the window, surf and work. The activities most likely considered on a short trip were: surf, sleep, loop out, read, work, eat and watch a movie or play the guitar. So, during long trips people are more likely to carry out longer activities such as watching a movie, playing a game or eating while on short trips people usually choose to surf the internet, look out the window, talk on phone and rest.

In the study by Fraedrich et al. (2016), the respondents were asked what advantages they would perceive in using a vehicle from one of the four use cases previously presented [13]. It is worth noting that a large proportion of respondents did not expect to use their time in an autonomous car with activities like surfing the internet, watching movies or social networking. Working enjoyed the least reception among all options of activities to be done while travelling in a self-driving car. When asked if they perceive the option to work as an advantage of autonomous driving the highest disagreement

(52 %) came for the case of Highway Pilot; for Vehicle on Demand the corresponding rate was 30%. At the same time, 17 % of participants felt that working while travelling in a Vehicle on Demand would be a good option for them. For Fully Automated Vehicle, the corresponding share amounted to 13 %. With the little attraction the possibility of working in the car seemed to hold for the users interviewed, the findings of this study clearly differ from the results of a German survey conducted by Autoscout24 (2012). Here, almost a third of the respondents wished for the opportunity to use their car as a mobile office. Answering options were given parallel to the ones provided for current time use. The differences in answering patterns between the uses case are significant for social networking and highly significant for all other answering options. An exception is the opportunity to talk – here, no statistically significant differences exist between the three use cases

Kyriakidis et al. (2015) performed a wider survey with more than 4 thousand people form 40 countries (with at least 25 respondents) [27]. They asked the vehicle users what activities they would be most likely to do if they were to engage in secondary tasks for different driving modes – manual, partially automated, highly automated, fully automated. It can be observed that people are more likely to engage in side tasks in fully automated vehicles, then with higher automated vehicles, less people would do it in partially automated vehicles and even less in manual vehicles, except listening to radio - which would be done by nearly all of the users in any automated driving mode. However, some activities - such as reading, emailing, watching a movie or resting - would mainly be done in a fully and highly automated vehicle. Apart from listening to the radio, the most likely activity to do in a fully automated vehicle are eating, observing, phoning and interacting with passengers followed by mailing, watching movies, reading and resting (Figure 11).

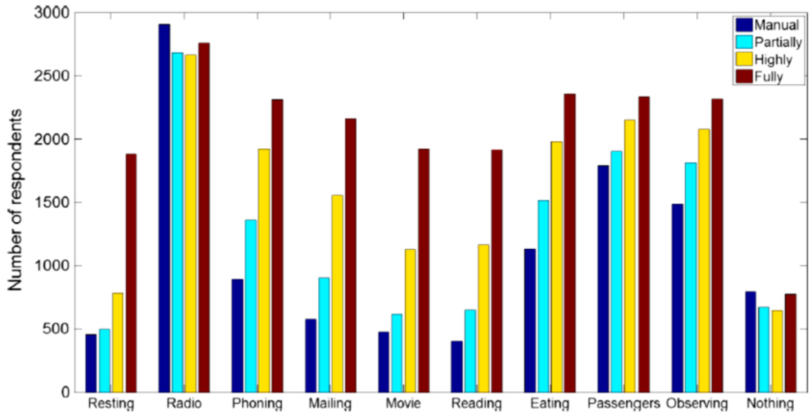


Figure 11 Number of respondents who indicated that they would engage in secondary tasks for different driving modes. People could select multiple secondary tasks per question in a checkbox question, from Kyriakidis et al. (2015) [27].

Gaydoul (2018) performed an online survey in five countries; China, USA, Japan, Germany and France, with a total of 2.5000 participants [15]. It was arranged in such a way that a representative distribution of demographic characteristics such as age and income structure, place of residence or household size was given. The first part of the study was focused on the use done by students who answered: sleep and rest 46,5%; work 36.4% eat and drink 38.2% entertainment 39.8% and wellness & fitness 23.2% (Figure 12). According to this study, the prospect of impending changes in the transportation system promises high demand for mobility solutions with autonomous vehicles and customer-oriented services on the supply side. The sharing of vehicles is the biggest lever to sustainably reduce traffic and parking problems. Intelligent network autonomous vehicles can become an integral part of intermodal transport systems in smart cities, both for individual transport and for transport logistics. In addition, new business models and services will be created by autonomous mobility services such as Mototaxis. In the second part of the survey, it was asked the use of the automated vehicle with 1 passenger, or 2+ passengers. If the type of use is considered for two or more persons, then food and drink and entertainment outstrip the one-person preferred use, namely sleep and rest or work. The results observed also give an idea of the importance of sharing the space with other people in occupant's activities and behaviour.

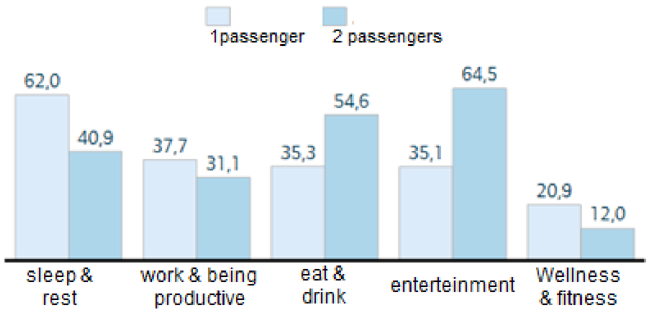


Figure 12 Percentage of people engaged in different activates while travelling in a share vehicle with 1 o 2+ people, from Gaydoul (2018) [15].

It is difficult to summarize and put together all the information obtained in these studies. However, it is interesting to realize which activities have been asked the most and which are usually more likely to be carried out. To evaluate this, we have defined a list of common activities and we have rated each of them regarding their ranking in each of the previously commented surveys. In the following graph we can see the importance of each of the likely activities to be carried out in autonomous vehicles (Figure 13).

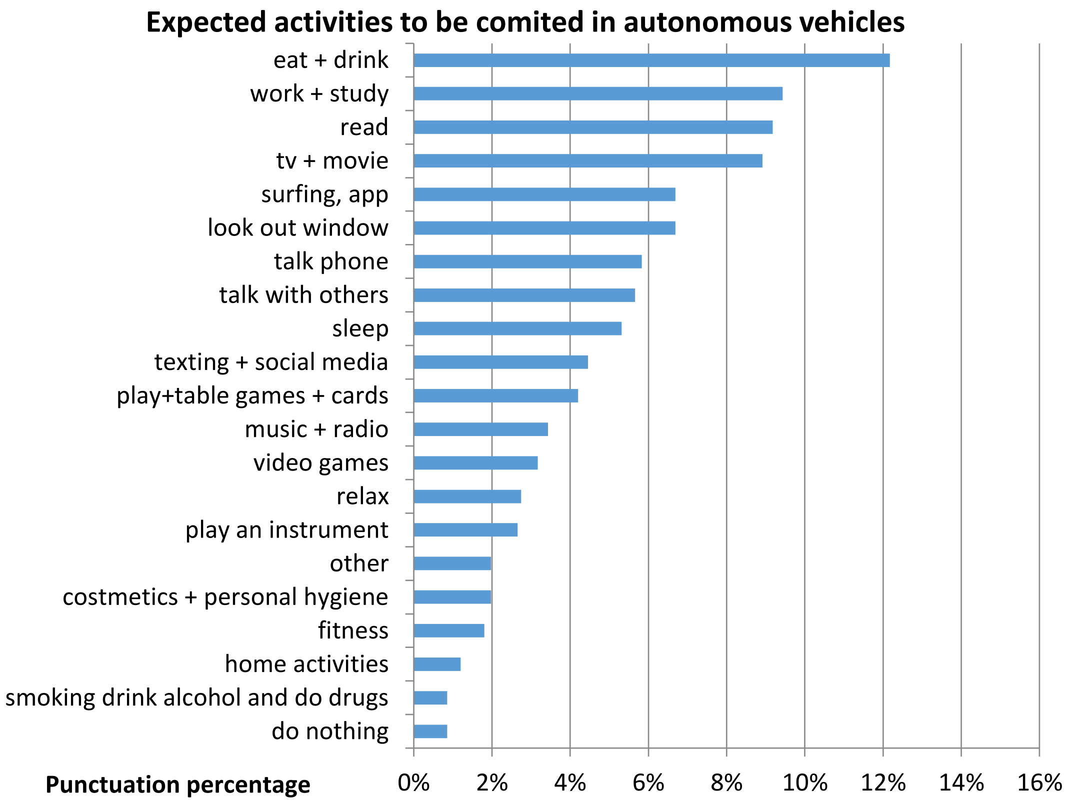


Figure 13 Expected activities to be performed by occupants in autonomous vehicles

It should be considered that many of the listed activities are using the phone and that also a big part of them can be considered as entertainment. If we pool the corresponding activities into more general ones, “entertainment” has more importance and may be in the first place of the desired activities to be carried out in an autonomous vehicle (Figure 14).

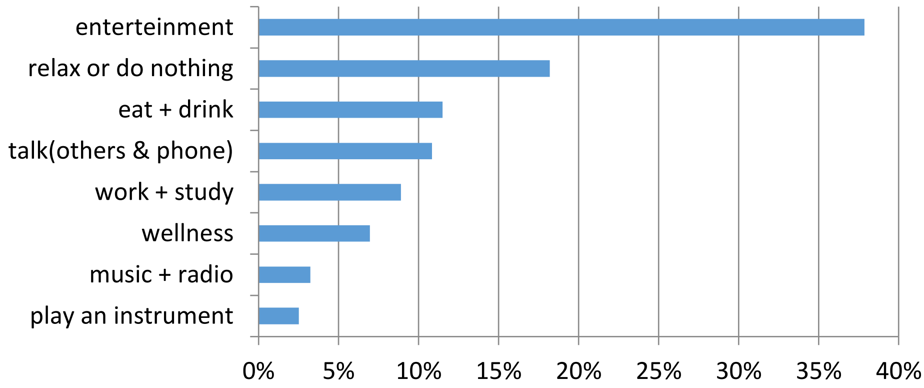


Figure 14 Simplified activities to be performed by occupants in autonomous vehicles

The current activities and the desired ones in the future autonomous vehicles are also related with their needs. In the following lines studies about the vehicle occupant’s requirements have been summarized.

According to Fraedrich et al (2016) behaviour and mobility related needs are not stable categories but rather subject to constant change, thus related to cognitions and emotions, or on a societal level, thus embedded in social dynamics and societal change [13]. Mobility decisions are an assemblage of rational and irrational, conscious and unconscious aspects, of learned behaviour, and approved, long-lasting routines (see, for example [8] [38]). This project conducted univariate analyses, restricting the explanatory power of mobility related needs in conjunction with autonomous driving to understand the important vehicle characteristics or specific needs. The most important point for an automated vehicle is safety followed by independence, costs, freedom from stress, time, comfort, eco friendliness, driving experience and, considered as utmost unimportance, social status.

In Bengtsson (2017) four main necessities of occupants in autonomous vehicles are defined [3]. They observed that eating and drinking are frequent activities among train passengers depending on travel time, but the autonomous vehicle will, unlike the train, still drive through curves and it will perform lots of acceleration and deceleration and therefore the demand for stability will increase. Moreover, if passengers increase their time doing things other than watching the road, the risk of motion sickness will increase. As this need is not expressed overtly by the user, it is defined as an unspoken wish Moreover, looking at the needs of car buyers today, seat related features were among the most important factors which indicate the weight of comfort. The high demand for power seats (79% of respondents) indicates that customization is essential. The demand for leather seats (58%) or heated seats (70%) can be neglected neither.

Having the requirements sorted after weight, it is defined that providing stability is the most important requirement as it is both defined as an unspoken wish and a key function for a lot of other requirements. Providing different positions for active use, entertainment and work are all related to providing customization. Providing spaciousness and a clear outside view are both solved by minimizing or hiding component. These four needs are provided: stability; customization; (active, entertainment, working position); spaciousness and a clear outside view; green status.

The survey performed in [2] also asked about the elements inside of a self-driving would they wish to have. The most chose option was to have the same design (31.6%), but when they think about new devices options they would like to have in a first place a refrigerator (even though eating was only the 6th most likely activity reported) followed by beds (sleeping was the 8th most likely action), then table and chairs (14.7%), a lounge, a fully stocked bar and finally a massage table (2.9%).

First of all, when we analyse the literature it is important to understand the effect on the results of the way the information has been obtained – survey or observation. The conclusion is that in general people usually answer with more active activities than can be observed

It can also be observed that there are many aspects that effect vehicle users' activities. It is necessary to take into account the comfort and trip length - Length of the journey, sharing space or living space, seating characteristics, noise, exterior or subway journey, accelerations and brakes – but also the driving mode – high automated, fully automated, vehicle on demand with 1 person or vehicle on demand with 2 + people. In conclusion, people are usually more active when the environment is more calmed and they feel more comfortable – less people, seating places, long trips.

In a study by Pleging et al. (2016) the activities that passenger carry out currently in cars and public transports were compared with the expected activities they would carry out during a highly automated car ride [34]. The survey had 300 participants and was a combination of a web, in-situ survey in suburban trains and in situ observations in subway. The top 3 current activities reported were looking out the window, texting and listening to music or radio, which 50%of the population defined as very frequent. In the survey about the expected activities, it can be observed an increase (more than 15%) of the interviewed people that consider as very frequent the activities in an automated vehicle: talking to the other passengers, listening to music and calling. They also consider that they frequently surf internet, sleep and eat in autonomous vehicles.

Different results have been observed between the likely activities performed currently in a journey and the ones expected in the future autonomous vehicle. In fact is should be taken into account that many of the current activities listed have been observed in public transports – which have different transport characteristics than cars- and also, expected activities are based on the wishes and hopes of the autonomous vehicle characteristics – which may not be the real ones. In order to see these facts we have compared the expected activities with the currently performed in Figure 15, following the same rating criteria as for Figure 7. In conclusion we see that people in an automated vehicle would tend to be more engaged in entertainment, eat and drink or working activities.

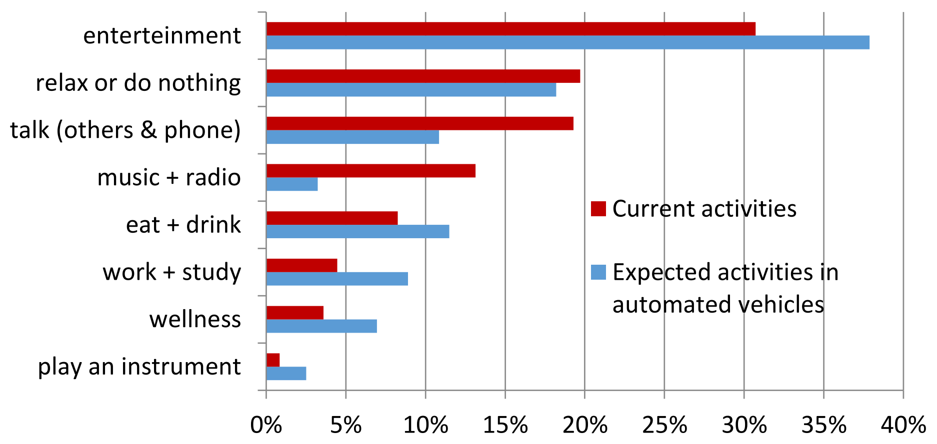


Figure 15 Comparison between the user activities in current journeys and the expected to be performed in autonomous vehicles

The user necessities are: safety, tame safe, comfort, eco friendliness, stability; spaciousness and a clear outside view, with gut design and customization options - active, entertainment and working positions, refrigerator, bed, table and lounge furniture options.

1.3 Motion sickness

In the previous points it can be seen that users of autonomous vehicles would be more active while travelling. This, according to some studies, could generate some inconvenience to the passengers. According to an article by Lazzaro (2015) having predicted that users of an autonomous car will be more active compared to travelling in a conventional car, users will increase their risk of being motion sick [28]. Therefore, literature information has been analysed and summarized below.

Sivak and Schoettle (2015) [40] report that, motion sickness it is most frequently caused by a conflict between visual and vestibular inputs, loss of control over one's movements and reduced ability to anticipate the direction of movement [16][36] are also important in the of motion sickness. Motion sickness is more frequently experienced by vehicle passengers than by drivers, who rarely experience motion sickness [35].

Alternative activities on critical functions influence the frequency and severity of motion sickness. In the study by Sivak and Schoettle (2015) activities were classified [40]. Negative sign indicates a worsening of motion sickness, and a positive sign indicates an improvement (Table 1).

Alternative activity while riding in a self-driving vehicle	Critical factor		
	Conflict between vestibular and visual input	Ability to anticipate the direction of movement	Control over the direction of movement
Watching the road	+	+	-
Reading	-	-	-
Sleeping	+	-	-
Texting	-	-	-
Talking on the phone	depends on the direction of gaze	depends on the direction of gaze	-
Watching movies/TV	- especially for downward gaze	- especially for downward gaze	-
Working	- especially for downward gaze	- especially for downward gaze	-
Playing games	- especially for downward gaze	- especially for downward gaze	-

Table 1 Activities while riding a self- driving vehicle, from Sivak and Schoettle (2015) [40].

The prediction of motion sickness or ride comfort of vehicles is important to create comfortable vehicle motion. According to Wada and Kamij (2015) [42], the sensory rearrangement theory postulated that motion sickness is provoked by accumulation of the conflict between sensory information from the vestibular system and the estimated sensory information from an internal model [35]. It is known that the driver tilts his/her head toward the curve direction when curve driving, whereas the passengers' head movement is likely to occur in the opposite direction. Thus, the effect of the head tilt strategy on motion sickness was investigated in the project by Wada and Kamij (2015), by the proposed mathematical model. The head movements of drivers and passengers were measured in slalom driving. Then, the model of motion sickness incidence (MSI) of the drivers and that of the passengers predicted by the proposed model were compared. The results revealed that the estimated MSI of the driver was smaller than that of the passenger. It was suggested that the driver's head movement toward the centripetal direction has the effect of reducing motion sickness.

This result suggested that that the severity of the MSI of the passengers can be reduced by the passengers tilting their head toward the centripetal direction, as is done by the drivers

To reduce the motion sickness in autonomous vehicles, some solutions has been suggested.

According to Wada and Kamij (2015) [42], since autonomous car users may start experiencing discomfort at lower rates of acceleration, it is plausible that occupants of an autonomously-operating vehicle may wish to instruct their vehicle to manoeuvre in a way that provides them greater ride comfort – softer manoeuvres, less accelerations and decelerations. It could be a possible option to reduce motion sickness, however, on the basis of traffic microsimulation analysis studied in this project, it was found that restricting the dynamics of autonomous cars to softer acceleration/deceleration characteristics leads to reductions in a signalized intersection's vehicle-processing capacity and increases in delay.

Another option, according to Schmäl (2013) [37] and described in [3], is that the traveller keeps her or his eyes forward avoiding glancing backward or sideways in order to prevent conflicts between visual and gravitational information. However, in the same study it is said that the human body adapts itself to this conflict by simply being exposed to it. Other findings in Schmäl´s research were that music, sleep, controlled breathing and the absence of alcohol had positive prevention effects.

Moreover: Sivak and Schoettle (2015) [40] said that by switching from driver to passenger, one gives up control over the direction of motion, and there are no remedies for this. The other two factors—the degree of conflict between vestibular and visual inputs, and the ability to anticipate the direction of motion—could be improved for passengers in self-driving vehicles. These two factors are influenced by the extent of the visual field, the direction of gaze, and posture. Extent of the visual field and the direction of gaze is solved by having large transparent windows [9], having displays (e.g., for video, or work) oriented in such a way that the gaze is focused nearly straight ahead, or by having transparent (head-up) displays. Posture can by optimized by not having swivel seats [9], by restricting head motion [22], or by having fully reclining seats that would allow being in a supine position—lying down flat and facing up [4]. Recent research provides some support for two novel strategies for reducing the visual-vestibular conflict while watching videos. One approach imposes visual stimuli on or around the video screen to mimic the perceived motion and forces of the moving vehicle [32] The other method involves controlling the position of displayed images in synchronization with vehicle motions and passenger head motions produced by vehicle acceleration/deceleration, thus providing video that appears to be stabilized in relation to the movement of the vehicle [22].

1.4 Seating posture, seating position and seat concept

When describing the most important user cases for occupants in autonomous vehicles, the seat position is a key point to be defined. They will be determined by the occupant's desires and most likely activities, but also by their comfort seating postures.

The seating posture depends on the traveller activity and the seat itself. Kamp et al. (2011) observed and analysed 580 train travellers and determined the typical seating postures for each of the most common activities while travelling, with the aim designing comfortable seating in the transportation industry [21]. The analysis suggests a significant relationship between most activities and the position of the head, trunk and arms during transportation situations. Surprisingly, differences in head, trunk, arm and leg postures were not significant when using small electronic devices.

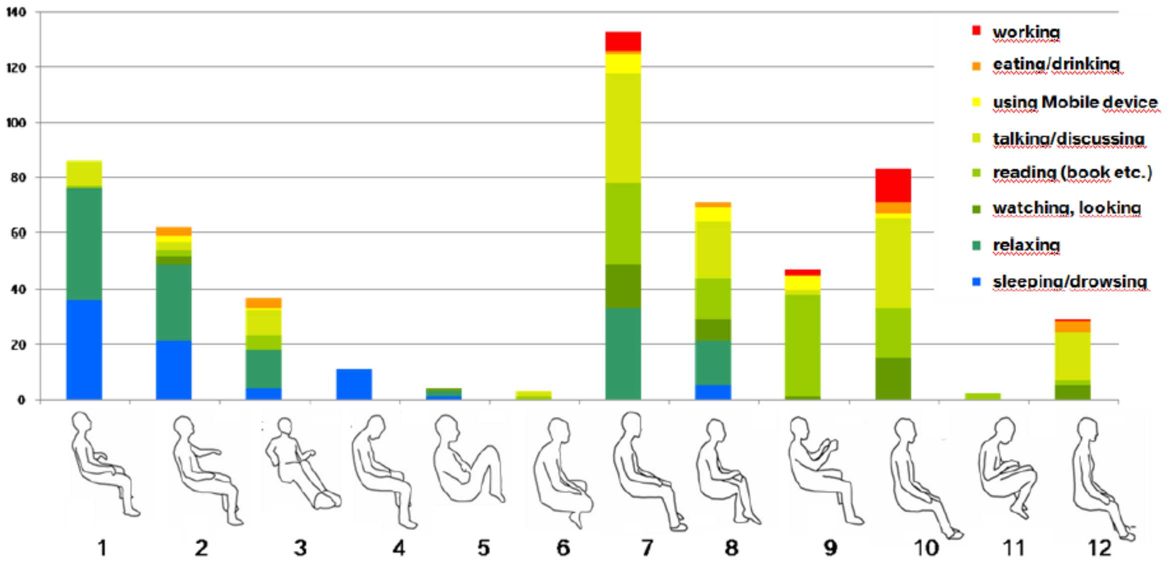


Figure 16 Research of typical activities of train passenger and the resultant postures, from Kamp et al. (2011) [21]

Kilincsoy et al. (2014) [24] analysed and described Figure 16 as follows. On the left, postures for relaxing and sleeping activities are shown and in the middle the tasks are reading, watching and talking. These activities show a more upright posture. On the right side, postures seen for activities like working, eating, drinking and using mobile gadgets are illustrated. Based on these 12 postures, which were observed during travelling, a selection was made for the rear seat of a car. Most of these postures are not applicable for the rear seating of a car, because of safety requirements and physical constraints due to the car's package. For instance, there is a shaft tunnel in the middle between the seats which limits space for your feet and lower legs. However, three positions out of the 12 observed postures are possible and most observed [21]. Figure 17 represents those possible three postures a back-seat passenger could choose

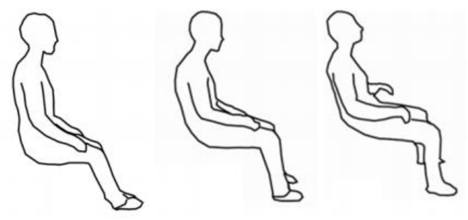
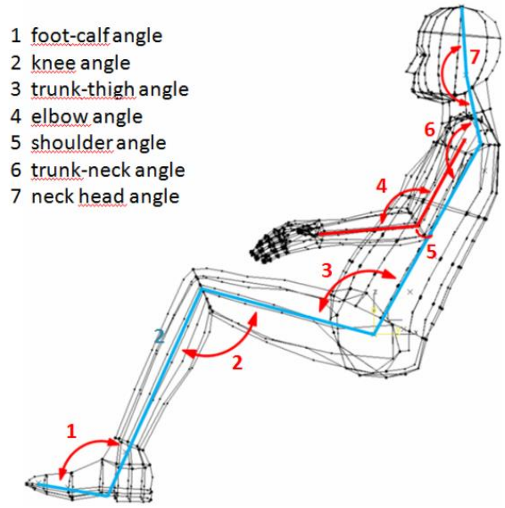


Figure 17 Resulting 3 possible postures applicable for back seat passenger after a selection from the 12 observed postures

According to Kilincsoy et al. (2014) [24], the left posture represents an upright position for short term travelling and could be the most frequent one for diverse activities with high, medium and low activity levels, which is a comparable travel situation to the rear seats. In the middle, the posture would need more space for a slightly relaxed seating, still awake and typically performing activities like listening to music. The right one is a special position for bigger cars and long distance travelling with relaxing, which may be even more important for long distance travelling [23]. Moreover, it is said that it is important to further specify the posture for the different body parts and therefore, Kilincsoy et al. have done a closer look on these postures and have analysed them more deeply. For this purpose, posture measurements were performed to 20 people positioned in the mentioned postures. In Figure 18 and Table 2 average measured joint angles for each posture are shown, which are very important to design a comfortable seat.



Classification	Passenger Sitting posture		
	Upright (SD)	Standard (SD)	Relaxed (SD)
Trunk-thigh angle	105.5 (5.5)	104.2 (7.6)	118.9 (10.5)
Knee angle	103.4 (12.5)	99.5 (9.9)	104.9 (11.9)
Elbow angle	113.1 (11.7)	128.5 (14.1)	139.9 (11.8)
Foot-calf angle	104.9 (5.8)	104.7 (4.6)	107.9 (8.2)
Shoulder angle	32.4 (13.3)	0.6 (12.6)	1.0 (11.8)
trunk-neck angle	130.3 (3.5)	139.5 (0.7)	142.7 (2.1)
Neck-head angle	177.5 (4.6)	187.2 (3.9)	185.3 (4.3)

Figure 18 Projection of RAMSIS manikin in 20 plane showing the measured joint angles, from ref [24]

Table 2 Average of measured joint angles for 20 subjects projected on the sagittal plane, from ref [24]

The difference in the sagittal plane was largest between relaxed and the other two (see Figure 19), while the trunk-thigh angle is 104.2° for the standard posture the relaxed position showed here 118.9° because subjects sit more relaxed. Accordingly, the elbow angle in the relaxed position is 139.9° compared with 128.5° for standard position. Also, foot-calf angle and trunk-neck angle show a slightly more open angle

The visualization of the three different postures in RAMSIS can be seen in Figure 19, presenting the mean values.

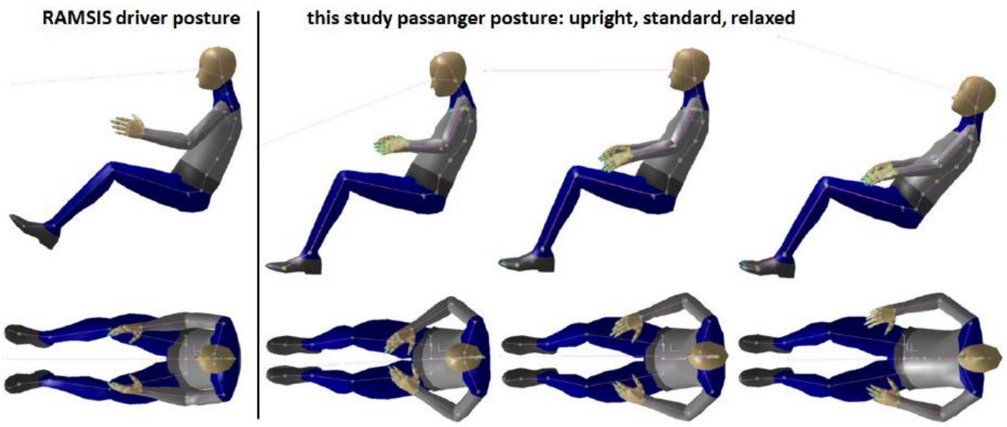


Figure 19 Visualization of the results in RAMSIS upright posture (left), standard posture (middle), relaxed posture (right), from ref. [24]

Kilincsoy et al. (2014) studied 20 subjects positioned in a mock-up of a car interior - which had the same size as a real car - in the three postures most common postures of passengers sitting in the rear seats (sleeping, standard, upright) [24]. The joint angles of those postures were recorded to develop an ideal posture model for rear seat passengers within a car. It was observed that the passengers were positioned in a realistic mock-up of a whole car interior with a fully adjustable back seat and postures recorded. The results showed that the upright and standard postures have similarities to the postures of the driver's seat in the literature. The relaxed posture showed a higher angle between trunk and thigh compared with the driving position and the variation in leg postures was much larger, which can be explained by the fact that the legs have more freedom in the rear seat than in the driving position.

Considering the occupants desires and their most likely activities, the seating position within an autonomous will be different from now. They will probably make possible to rest, work, eat or interact with others in the vehicle. However, it is interesting to see that lateral or rearward facing seating positions for rear occupants already exists in current and old vehicles designs. The 2011 Mercedes-Benz E-Class Wagon resurrected the rumble seat. It has two extra seats rearward (Figure 20).

Figure 20 2011 Mercedes-Benz E-Class Wagon

And in the past also some wagons — mostly Ford Country Squires — featured third row jump seats that faced each other and folded up from the floor (Figure 21).

Figure 21 Ford Country Squires

Jorlöv et al. (2017) carried out a qualitative study with 52 users aged 11 - 63 in Sweden with the aim of identifying future seating positions and activities in highly automated cars [19]. The participants were asked to position four seats within a simplified physical environment representing a highly automated car, visualizing a short drive alone and a long drive with several occupants. In the short drive scenario, 16 of 18 tests participants chose to sit forward facing ("For such a short distance it is not worth it to sit rearward-facing."). There was no desire to rotate the seat, but to recline the seat to a more relaxed position. For longer drives most participants envisioned the highly automated car as an extended living room (with front seats rotated between 90° and 180°). The motivation for not fully rotating the seats was to increase the "drivers'" possibility to gain control of the car, if necessary.

The study by Jorlöv et al. had prepared predefined seating positions which were presented to the participants (Figure 22): the normal forward-facing position (A), a conversation position with the front seats rotated inboard (B) and three living room positions where all seats faced each other (C,D,E).

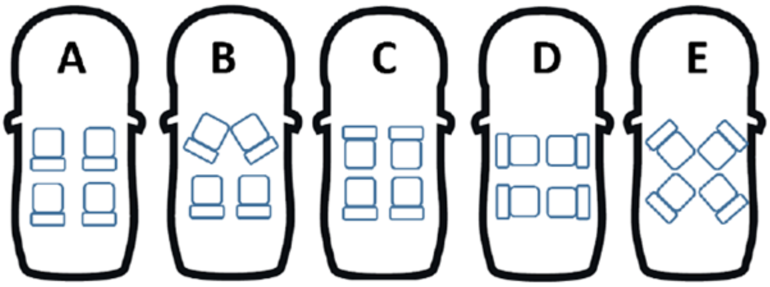


Figure 22 Possible seat configuration in an autonomous car, from Jorlöv et al. (2017) [19]

Seat suppliers have also studied the future seating position and seat concepts. Adient, an automotive seating supplier, showed how new forms of mobility affect vehicle interiors with the AI18 concept's seating system [1]. It is highly flexible yet compact for use in urban vehicles. Adient also defined seating configurations for autonomous vehicles Level 3 and 4 and gave characteristics of the seat and safety systems used. They defined different seating situations where seats can be rotated and moved: lounge mode; communication mode, cargo mode (additional space), family mode and baby plus mode.

Several studies have been performed regarding the new seat concepts for autonomous vehicles

The Adiant AI18 [1] defined setting configurations and a seats concept that provide passengers with the appropriate seating configurations, space and convenience for comfortable and safe mobility in each situation:

- Lounge mode: The front seats have an "anthropometric" pivot that ensures the seat can recline and still provide support if the angle is beyond the normal range. To provide optimal safety, the seatbelts in the front row are integrated into the seat structure -- not in the B-pillar of the vehicle as is the norm today. Adient's improved design ensures the belt withstands the modified loads and movements required by new seating positions in autonomous vehicles.
- In communication mode: The front passenger may turn 180 degrees so the driver and passenger can talk facing each other.
- In cargo mode: The two seats in the first row provide a familiar level of comfort while the seat cushion in the back row retracts into the cargo area. This provides additional space behind the front seats for easier access during short trips.
- Family mode is closest to the interior of a conventional vehicle. The front two seats face the direction of travel; the rear seats are fully deployed.
- The baby plus mode: Seats turn 180 degrees opposite the driving direction so parents can interact with their children while travelling safely. The integrated ISOFIX restraint system securely connects the child's seat to the vehicle. In addition, one of the rear seats can be extended so both parents can turn toward their children during a trip

Figure 23 Picture of the AI18 seat configurations proposal, from ref. [1].

Bengtsson (2017) also defined a new seats concept and autonomous driving interior concept taking into account the user needs described: stability; customization (active, entertainment, working position); spaciousness and clear outside view [3]. Different solutions to improve stability inspired by tilting trains and the Lexus Kinetic Seat ideas for different kinds of integrated tilting features were generated. The following concepts were considered to further concept development.

The traditional arrangement, Concept 2, is comfortable as all passengers see the line of action and reclining seats are possible Concept 4 is ideal in a social context, and it is also very spacious. Seats can be reclined without affecting each other. This maximizes the outside view and interior space which enhances comfort and minimizes risk for motion sickness. Having established that the back seats should be fixed in one direction, those should in that scenario become the primary seats, while the front seats are removable/foldable, see Figure 24.

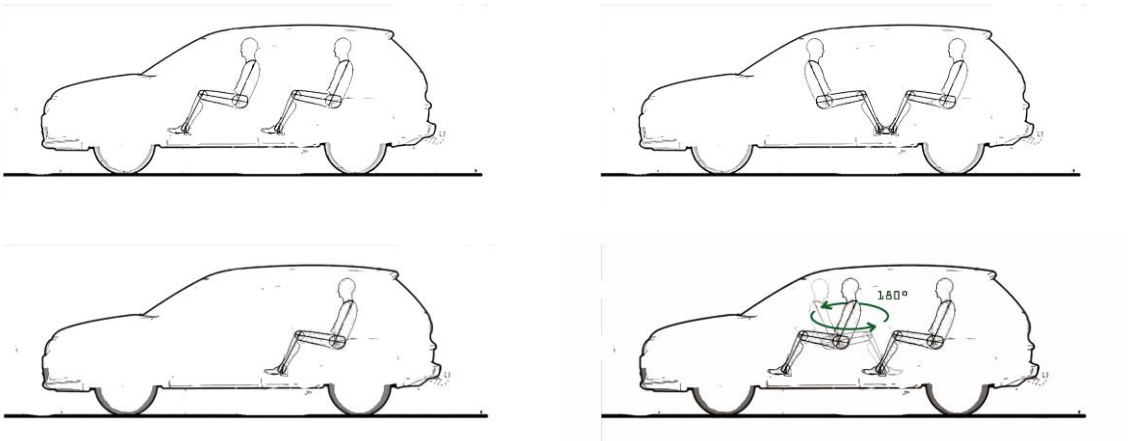


Figure 24 Possible seat configuration in an autonomous car, from Bengtsson (2017), [3]

A better concept for this kind of vehicle is a 2-2 formation (Figure 25). The two seats in the front are now able to turn, and the requirements of cabin width are no longer that intense. This enhances potential of designing a spacious and customized interior.

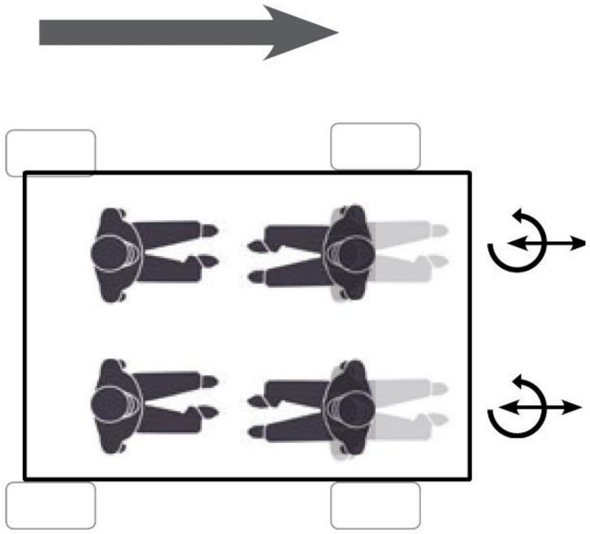


Figure 25 A 2-2 formation, seat configuration, from Bengtsson (2017), [3]

Provide stability: Different options to provide stability to the occupants were studied within the mentioned document.

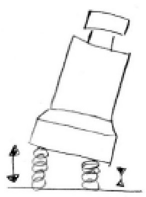
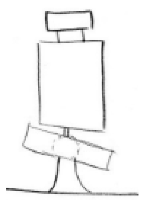
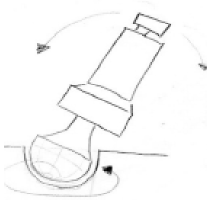
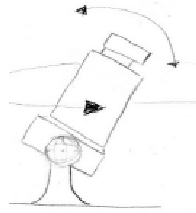
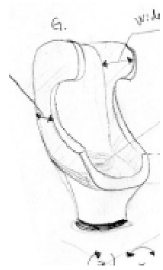
Tilting mechanism with floor attachments at (a minimum of) two points.	Seat cushion rotates around Y but back and neck support remain fixed.	Seat rotates around a half sphere hidden beneath the floor	Seat is attached to a sphere joint, elevated above the floor	Seat is mounted on a U-shaped groove, which makes it tilt in curves.	Side support in seatback, seat cushion and headrest.
					

Figure 26 Different option to provide stability, from Bengtsson (2017), [3]

Provide customization and adapt to the different seating positions, which can be divided in 5 options according to [3], see Figure 26.

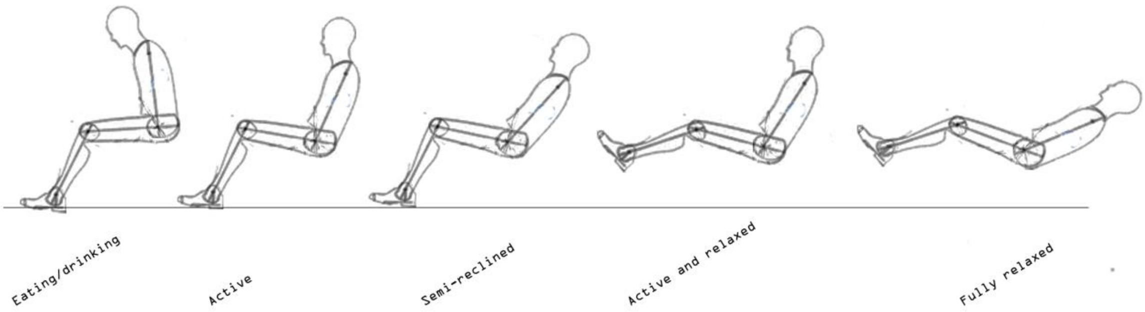


Figure 27 Seating positions and seat customization [3]

According to [3] the arrangement of the new seat concept is:

- The traditional arrangement, is comfortable as all passengers see the line of action and reclining seats are possible
- Face-to-face rows are ideal in a social context and are also very spacious. Seats can be reclined without affecting each other
- That the back seats should be fixed in one direction, those should in that scenario become the primary seats, while the front seats are removable/foldable, see Figure 28: Concept with folded/removed front seats
- The two seats in the front are now able to turn, and the requirements of cabin width are no longer that intense. This enhances the potential of designing a spacious and customized interior

To design the new seat concept, Bengtsson [3] specified requirements to be considered were rated regarding their importance and need categories (spoken/unspoken basics/unspoken desires).

The final concept was:

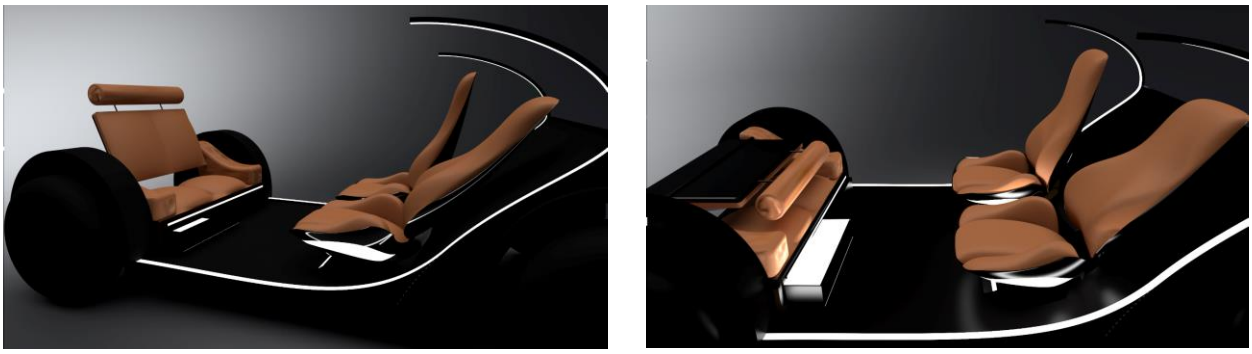


Figure 28 Pictures of the final seat concept created in the study by [3]

Other seat concepts were evaluated within the same project:

Figure 29 Volvo S90 excellence

In this concept, the front passenger seat is removed, and instead a multifunctional console is installed.

+ Comfortable - Maximum of only 3 passengers I: Focusing on luxury

+ Productive - Sensitive colours

+ Spacious

+ Prestigious

+ Compact

+ Seat stability

+ Feels safe

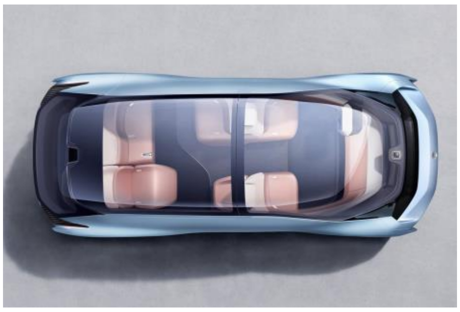


Figure 30 Nio Eve

Nio Eve is an American start-up which recently showcased the supercar Eve. It has an asymmetric seat arrangement with one permanent seat turned backward and one foldable seat that also could be used as leg support.

+ Spacious - Requires large dimensions I: Cost 1 million $

+ Productive - Seats have thin side cushions

+ Social - Stability

+ Large passenger capacity

+ Flexibility

Figure 31 Local motors Olli

Olli is a vehicle designed to be shared among many users. The manufacturer is Local motors. The vehicle is supposedly meant to drive at slow speeds and over short distances – Local motors exemplify the use of the vehicle as it could "…transport students across campus efficiently" (Localmotors.com, 2017).

+ Spacious - Requires height I: This may be good at slower speed

+ Supports standing - No head support and shorter journeys

+ Social - Not very stable seat

+ Outside view - Sensitive colours

- Does not feel safe

Figure 32 BMW interior concept

BMW showed off an interior where the four seats had a lot of interesting functions. Head rest had built in speakers. The seat could monitor its user´s heartbeat and help him/her make

decisions based on that information. Controlling the front display was holographic, which meant that the seat does not have to be near it while interacting. In the back, touchscreens are integrated in the armrest. Holographic displays are further described here: Wired.co.uk (2017-01-04)

+ Spacious - Sensitive colours I: Head rest mounted in roof

+ Outside view - Flexibility

+ Productive position

+ Stability

+ Intelligent

Figure 33 Mercedes F015

Has an interior filled with exclusive materials like nappa leather and walnut. It is supposed to reflect Mercedes style of "…modern luxury, emotion and intelligence" Referents

+ Spacious - Sensitive colours I: Seats has an interesting mix of classic

+ Prestigious - Expensive car seat and a lounge chair

+ Productive position - Requires large dimensions

+ Stability

+ Flexible

+ Intelligent

+ Calm

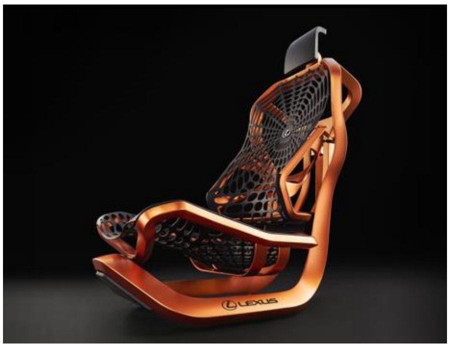


Figure 34 Lexus kinetic seat

This seat is supposed to follow the movement of the user while in motion. The seat and the back rest can rotate in the direction of the vehicle which "…helps stabilize head movement caused by vehicle motion, keeping the field of vision steady". The environmentally friendly spider weblike back rest (*QMONOS™ material developed by Spiber Inc.) is supposed to give customized support to the user.

+ Spacious - Sensitive colours I: Could this be a solution for stability

+ Unique look - Head rest seems thin in curves and acceleration?

+ Productive position - Requires large dimensions

+ Stable

+ Organic material

+ Insensitive colours

Figure 35 Tesla Concept Model X 2013

Tesla has become one of the most influential actors on the car market today. This model is chosen in the benchmark mainly because of its simple seat attachments in the middle row.

+ Spacious - Messy look I: Middle seats' attachment in floor

+ Feels safe - Mixed colours is very simplistic

+ Productive position - Requires large dimensions

+ Stability

+ Flexible

Figure 36 Hyundai mobility vision concept

Hyundai mobility vision concept: In this concept, Hyundai uses the car as an extension room of the home. This may reflect the needs of the crowded mega cities in Asia

+ Spacious - Hospital look I: Extension of home

+ Comfortable - Mixed colours

+ Productive position - Insensitive colours

+ Stability

+ Flexible

1.5 Safety systems

Safety is one of the most important issues in vehicles and it has also been mentioned by occupants as a user need. While defining the interior of an autonomous vehicle, safety should be considered at any of the possible configurations. It will be closely linked with the passive safety elements, but also will be linked with the active safety systems to improve the performance of the passive elements. In the following paragraphs several studies and proposals regarding the safety and safety systems of different seating positions have been analysed.

Active safety systems have an important effect on occupants and other road user's safety avoiding possible crashes. As an example, and according to the study performed by Kusano and Gabler (2012) [26], the pre-collision system could reduce the severity of the collision between 14% and 34%, the number of moderately to fatally injured drivers who wore their seat belts could have been reduced by 29% to 50% and these collision-mitigating algorithms could have prevented 3.2% to 7.7% of rear-end collisions. Within this study three pre-collision system (PCS) algorithms were studied: 1) forward collision warning only; 2) forward collision warning and pre-crash brake assist; and 3) forward collision warning, pre-crash brake assist, and autonomous pre-crash brake.

This and other active safety systems affect the vehicle occupant's kinematics and also the passive safety systems' effect. Holt et al (2018) evaluated the effect of bracing and two vehicle based countermeasures in a simulated pre-crash evasive swerving manoeuvre with the aim of systematically quantifying the kinematics of adult human volunteers [18]. Adult subjects (n=19, age: 26.0 ± 6.8 years) were exposed to a series of test conditions (relaxed, braced, pre-pre-tensioned seat belt, sculpted vehicle seat with and without inflated torso bolsters) while their kinematics were captured using 3D motion capture and muscle activity was recorded. It was observed that similar reductions in the head and lateral trunk displacement were achieved by actively bracing and by the implementation of a pre-pre-tensioned seatbelt. The sculpted seat with inflatable torso bolsters did not show similar benefits in reducing maximum lateral displacement. Differences in kinematics existed across subsequent oscillations within a given test, with the first oscillation demonstrating the largest displacement, suggesting that active neuromuscular strategies are being employed to counteract motion. The implementation of a pre-pre-tensioner or reversible motorised seat belt was an effective vehicle countermeasure during evasive swerving manoeuvres as it substantially reduced lateral head and trunk displacement. The lateral support from the sculpted seat and inflatable torso bolsters were not a beneficial countermeasure for the adult size occupant as their torso geometry caused them to sit forward of the torso bolsters.

The introduction of new highly automated vehicles holds the promise to influence occupant seated behaviour and seat design. Different seat orientation with respect to the vehicle, and increased seatback recline angles are some novel factors that may challenge occupant restraint systems currently available in the vehicle fleet. In the study by Lin et al. (2018) simulations were performed with the 2012 Toyota Camry finite-element model, impacted by the National Highway Traffic Safety Administration Research Moving Deformable Barrier (RMDB) model in frontal crash closing speed of 56 km/h [29]. Using: 3-point belt with pre-tensioner and force-limiter (two types: standard d-ring, and seat-integrated d-ring (with a reinforced seat structure)), passenger frontal airbag, side curtain airbag, side torso airbag. Taking positioned M50-OS models as golden standard, M50-O were postured to match them respectively (evaluated in three recline positions - nominal-upright (25˚), semi-reclined (45˚) and fully reclined (60˚). Both occupants were positioned using a pre-simulation method. Under gravity load, M50-OS settled into the seat and reclined back into the seatback. An additional simulation to position the upper torso of the occupant into the seatback for semi-reclined and reclined postures was necessary with applied external forces. Both occupant models submarined in the semi-reclined and reclined postures. Submarining resulted in pronounced posterior rotation and forward excursion of the pelvis, and substantial lap belt intrusion into the abdomen. Reclining the seatback exacerbated this issue. With the standard d-ring shoulder belt, the delay in torso engagement resulted in more forward excursion of pelvis. This was partially mitigated through the use of the integrated shoulder belt, but it did not eliminate submarining. Compared with M50-O in the same posture constrained by the same type of seat belt, M50-OS sustained more severe submarining coming with more forward excursion and posterior rotation. The kinematic difference might result from different boundary conditions between pelvis bones and surrounding flesh in two occupant models. Occupant kinematics varied with recline angle

Kitagawa et al. (2017) analysed occupant kinematics in simulated collisions of future automated driving vehicles in terms of seating configuration [25]. In part one, a frontal collision was simulated with four occupants with the front seats reversed. The left front seat occupant was unbelted while the others were belted. The results showed that the front seat (rear-facing) occupants were restrained by the seatback, resulting in T1 forward displacement less than 100 mm; the rear seat occupants were restrained by the seatbelt resulting in larger T1 forward displacement more than 500 mm. In part two of the study, occupant restraint was examined in various seating configurations using a single seat model with a three-point seatbelt. The results showed the directional dependence of occupant restraint. Greater T1 displacements were observed when the occupant faced lateral or front oblique. However, the seatbelt provided some restraint in all directions considered. The seatback generated contact force to the occupant when it was in the impact direction, including the lateral directions. The relaxed position allowed increased excursion compared to the driving position when the occupant faced rearward, but the magnitude of this increase was lower with lower impact speed. The seat direction with respect to impact was considered as forward, rearward, and lateral facing in 45-degree increments. With the standard d-ring seat belt, reclined M50-O has the largest posterior rotation while the results of upright and semi-reclined M50-OS are fairly close. However, as the recline angle increases, the posterior pelvis rotation of M50-OS also increases. The effect of seat recline was also studied in the forward-facing and rear-facing cases by assuming three positions: driving position, resting position and relaxed position. Occupants were represented by human body finite-element models.

Jin et al. (2018) suggested that the protective effects of current restraint systems vary among different seating configurations and that by using the rotational seat to alter the occupant's orientation in accordance with the direction of impact, occupants will be better protected [20]. Moreover, in a HAV it is likely that an imminent impact could be detected at a time of 200 ms, or even longer, prior to the initial contact. The availability of this additional time could be used strategically to actively position the occupants into a safer position for impact. Finite-element simulations were performed using the THUMSTM model to test the hypothesis. The simulation results indicated that during a frontal impact, the backward-facing occupant is safer than occupants in other seating orientations. Moreover, 200 ms is sufficient to rotate the occupant by ±45° without introducing additional injuries. Further studies are needed to optimize the rotating seat parameters in order to maintain occupant posture and improve crash safety in HAVs. This strategy consists of two parts: identifying the relatively safer seating orientation; and rotating the seat to this direction. Four selected seating orientations, 0°, 90°, 135° and 180°, were studied during a frontal collision. Simulation results indicate that the 180° seating configuration had the least injury risk among the four tested. In the second part of the study, the seat was rotated within 200 ms of pre-collision time. Two rotation levels were selected: 45° and 90°. Simulation results showed that it was safe to rotate the seat 45° within the pre-collision time. There was an increased injury risk when increasing rotational velocity.

In order to ensure the occupants protection in new seating position, more restraint systems may be necessary. The study of Osvalder et al. (2017) identified children's and adult's attitudes toward extra seat belts added to the three-point belt in the rear seat of a passenger car [33]. Five focus groups were conducted with 11 children (8-10 years) and 18 adults in Sweden. Two concepts were studied, the Backpack with an extra belt over the inboard shoulder, and the Criss-Cross with an extra belt across the torso. The results showed that seat belt usage was not questioned. The three-point belt was experienced as very safe, and extra seat belts were considered to further increase safety. Both concepts were accepted, but Criss-Cross was preferred due to greater perceived safety and comfort. Discomfort occurred in both concepts due to chafing at the neck, extra pressure on the upper body, and reduced ability to move. In conclusion, extra seat belts were in line with children's current attitudes toward car safety, while adults were more hesitant. Increased understanding of user attitudes provides input to future restraint system design, resulting in attractive systems with improved restraint function. Start the discussion in a phase where the participants knew nothing about the product, and successively include more information about the extra seat belt concepts in the discussion. The intention was to explore the attitudes toward extra seat belts, but also to explore how attitudes changed depending on how much information they had been given. The first part of the focus group dealt with the ordinary seat belt. The adults were to individually write 3-5 aspects they considered most important with the three-point belt. They also presented what they thought was good and bad about the seat belts of today. They were to choose one of the words from each pair of antonyms; nice/ugly, cool/silly, simple/troublesome, good/bad, comfortable/uncomfortable. In the second part of the focus group discussion, the idea of extra seat belts was introduced using an oral presentation and PowerPoint slides shown on a wide screen. First a brief explanation was made about the concept of an extra seat belt. In the third part of the focus group the actual prototypes were shown and tested. Each group went to the car. All participants buckled up in both concepts for a few minutes to create their own opinions based on their own experiences. The fourth part of the focus group discussion dealt with the extra seat belt concepts. In each group a discussion was held about what the participants liked and disliked regarding the concepts. They also stated which concept they preferred.

2 H2020 PROJECTS

The first literature research has been performed regarding other projects linked with autonomous vehicle development.

2.1 CARTRE

https://connectedautomateddriving.eu/

Coordination of Automated Road Transport Deployment for Europe

With the aim of progressing in the strategic development of connected automated driving, the CARTRE initiative has opened a series of public consultations on the different CARTRE thematic areas.

Interesting: More interesting are:

- Human factors
- User and societal awareness and acceptance

2.2 VRA

http://vra-net.eu/wiki/index.php?title=Main_Page

VRA – Vehicle and Road Automation is a support action funded by the European Union to create a collaboration network of experts and stakeholders working on deployment of automated vehicles and the related infrastructure.

2.3 ERTRAC

ERTRAC is the European Road Transport Research Advisory Council. It is the European technology platform which brings together road transport stakeholders to develop a common vision for road transport research in Europe.

Interesting: The ERTRAC working group on road safety is actively cooperating with the PROS project on priorities for road safety research in Europe. It has several research topics that are interesting for OSCCAR:

1. Biomechanical models and injury prediction
2. Crash compatibility and improved crashworthiness of light and/or new vehicle concepts
4. Advanced passenger protection systems including elderly/more fragile people

ERTRAC has also defined the levels of automation:

- **SAE level 2**: **T**he driver is no longer continuously involved in the lateral and longitudinal control subtask of the dynamic driving task; the driver does not have to constantly steer or accelerate/brake, so he/she is disengaged from constantly physically operating the vehicle e.g. by having his hands off the steering wheel and foot off pedal at the same time. Although the driver is physically disengaged, mentally the driver must be engaged and must monitor the driving environment and must immediately intervene when required, e.g. in case of an emergency or system failure

- **SAE Level 3: T**he driver's task is to determine when activation of the automated driving system is appropriate and to take over upon request within a limited period of time. The driver may also request deactivation of the automated driving system.

  The system monitors the driving environment when activated; permits activation only under conditions (use cases and operational design domain) for which it was designed; executes longitudinal (accelerating/braking) and lateral (steering) portions of the dynamic driving task when activated; deactivates only after requesting the driver to take-over with a sufficient lead time; may − under certain, limited circumstances − transition to minimal risk condition if the human driver does not take over; and may momentarily delay deactivation when immediate human takeover could compromise safety.

  - Remark 1: For Level 3 systems, with the driver providing the ultimate fallback performance, he must be in position to resume control within a short period of time when a takeover request occurs. This may happen with an increased lead time, but the driver must react. Therefore, only secondary tasks with appropriate reaction time are allowed. This would in an extreme case exclude e.g. sleeping. Driver activation monitoring might be used to avoid such unintended use. Potential technical solutions range from detecting the driver's manual operations to monitoring cameras to detect the driver's head position and eyelid movement.
  - Remark 2: To enable predictable and reproducible takeover scenarios it would be beneficial if vehicle displays that are controlled by the automation system would be used for secondary tasks (e.g. texting, internet surfing, video-telephony). If a takeover request occurs the secondary task content on the display is faded out and the takeover request is displayed instead.
  - Remark 3: The driver is not capable of reacting to emergency braking manoeuvres of the vehicle in front of the driver due to secondary tasks. Such scenarios must be accomplished by the system.

- **SAE Level 4:** The driver's task is to determine when activation of the automated driving system is appropriate, and to take over upon request within lead time. The driver may also request deactivation of automated driving system.

  The system monitors the driving environment when activated, permits activation only under conditions (use cases and operational design domain) for which it was designed, and executes longitudinal (accelerating, braking) and lateral (steering) portions of the dynamic driving task as well as OEDR when activated.

  It also initiates deactivation when design conditions are no longer met, e.g. requests driver to take over and initiates deactivation to reach a minimal risk condition if driver does not respond to the takeover request, fully deactivates only after human driver takes over or minimal risk condition is achieved; transitions to minimal risk condition if human driver does not take over, and may momentarily delay deactivation when immediate human takeover could compromise safety

  - Remark: Level 4 systems do not require the driver to provide fallback performance. Therefore, the system must be capable of transferring the vehicle to a minimal risk condition within the operational design domain. This might increase technical effort.

- SAE Level 5**:** The driver may activate the automated driving system and may request deactivation of the automated driving system.

When activated, the system monitors the driving environment, executes longitudinal (accelerating/ braking) and lateral (steering) as well as the OEDR subtasks of the dynamic driving task, deactivates only after the human driver takes over or vehicle reaches its destination, transitions to a minimal risk condition as necessary if failure in the automated driving system occurs, and may momentarily delay deactivation when immediate human driver takeover could compromise safety

- Remark 1: Level 5 systems can complete any on-road journey from origin to destination without the help of a human driver. Consequently, typical driver controls are not required in an extreme scenario (no steering wheel, pedals or instrument cluster). Completely new vehicle designs or even completely new classes of vehicle are possible.
- Remark 2: In a theoretical analysis of vehicle automation, Level 5 systems must be considered because they complete the automation scale. Such systems are not in the focus of AdaptIVe because it is unlikely that they will be available as a product in the foreseeable future

2.4 AdaptIVe

http://www.adaptive-ip.eu/index.php/objectives.html

AdaptIVe develops various automated driving functions for daily traffic by dynamically adapting the level of automation to situation and driver status. Further, the project addresses legal issues that might impact successful market introduction.

Interesting: D3.1 is a use case catalogue (not public…) → describes the behaviour of the functions especially in view of the HMI to be deployed.

2.5 Brave

http://www.brave-project.eu/

BRAVE's approach assumes that the launch of automated vehicles on public roads will only be successful if a user centric approach is used where the technical aspects go hand in hand in compliance with societal values, user acceptance, behavioural intentions, road safety, social, economic, legal and ethical considerations. The main objective in BRAVE is to improve safety and market adoption of automated vehicles, by considering the needs and requirements of the users, other road users concerned (drivers and vulnerable road users) and relevant stakeholders (i.e. policy makers, standardisation bodies, certifiers, insurance companies, driving schools), assuring safe integration of key enabling technology advancements while being fully compliant with the Public deliverables.

Interesting: User-centred development requires engineers to be aware of and to consider a broad array of needs, expectations and concerns of all road users (potential drivers of automated vehicles and also drivers of non-automated cars and vulnerable road users) and the human factors that influence automation operation. These being met will facilitate acceptance and market entry. Following the exploratory work of focus groups and expert interviews a cross-cultural population survey of the general public in the countries of the BRAVE-participants will explore societal values, user acceptance, behavioural intentions, road safety, social, economic, legal and ethical considerations regarding the implementation of automated vehicles. These insights will lay the foundation for the integration of innovative Advanced Driving Assistance Systems and Human Machine Interface concepts. These new concepts will be validated back against the (baseline) requirements using an agile, iterative and incremental user-centric methodology evolving through 3 stages.

No public publications, no public deliverables

2.6 ADAS&me

https://www.adasandme.com/

In ADAS&ME a holistic approach that considers automated driving in conjunction with information on driver state is taken. The work is based around 7 Use Cases aiming to cover a large number of critical driving scenarios. The use cases are about different transports.

Interesting: They have organized workshops where the different scenarios has been studied and discussed. First workshop described D1.2Use Cases and implementation scenarios. In section 2.6 the multicriteria analysis (MCA) methodology and in section 2.7 the workshops methodology is explained.

2.7 DOMUS

https://www.domus-project.eu/

Design Optimisation for efficient electric vehicles based on an user-centric approach.

As a result, DOMUS aims to reduce the overall energy consumption of future EVs in order to increase 25% of the electric range for different ambient conditions.

Interesting: The specific technical objectives of DOMUS are:

- Acquiring a thorough understanding of all factors influencing comfort perception and capturing the capability to improve EV energy efficiency while maintaining optimal user experience
- Development of radical new cabin and EV designs and the methodology for virtual assessment of EV (cabin) designs that includes comfort perception, efficiency, well-being and safety
- Development of new cabin components, systems and control strategies for energy efficient, safe and comfortable future EVs up to TRL 5/6 (for some potentially up to TRL 7)
- Implementation and validation of the developed models, cabin/EV designs and instrumental innovation of cabin components, systems and controls and assessment methodology
- Assess the impact and applicability of the solutions developed across different types of EV

Interesting:

DOMUS Design Workshop by ViF →July 5th, 2018 DOMUS (WP2) held a workshop to support the goal of developing innovative and disruptive cabin designs for electric. Explore different mobility personas in different future urban environments to identify EV mobility scenarios. Project information is displayed in Figure 37.

1 September 2018. → definition of design hurdles

October 2018 → concepts and design hurdles will be translated by multi-disciplinary team into innovative, disruptive design solutions.

DOMUS Workshop – Towards a more holistic comfort model →July 19. The aim of the workshop was to prepare the experimental work aiming to enrich existing thermal comfort model with new moderating factors and the acoustic comfort dimension in order to create a more holistic comfort model (WP1).

IKA Workshop on user requirements in thermal environments →25th April 2018 worked out one comprehensive experimental use case, user-studies on thermal perception. This specific experimental use case will serve as a framework for further user-studies on comfort and cabin energy requirements in the DOMUS project.

Interesting:

WP1 Determination of user's perception and requirements of comfort and cabin energy requirements

WP2 Advanced Cabin Design and Virtual Assessment implementation and testing of the different solutions at the full vehicle level

WP5 Advanced systems and components and their control in the Active comfort System by DNTS

- Development of an active system capable of following the indications from both the holistic comfort model and the assessment framework from WP1, in order to achieve the comfort perception expectations while reducing the energy required to a significant extent
- Description of the active safety solutions
- Indicators and Competence Structures for Efficient Driving with a Validated DEB demonstration application (CO)
- Regulation strategies for holistic comfort systems and logic control implementation in ECU (CO)

See further in Project information displayed in Figure 37.

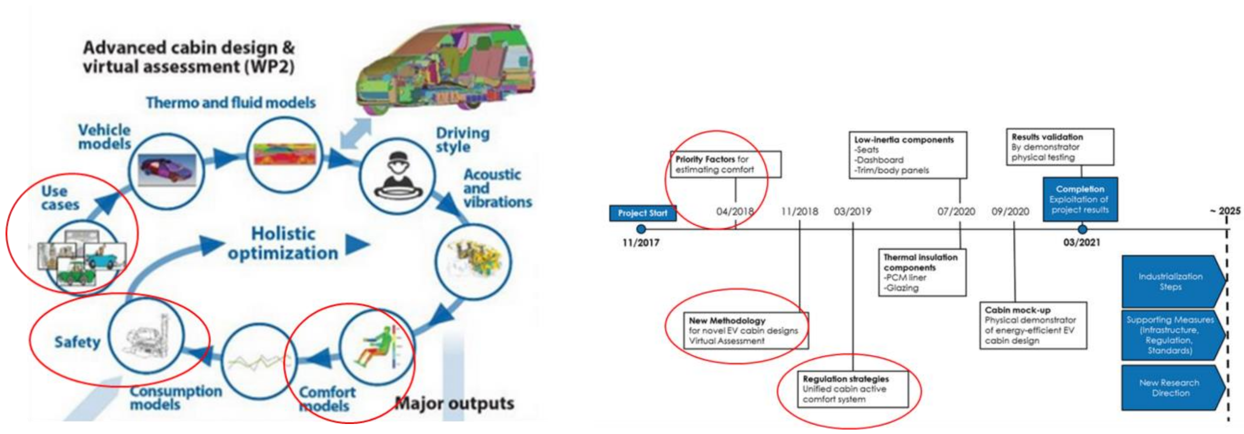


Figure 37 DOMUS project

2.8 UK Autodrive

http://www.ukautodrive.com/the-uk-autodrive-project/

UK Autodrive is the largest of three separate consortia that are currently trialling automated vehicle technology as part of a government-backed competition to support the introduction of self-driving vehicles into the UK.

Objectives:

Integrate autonomous and connected vehicles into real-world urban environments.

Show how autonomous and connected vehicles could solve everyday challenges such as congestion.

Demonstrate the commercial operation of electric-powered self-driving “pods” at a city scale.

Provide insight for key stakeholders and decision-makers, including legislators, insurers and investors.

Survey finds UK public still “open minded” about self-driving vehicles:

http://www.ukautodrive.com/survey-finds-uk-public-still-open-minded-about-self-driving-vehicles/

The 49-question survey also asked people what they would do while riding in a self-driving vehicle, with more than half (55%) saying they would look out at the scenery. Checking emails (37%), making phone calls (35%) and eating or drinking (also 35%) were among the other popular choices.

People would want to use a self-driving vehicle, with 23% of respondents saying that they would most use one for shopping excursions, followed by commuting (22%), social/leisure travel (22%), and a sizeable 15% who would be mainly interested in using self-driving vehicles after drinking alcohol.

When asked how they would like to summon a self-driving vehicle if using one as a form of public transport, 45% of respondents said they would like to use a smartphone app, though calling one up from home (27%) or catching one at a bus stop (23%) were also popular options.

A large majority (80%) of those surveyed felt that self-driving vehicles would assist people with impairments or disabilities, but the results were far more varied when it came to such vehicles being used by other members of the public.

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APPENDIX 2 – USER STUDIES

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March 2019

This appendix gives detailed information about the user studies conducted in WP2 and is directly linked to the D2.1. Report. A summary is provided in Chapter 3.3.1.2.

In order to understand the potential of new sitting postures and seat positions of occupants in fully autonomous vehicles (SAE level 4-5), user studies were conducted and evaluated. To this point, sitting postures and activities in a vehicle considered for restraint systems are usually limited to Level 0-2. These are usually, in the case of the driver, limited to the driving task or, in case of passengers, usually closely related to classical vehicle designs of 4-5 seats facing in the driving direction. However, vehicle concepts especially in the field of autonomous driving provide more degrees of freedom to apply novel seating configurations and follow different activities. In this vein, two user studies were conducted for refining the test case matrix within OSCCAR.

The results of the user studies can be used as direct input to the test case matrix. Two user studies were performed within OSCCAR. According to the Grant Agreement, the overall purpose of the studies was to assess preferred seat rotations, different seating positions, sitting postures, and activities that people take and execute in a car as passengers, especially against the background of autonomous vehicles in order to limit the test case matrix to the most frequently occurring specifications. The first study addressed preferences of users regarding different seat rotations, while the second study focused on seat positions (except rotations), sitting postures, and collected activities.

1 STUDY ON SEAT FOTATIONS

The first user study aimed at assessing preferences of users regarding different seat rotations when sitting in an autonomous vehicle without any secondary activities or social components involved. When a driver is not required for executing the driving task anymore, more degrees of freedom apply regarding the arrangement of seats, e.g. including seating concepts with seats facing each other, enabling people to communicate more efficiently. This first user study aims at assessing preferences and the subjective feeling of comfort of participants in different seat rotations in a safe environment on the test track. The output serves as guideline for limiting the test case matrix to certain seat rotations. This chapter specifies the evaluation of seat rotations and gives detailed information on the results.

1.1 Methods

This chapter describes the methodological approach of the user study. First, an overview over participants is given, before materials including the testing vehicle and different seat positions, the testing parkour and the questionnaires used in this study are described. This chapter is summed up with the experimental design and a description of the testing procedure. The user study followed the projects' ethics requirements. No ethical concerns were raised for this user study as the study was performed on a closed test track with no interfering traffic.

1.1.1 Participants

In total, 31 participants (61.3% female and 38.7% male) with age ranging from 19 to 66 years and a mean age of M = 31.52 (SD = 14.05; Mo = 25), participated in this experiment. All participants had normal or corrected hearing and vision. The mean time spend as a passenger weekly was indicated to be M = 4.52 hours, ranging from 0 to 20 hours per week (SD = 4.31; Mo = 4). 96.8% stated being German, the remaining 3.2% were Dutch. The precondition for participating in the experiment was to be fluent in German in order to understand all instructions and questionnaires appropriately. In a pre-questionnaire participants were asked to name their preferred activities as a passenger (multiple mentions were possible). Most popular activities were having a conversation (N = 18; 11.61% of all named activities), reading (N = 16; 10.32%), listening to music or to the radio (N = 16; 10.32%) or being occupied with their mobile phone (N = 16; 10.32%). Other participants stated that they like looking out of the window (N = 15; 9.68%) or to eat or drink (N = 12; 7.74%) while riding in a car. Furthermore, participants named other activities such as navigating (N = 8; 5.16%), sleeping and resting (N = 8; 5.16%), working on the laptop (N = 5; 3.23%), texting (N = 4; 2.58%) or talking on the phone (N = 4; 2.58%). Eight participants (5.16%) stated to prefer other activities and three participants prefer doing nothing (1.94%).

Participants were screened according to their prevalence for motion sickness. Participants were tested in groups of two, ensuring to control for motion sickness prevalence as one person who had experienced motion sickness before and a person who had not were always tested in the same rotation.

1.1.2 Materials and Stimuli

In this chapter the used materials and stimuli are described in detail. Therefore, the vehicle is described in a first step. After that the course of the parkour is illustrated, before an overview of the used questionnaires is given.

1.1.2.1 Vehicle

The testing vehicle used for the study was a Ford Transit (FT300, KW92, 2.2l). The overall length of the vehicle is 4863mm. The overall width including mirrors is 2374mm, and 1974mm without mirrors. The vehicle has an overall height of 2067mm. Windows are placed around the entire vehicle and allow for unobstructed view out of the vehicle. The vehicle is equipped with three rails in the rear of the vehicle, on which up to four seats can be placed anywhere in the car. Each seat is equipped with armrests and a seatbelt and can be turned around the clock in steps of 30°. For the study, two seats were placed in the middle rail of the rear of the vehicle. This way, two participants could be tested at once without the participant's perception and rating of comfort being distorted by the side of the vehicle where the seat was placed. This way, both participants experienced the same dynamics of the vehicle. The seats were always turned in the same direction for two participants, also ensuring that the participants were not able to face each other. Participants were not allowed to use the armrests in order to make sure they experienced the vehicle dynamics in the seat with their body and did not distort this feeling by using their arms as support. Furthermore, it was ensured that people always used the seatbelts. Figure 1 shows an exemplary setting of the seats in the vehicle and gives a close up of one of the seats.

Figure 1 Seats and exemplary seat configurations

1.1.2.2 Parkour and Procedure

The user study was executed on a restricted test track of the Institute for Automotive Engineering (ika) of RWTH Aachen University. During the user study, no other vehicles were allowed to drive on the test track, ensuring maximum safety for participants. Figure 2 shows the parkour used for testing on the test track.

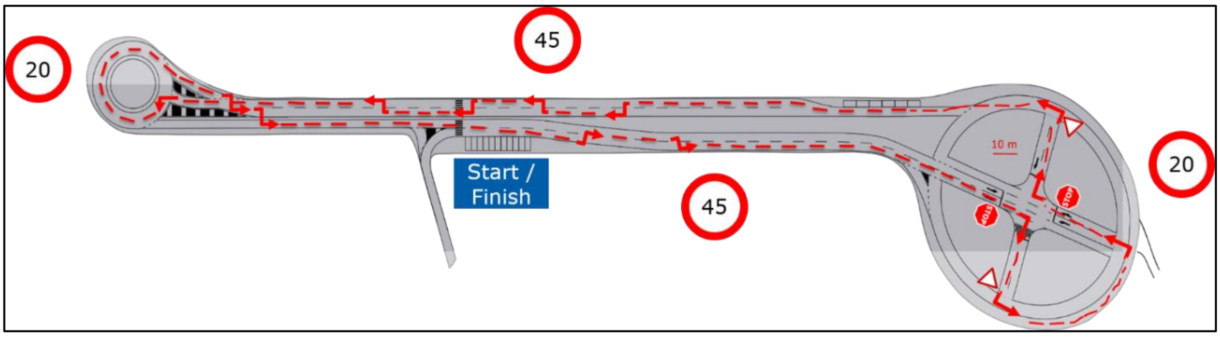


Figure 2 Testing parkour on the test track

Each trial started with the vehicle accelerating to 45 km/h, followed by a double lane change. After this, the vehicle stopped before turning right. While driving in the big circle as displayed on the right of Figure 2, the car drove at a maximum speed of 20 km/h. After this, the vehicle turned left without stopping but with simulating to be ready to give way to other vehicles, therefore slowing down gradually. This was done once more after having turned left, as can be seen on the right side of the figure above. Subsequently, the vehicle sped up to 45 km/h and drove two double lane changes. Then, the vehicle again slowed down to 20 km/h and drove into the curve displayed on the left of the figure above in order to not only expose people to just one-sides tilts in longer curves. After this, the vehicle returned to the start/stop mark. One trial lasted about 2 minutes. It was ensured to not drive abrupt or harsh manoeuvres but to simulate a normal ride in a car. Only two drivers conducted the experiments in order to keep the influence of different drivers as low as possible.

1.1.2.3 Questionnaires

Throughout the study, a number of questionnaires was used. This chapter gives a brief overview into the used tools.

1.1.2.3.1 Pre-Screening on Motion Sickness

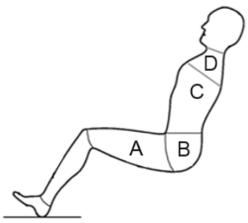
A pre-screening questionnaire was used in order to assess whether participants had experienced motion sickness before and to ensure a balanced distribution of participants with and without a prevalence for motion sickness to each condition. Each tested “couple” showed therefore a balance of one participant with and one participant without motion sickness experience. This was done in order to ensure that comfort- and motion sickness-ratings were not distorted by people that might have had a higher acceptance threshold for motion sickness anyway.

1.1.2.3.2 Overall Acceptance

Participants were asked just after each trial whether the rotation they had just experienced would be acceptable for them. They could reply either with yes or no. If the answer was no, they would have been asked why not.

1.1.2.3.3 Comfort in Different Body Parts

After each ride in a certain seat rotation, participants filled out a questionnaire to collect data of their extent in discomfort in different body parts. For this, the CP50 scale according to [1] was adjusted to a 26-point scale. Figure 3 illustrates the assessed body parts and the rating scale. Participants were asked to rate the extent of discomfort, which arises from their seating position for both body halves separately for each body part. Please note that the questionnaire assessed subjectively perceived comfort of certain body parts. An overall comfort rating apart from this was not summarized.



A Thigh		B Buttocks		C Back		D Shoulder/Neck	
Maximal discomfort	☐ 26	Maximal discomfort	☐ 26	Maximal discomfort	☐ 26	Maximal discomfort	☐ 26
Very high discomfort	☐ 25	Very high discomfort	☐ 25	Very high discomfort	☐ 25	Very high discomfort	☐ 25
	☐ 24		☐ 24		☐ 24		☐ 24
	☐ 23		☐ 23		☐ 23		☐ 23
	☐ 22		☐ 22		☐ 22		☐ 22
	☐ 21		☐ 21		☐ 21		☐ 21
High discomfort	☐ 20	High discomfort	☐ 20	High discomfort	☐ 20	High discomfort	☐ 20
	☐ 19		☐ 19		☐ 19		☐ 19
	☐ 18		☐ 18		☐ 18		☐ 18
	☐ 17		☐ 17		☐ 17		☐ 17
	☐ 16		☐ 16		☐ 16		☐ 16
Medium discomfort	☐ 15	Medium discomfort	☐ 15	Medium discomfort	☐ 15	Medium discomfort	☐ 15
	☐ 14		☐ 14		☐ 14		☐ 14
	☐ 13		☐ 13		☐ 13		☐ 13
	☐ 12		☐ 12		☐ 12		☐ 12
	☐ 11		☐ 11		☐ 11		☐ 11
Slight discomfort	☐ 10	Slight discomfort	☐ 10	Slight discomfort	☐ 10	Slight discomfort	☐ 10
	☐ 9		☐ 9		☐ 9		☐ 9
	☐ 8		☐ 8		☐ 8		☐ 8
	☐ 7		☐ 7		☐ 7		☐ 7
	☐ 6		☐ 6		☐ 6		☐ 6
Very slight discomfort	☐ 5	Very slight discomfort	☐ 5	Very slight discomfort	☐ 5	Very slight discomfort	☐ 5
	☐ 4		☐ 4		☐ 4		☐ 4
	☐ 3		☐ 3		☐ 3		☐ 3
	☐ 2		☐ 2		☐ 2		☐ 2
	☐ 1		☐ 1		☐ 1		☐ 1
No discomfort	☐ 0	No discomfort	☐ 0	No discomfort	☐ 0	No discomfort	☐ 0

Figure 3 Adjusted CP50 scale

1.1.2.3.4 Motion Sickness

The questionnaire to elicit the level of Motion Sickness [2] consisted of a total of 16 items with a nine-point-scale, ranging from 1 = "not at all" to 9 = "severely". The calculation followed the instructions of the authors, saying that the overall score of each participant is a percentage value resulting from the sum score of all items divided by maximum sum score multiplied with 100. Therefore, the possible overall scores range from 11.11% to 100%.

The questionnaire can be interpreted as an overall scale as well as subdivided into the four sub-scales. Gastrointestinal symptoms include feeling sick to one‘s stomach, feeling queasy, nauseated or feeling as if may vomit. The experience of light-headedness, dizziness, disorientation, the feeling of spinning and feeling faint-like are central symptoms. Moreover, peripheral symptoms can be distinguished including feeling sweaty, clammy, having cold sweat and feeling hot or warm. Sopite-related symptoms are feeling irritated or annoyed, felling drowsy, tired and uneasy.

Participants were asked after every trial how accurately the statements described their experience in the trial they had just been driven in. Table 1 illustrates the items and rating scale of the questionnaire.

Table 1 Items of the motion sickness questionnaire

1. I felt sick to my stomach.	☐	☐	☐	☐	☐	☐	☐	☐	☐
2. I felt faint-like.	☐	☐	☐	☐	☐	☐	☐	☐	☐
3. I felt annoyed/irritated.	☐	☐	☐	☐	☐	☐	☐	☐	☐
4. I felt sweaty.	☐	☐	☐	☐	☐	☐	☐	☐	☐
5. I felt queasy.	☐	☐	☐	☐	☐	☐	☐	☐	☐
6. I felt lightheaded.	☐	☐	☐	☐	☐	☐	☐	☐	☐
7. I felt drowsy.	☐	☐	☐	☐	☐	☐	☐	☐	☐
8. I felt clammy/cold sweat.	☐	☐	☐	☐	☐	☐	☐	☐	☐
9. I felt disoriented.	☐	☐	☐	☐	☐	☐	☐	☐	☐
10. I felt tired/ fatigued.	☐	☐	☐	☐	☐	☐	☐	☐	☐
11. I felt nauseated.	☐	☐	☐	☐	☐	☐	☐	☐	☐
12. I felt hot/warm.	☐	☐	☐	☐	☐	☐	☐	☐	☐
13. I felt dizzy.	☐	☐	☐	☐	☐	☐	☐	☐	☐
14. I felt like I was spinning.	☐	☐	☐	☐	☐	☐	☐	☐	☐
15. I felt as if I may vomit.	☐	☐	☐	☐	☐	☐	☐	☐	☐
16. I felt uneasy.	☐	☐	☐	☐	☐	☐	☐	☐	☐

1.1.3 Design and Procedure

Participants were welcomed at the start/finish as shown above. After a demographic questionnaire, a privacy statement on data protection, a confidentiality statement and test track regulations were explained to and filled in by the participants, they were assigned to the testing conditions according to Figure 4. Participants were tested in groups of two, ensuring to control for motion sickness prevalence as one person who had experienced motion sickness before and a person who had not were always tested in the same rotations. Each participant started in a different seat rotation and experienced a total of 7 rotations (random sequence, not fully crossed). One group of participants was rotated clockwise between 0° and 180°, the other group counter-clockwise.

After having been instructed to buckle up, to not interact with one another during the rides and to not engage in any secondary activities such as texting, reading or similar, the first trial started as described in the chapter “Parkour”. After the last trial, people were debriefed about the objectives of the user study and of the overall project. The entire experiment was executed in comoliance with the project’s ethics requirements

Couples 1-8								Seats turning right
Couple 1	0°	180°	60°	150°	30°	120°	90°	
Couple 2	30°	120°	150°	0°	90°	180°	60°	
Couple 3	60°	30°	120°	150°	180°	0°	90°	
Couple 4	90°	150°	120°	180°	0°	30°	60°	
Couple 5	120°	90°	180°	60°	30°	0°	150°	
Couple 6	150°	0°	120°	180°	30°	90°	60°	
Couple 7	180°	30°	60°	120°	150°	90°	0°	
Couple 8	90°	120°	60°	150°	180°	0°	30°	
Couples 9-16								Seats turning left
Couple 9	0°	180°	210°	240°	300°	330°	270°	
Couple 10	330°	300°	0°	270°	210°	240°	180°	
Couple 11	300°	210°	330°	0°	270°	240°	180°	
Couple 12	270°	330°	210°	0°	240°	180°	300°	
Couple 13	240°	180°	0°	210°	330°	300°	270°	
Couple 14	210°	300°	240°	180°	0°	270°	330°	
Couple 15	180°	270°	300°	240°	0°	330°	210°	
Couple 16	180°	330°	210°	270°	0°	300°	240°	

Figure 4 Detailed testing plan for each participant pairing

1.2 Results and Discussion

This chapter reports the results of the first user study collected with the instruments described in chapter 1.1.2.3. First, the results of the overall acceptance are displayed before the ratings of comfort for the individual body parts as described in chapter 1.1.2.3.3. are shown and discussed. The chapter is concluded by the motion sickness rating.

1.2.1 Overall Acceptance

After each rotation ride on a standardized parkour on the test track, participants’ acceptance of each rotation was assessed. 100% of participants accepted facing forward (0° rotated), while only 70% accepted the 180° and 270° rotations (clockwise). Figure 5 shows the percentage value of “yes“-replies to the question, if the rotation participants had just experienced would be acceptable to them. The section marked in red displays an extremely negative acceptance rating, while the section in green shows a rather positive outcome.

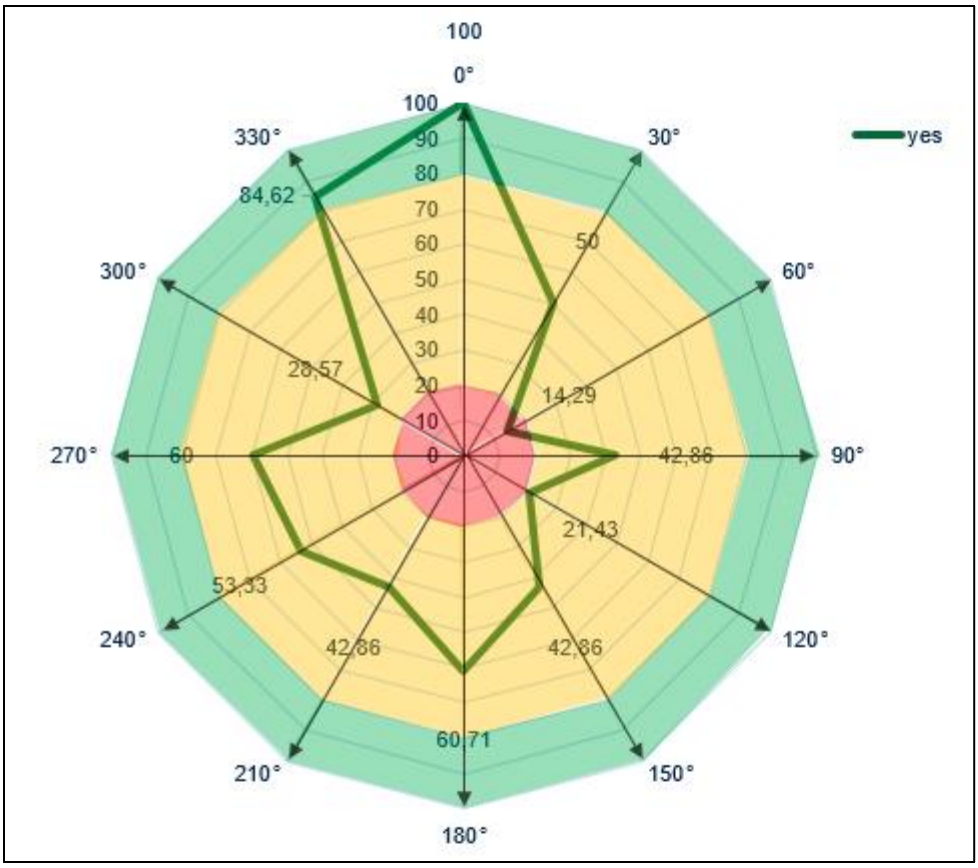


Figure 5 Percentage of participants agreeing that the seat rotation is acceptable for an autonomous vehicle dependent on the seat rotation. 0° means that no rotation was applied in relation to the driving direction

Overall, left-wing rotations were preferred. Rotations to the right (30°-150° clockwise) were accepted considerably worse than the rotations to the other side. This result was supported by the rating for comfort according to the adjusted CP50-scale. This low rating could be due to visual cues: less of the road was visible, leading to people looking towards a rather blurry wall of trees when driving by. Participants experienced higher dizziness and an uncomfortable overall feeling due to fast passing scenery (closer to trees surrounding the test track), whereas they had a higher feeling of control when being able to look into the test track when rotated the other way. However, this result might be different when changing the direction of driving to left hand traffic, but this is subject to further research.

In general, the rotation of the seat makes a difference in the feeling of comfort, especially when rating the discomfort for the back. In both groups, the equivalent rotations 60° and 300° were perceived as most uncomfortable. Furthermore, participants turned their heads in the direction of travel in forward-facing rotations, indicating 0° to be their preferred seat rotation when just sitting in a car. Preferences when being engaged in an activity like social interaction, reading or other remains subject to further research. Nevertheless, results indicate that most people prefer a certain feeling of control about where they are going, especially while looking out of the window.

In order to compare the ratings of the groups of participants with high and low motion sickness prevalence, Chi-Square tests per rotation were conducted. The analysis showed significant differences in the acceptance depending on the participants' motion sickness prevalence only for rotations 180° (p = .025) and 270° (p = .041). Therefore, motion sickness did only have limited influence on the overall acceptance of seat rotations. This should be investigated further in follow-up studies.

1.2.2 Comfort

After each ride with a certain seat rotation, participants filled out a questionnaire to assess their perceived extent in discomfort in different body parts (see chapter 1.1.2.3.3). In the following, the results of the participant's comfort ratings are described. These are very detailed and support the assumptions made in the overall acceptance of seat rotations.

Each figure refers to the level of discomfort in a particular body part, such as the thigh, the buttocks, the shoulder/neck and the back. Because the questionnaire differentiates between the right and left side of the body, the tables are split into two parts each. The extent of discomfort is depicted on the y-axis. Values from 0 to 6 on the y-axis indicate a very slight discomfort, 6 to 11 points on the scale stand for a slight discomfort, 11 to 16 accredit a medium discomfort, while 16 to 21 indicate a high discomfort and more than 21 points on the y-axis stand for a very high discomfort. When looking on the x-axis, the different seat rotation can be observed. The seat rotation varies from 0°, indicating no rotation, in 30° steps up to 330°. Angles from 30° to 150° represent a rotation to the right, whereas a rotation from 210° to 330° portray a rotation to the left.

Thigh

Figures 6 and 7 portray the comfort rating for the thigh separately for the left and the right half of the body. A Welch-test ($F(11,73.57) = 2.055$, $p < .05$) showed significant differences in comfort ratings of different seat rotations for the left thigh. The results match the ones reported in the overall rating in chapter 1.2.1 and support the discussion pointed out there.

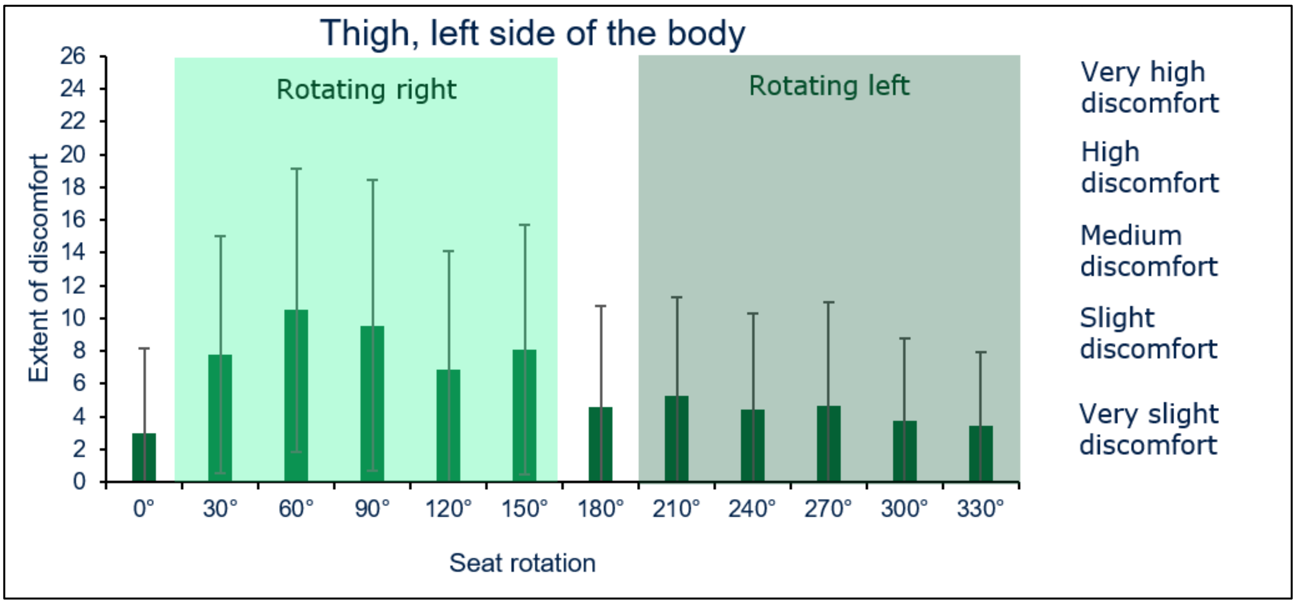


Figure 6 Discomfort for the left thigh dependent on seat rotation rated by participants

A univariate analysis of variance (ANOVA) showed no significant differences in comfort ratings of different seat rotations for the thigh of the right side of the body ($F(11,203) = 1.435$, $p > .05$). Therefore, the descriptive differences as shown in Figure 6 for the right thigh do not hold a statistically significant difference.

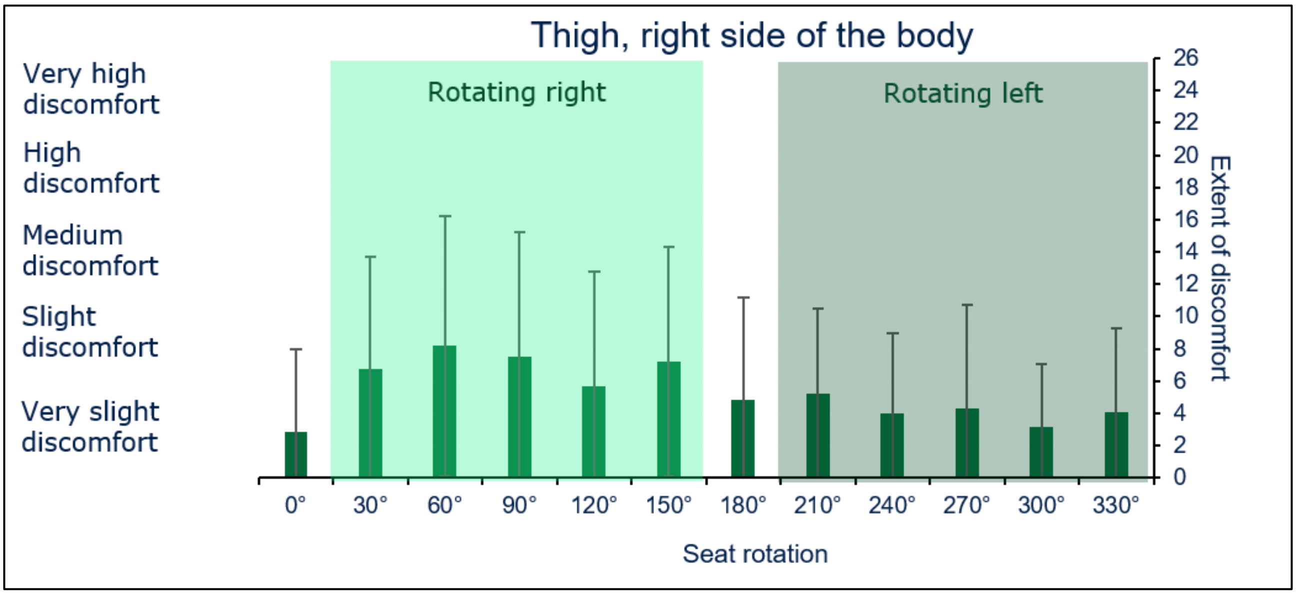


Figure 7 Discomfort for the right thigh dependent on seat rotation rated by participants

Buttocks

Figures 8 and 9 show the comfort rating for the buttocks separately for the left and the right half of the body. An univariate analysis of variance (ANOVA) showed significant differences in comfort ratings of different seat rotations for the left buttocks ($F(11,205) = 3.23$, $p < .001$). Bonferroni-corrected post-hoc tests showed significant differences between the rotations of 0° and 60° ($p < .05$). The results match the ones reported in the overall rating in chapter 1.2.1 and support the discussion pointed out there, especially the large difference between 0° and 60°.

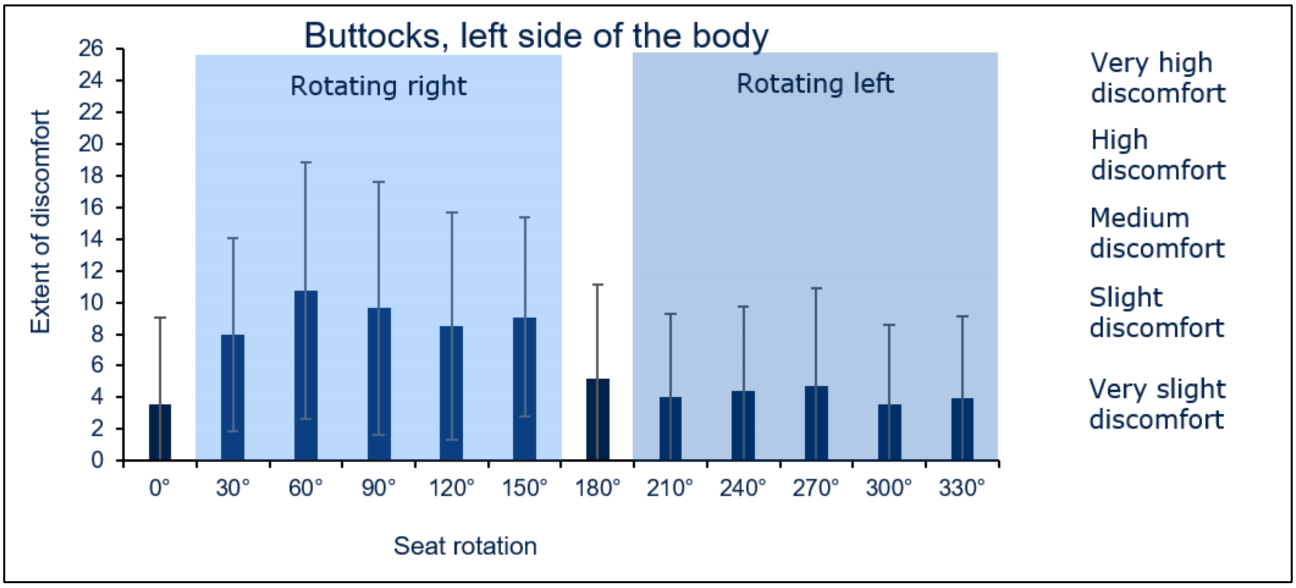


Figure 8 Discomfort for the left buttocks dependent on seat rotation rated by participants

A univariate analysis of variance (ANOVA) showed significant differences in comfort ratings of different seat rotations for the buttocks of the right side of the body ($F(11,204) = 2.189$, $p < .05$) as shown in Figure 10. Bonferroni-corrected post-hoc tests did not show significant differences ($p > .05$), indicating that the differences in the seat rotations for the right buttock are slight and overall, without one certain rotation triggering the significance of the ANOVA.

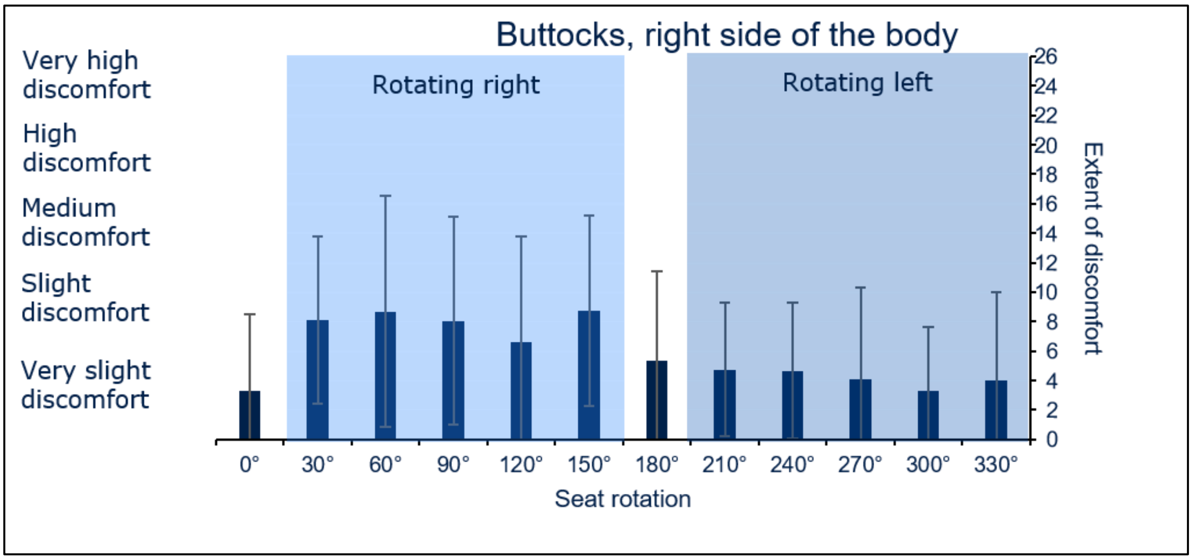


Figure 9 Discomfort for the right buttocks dependent on seat rotation rated by participants

Back

Figures 10 and 11 portray the comfort rating for the back for the left and the right half of the body. An univariate analysis of variance (ANOVA) showed significant differences in comfort ratings of different seat rotations for the left side of the back ($F(11,205) = 5.199$, $p < .001$). Bonferroni-corrected post-hoc tests showed significant differences between the rotations 0° and 60° ($p < .001$), 90° ($p < .001$), 120° ($p < .05$), and 150° ($p < .05$) each, always with 0° rated better than the other rotations named, supporting the preference of 0° over the other rotations from the overall comfort rating.

Further, Bonferroni-corrected post-hoc tests showed significant differences between rotation of 60° and 180° ($p < .05$), 240° ($p < .05$), 300° ($p < .05$), and 330°($p < .05$) each, always with 60° rated worse than the other rotations, again supporting the negative rating for a 60° rotations from the overall comfort rating.

One more Bonferroni-corrected post-hoc test showed a significant differences between rotations of 90° and 300° ($p < .05$), here with 90° rated more negatively. As this difference is relatively low in absolute terms, this result only holds marginal value.

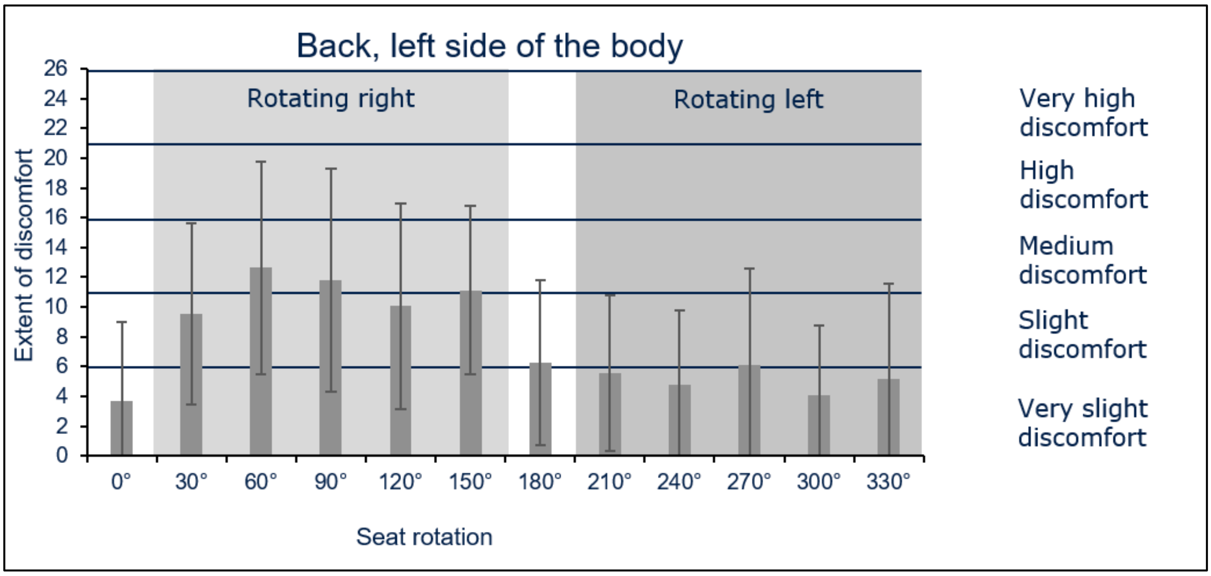


Figure 10 Discomfort for the left side of the back dependent on seat rotation rated by participants

A univariate analysis of variance (ANOVA) showed significant differences in comfort ratings of different seat rotations for the back of the right side of the body ($F(11,199) = 2.615$, $p < .05$) as shown in Figure 11. Bonferroni-corrected post-hoc tests did not show significant differences ($p > .05$), indicating that the differences in the seat rotations for the right side of the back are slight and overall, without one certain rotation triggering the significance of the ANOVA.

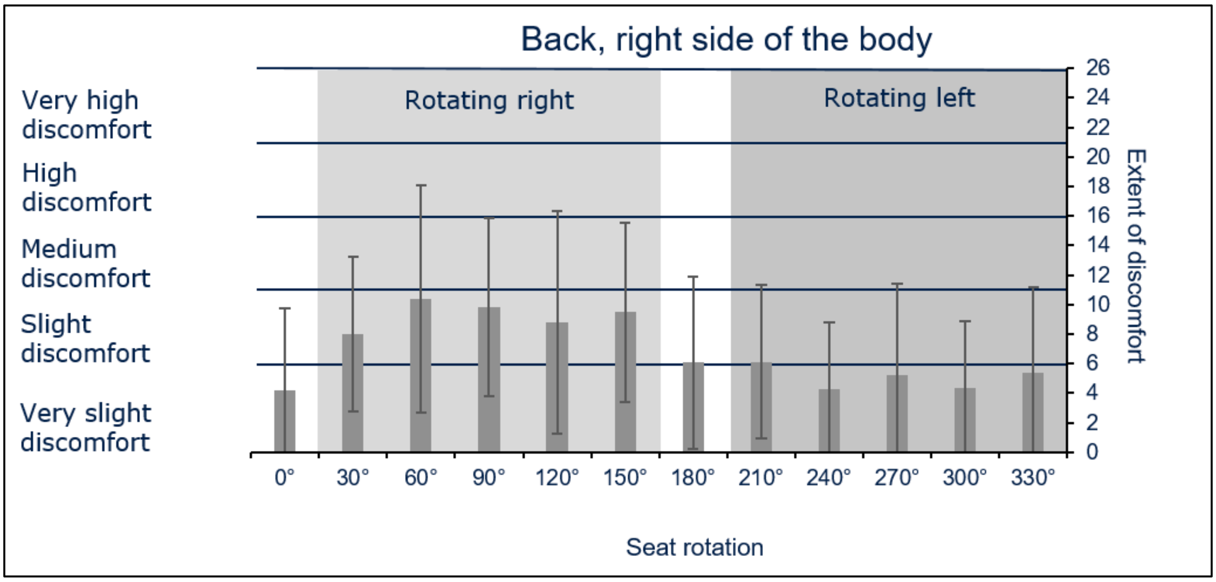


Figure 11 Discomfort for the right side of the back dependent on seat rotation rated by participants

Shoulders

Figure 12 and Figure 13 portray the comfort rating for the shoulders separately for the left and the right half of the body. A univariate analysis of variance (ANOVA) showed significant differences in comfort ratings of different seat rotations for the shoulder of the left side of the body ($F(11,204) = 3.073$, $p < .05$) as shown in Figure 13. Bonferroni-corrected post-hoc tests showed significant differences between the rotations 0° and 60° ($p < .05$), 90° ($p < .05$), 120° ($p < .05$), and 150° ($p < .05$) each, always with 0° rated better than the other rotations named, supporting the preference of 0° over the other rotations from the overall comfort rating.

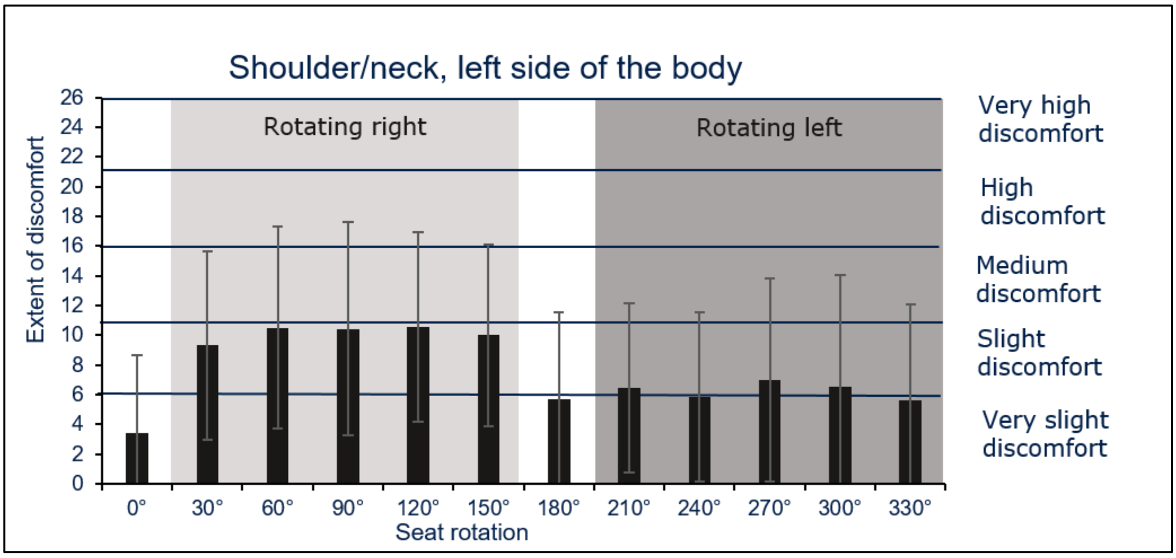


Figure 12 Discomfort for the left side of the shoulder/neck dependent on seat rotation rated by participants

A univariate analysis of variance (ANOVA) showed significant differences in comfort ratings of different seat rotations for the shoulder of the right side of the body ($F(11,204) = 1.834$, $p < .05$) as shown in Figure 13. Bonferroni-corrected post-hoc tests did not show significant differences ($p > .05$), indicating that the differences in the seat rotations for the right shoulders are slight and overall, without one certain rotation triggering the significance of the ANOVA.

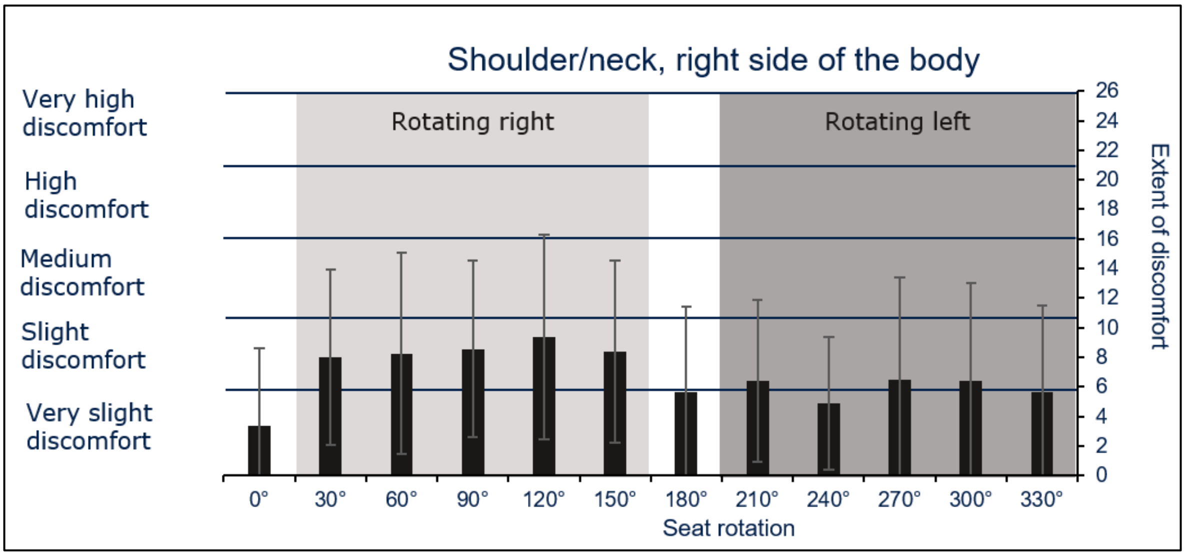


Figure 13 Discomfort for the right side of the shoulder/neck dependent on seat rotation rated by participants

In a nutshell, the rating for the left side of the back shows the most statistically significant differences, indicating that the back plays a crucial role in the subjective assessment of comfort for different seat rotations. One reason for this could be missing armrests, nevertheless this was the case for all rated body parts. The ratings for the left side of the body showed statistically significant differences between certain rotations, additionally to the overall significance, more often than for the right side of the body. This could not have come about because of the positioning of the seat in the vehicle, as the seats were always placed in the middle of the vehicle in order to control for this. If statistically significant, the right-hand rotations (30°-150°) were usually rated more negative than left-hand rotations (210°-330°). The subjective assessment of comfort for the individual body parts remains to have complimentary value to the overall rating of the seat rotations and only gives an indication on how this overall rating could have come about. The effects cannot be given absolute value here but will need further investigation in order to understand the effects properly and learn how and why the statistical significant and not-significant differences have come about and whether these can be replicated. Please note that the sample was not split in terms of motion sickness prevalence for the analysis of comfort for the individual body parts.

1.2.3 Motion Sickness

Figure 14 depicts the results of the Motion Sickness Questionnaire as described in chapter 1.1.2.3.4 depending on the seat rotation. Participants faced forward in seat rotations from 0° to 90° and from 270° to 330° and face backward in seat rotations from 120° to 240° of seat rotation.

Results indicate that the overall Motion Sickness was the lowest level when there was no rotation at all (0°, *M* = 12.05), followed by a 30° rotation to the left (330°, *M* = 12.92) or to the right (30°, *M* = 14.11). The mean overall score rated highest in a 60° rotation (*M* = 16.75), which is still a rather low level compared to the possible maximum of 35. The scores form a wavy shape with lower levels of motion sickness in conditions with a seat rotation facing forward, backwards or in a 90° angle to the left regarding the direction of travelling. In seat rotations that are in between the aforementioned angels, the score increases. The standard variation varies throughout the rotation angles, indicating that some rotation led to a wider spread rating than others.

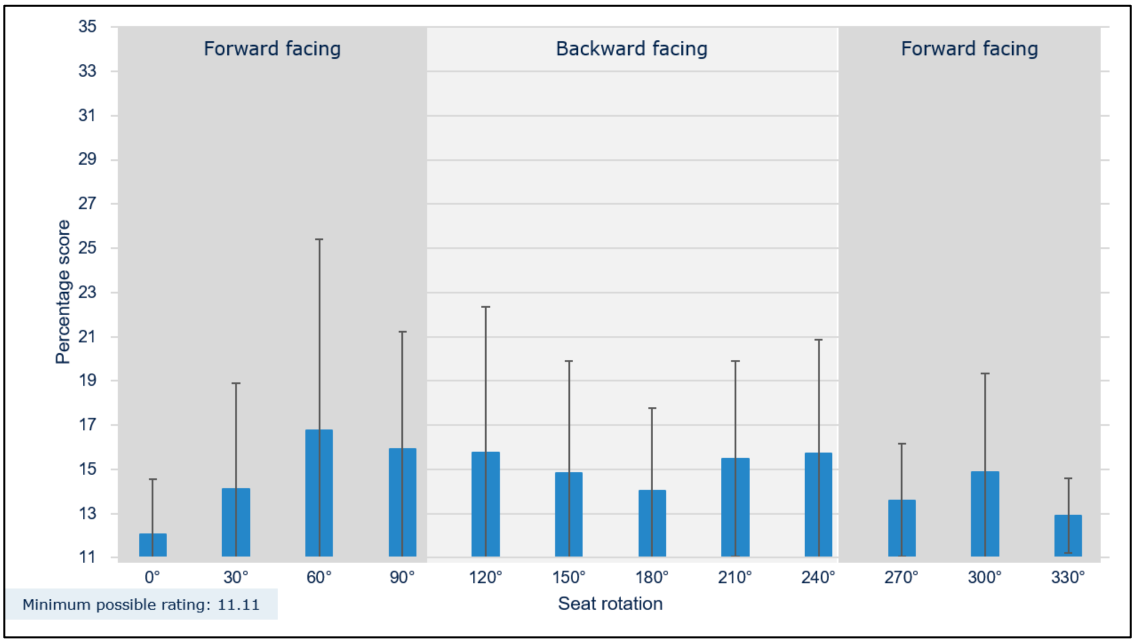


Figure 14 Results of the motion sickness questionnaire depending on the seat rotation

Please note that the motion sickness score only holds descriptive value and was not assessed towards its statistical significance. Motion sickness is an event that builds up over time and cannot be assessed for each rotation individually, as previous trials can distort the results. For this reason, this result on motion sickness only holds informal character and mostly shows that participants in this study did not feel too unwell. For a deeper understanding of the influence of different seat rotations on motion sickness, an individual study is needed. However, motion sickness in this study was assessed for controlling this factor and making sure that participants could express such symptoms individually from their comfort ratings, which were in the focus here.

1.3 Conclusion

Before the study, participants were asked to name the most common activities they do while sitting in the passenger seat. Nearly every participant (98%) reports some kind of activity. The majority of the participants stated that they have a conversation as a passenger. When they were asked to name their preferred seat position while driving passively, most participants would like to face front. When asked for their preferred seat position while driving, some participants stated that they wish to lie down or to sit.

The results of a post-survey that was conducted after the study indicate that the rotation of the seat makes a difference in the feeling of comfort, especially when rating the discomfort for the back. Overall, the results show that overall left-wing rotations were preferred. Under the given testing situations, the comparison between the two groups reveals that the equivalent rotations 60° and 300° were perceived as most uncomfortable.

However, the results of the user study are subject to certain limitations. People were not engaged in any activity, so we can’t make assumptions about the preferences for a certain rotation when people are actually sitting next to one another. Furthermore, the results of the post-survey point out that people in the forward-facing conditions were observed turning their heads in the direction of travel. Follow-up studies will have to clarify what happens if they can’t do this or even can’t look outside. A reason for this behaviour could be a subjective feeling of control when in control about the direction of travel.

The results of the study give a first overview about preferred seat rotations, indicating that people under the given testing specifications preferred left-hand rotations over right-hand rotations. These results are supported by a detailed comfort assessment for certain body parts. However, these results show only a tendency of preferred rotations. Further research is needed to understand these effects in detail. The results serve as a first indicator or the test case matrix in the OSCCAR-project, which rotations are more likely to be preferred by people in an automated driving situation.

2 STUDY ON SEAT POSITIONS, SITTING POSTURES AND ACTIVITIES

The second study focused on seat positions (except rotations), sitting postures, and activities. For this, participants were confronted with an experimental procedure sitting in the rear of a testing vehicle in real-world traffic, considering different use cases such as being engaged in an activity (e.g. work or leisure), either interacting with other participants or being by themselves, or even relaxing without following any kind of activity. Participants were sitting in the rear of the vehicle on seats facing each other and limiting the view on the driver of the vehicle, simulating an autonomous driving situation where they were not engaged in any traffic interaction. During each trial, participant's sitting postures were filmed and subsequently decoded. The output of proportional frequency of each sitting posture for the upper body, head, and legs in relation to the overall travel time serves as input to the test case matrix in order to limit considered activities and sitting postures depending on the seat position for the development of novel restraint systems. This way, the test case matrix can be limited to actually relevant specifications that are taken by people for the majority of the simulated automated driving scenario. This chapter specifies the deduction of the most relevant sitting postures and gives detailed information on the results.

2.1 Methods

The following chapter gives an overview of the methodological approach. In a first step, the participants are described. After that a detailed description of the used materials and stimuli is given before the design and procedure of the study is explained precisely. The user study followed the projects' ethics requirements. Participants were driven in public traffic with a TÜV-approved vehicle and their well-being was monitored throughout the entire ride.

2.1.1 Participants

In the second study, N = 50 participants (61.2% female and 38.8% male) with age ranging from 18 to 58 years and a mean age of M = 26.86 (SD = 10.26; Mo = 19), participated in this experiment. All participants had normal or corrected hearing. Nearly every participant (98%) had normal or corrected vision. On average people spend M = 4.53 times per month as a passenger on longer drives of about 2 hours (SD = 6.11; Mo = 2). A total of 98% stated being German, the remaining 2% are Belarusian. The precondition for participating in the experiment was to be fluent in German in order to understand all instructions and questionnaires appropriately. In a pre-questionnaire participants were asked whether they had ever experienced motion sickness. 51% of the participants stated that they had never experienced motion sickness, 34.7% experienced it seldom and 14.3% suffer sometimes from motion sickness. No participant experiences motion sickness often or always. Moreover, participants were asked which activities they do on longer drives. Therefore, multiple references were possible. Most participants like to listen to the radio or music (N = 39; 18.31%), like to read (N = 33; 15.49%), hold conversations (N = 29; 13.62), sleep (N = 28; 13.15%) or use their smartphone (N = 20; 9.39%). Besides that, participants named activities such as looking outside (N = 16; 7.51%), eating or drinking (N = 16; 7.51%) and working or learning (N = 15; 7.04%). Other less mentioned activities are watching videos (N = 10; 4.69%), playing games (N = 4; 1.88%), singing (N = 1; 0.47%), assessing cars (N = 1; 0.47%) and doing nothing (N = 1; 0.47%).

2.1.2 Materials and Stimuli

In the following, the used material und stimuli are described. First, an overview of the vehicle interior is given to give detailed information of the exact setting. After that the driven parkour is described. For a further understand how the footage of the participant was generated, the camera positioning inside of the vehicle is explained. Finally, the used questionnaires are described.

2.1.2.1 Vehicle

The testing vehicle was a TÜV-approved Ford Transit, as described in chapter 1.1.2.1 with a total of seven seats. All modifications, in the way they were used in this study, are TÜV-approved and judged safe to use in public traffic. The two investigators were seated on the driver seat and the front passenger seat. In comparison to the first study, some changes regarding the arrangement of the seats were made: the participants took seat in the rear part of the vehicle, where a total of four seats was placed, two facing in the direction of driving and two facing the rear window so that two participants sat directly opposite from each other (see Figure 15). Besides that, the rear part of the vehicle was visually isolated from driver's cab using dark fabric. This was done to ensure the best possible experience of an automated ride.

Figure 15 Interior of the testing vehicle

The backrest of the seats could be reclined up to 34 degrees. At the sides of all four seats, scales were attached to have the possibility to read off the chosen backrest position (from 0 to 34 degrees) in testing situations directly. These scales were developed by using a standardized measuring manikin (see Figure 16). By using this manikin, the reference point of the seat of 50cm was measured.

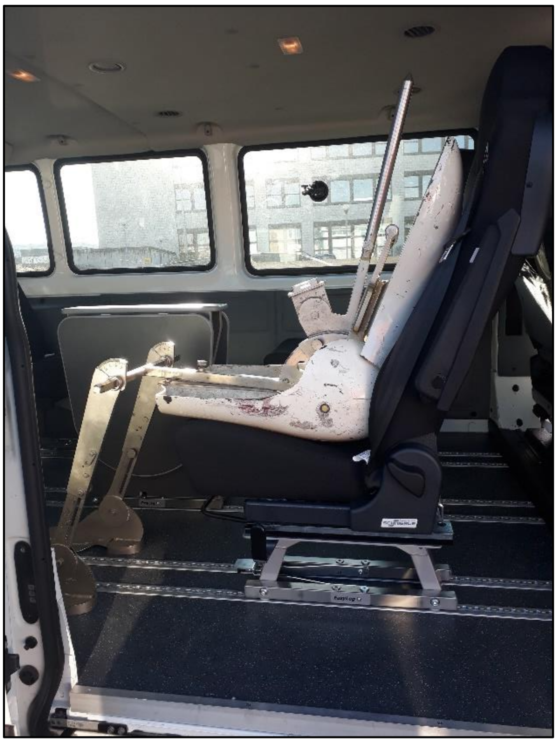


Figure 16 Standardized measuring manikin

As illustrated in Figure 17, the two seats directing in opposite directions were separated by a table (117cm x 52.5cm). Each seat had a width of 41cm and a depth of 55cm. The rear part of the vehicle had a length of 242cm and a width of 174cm.

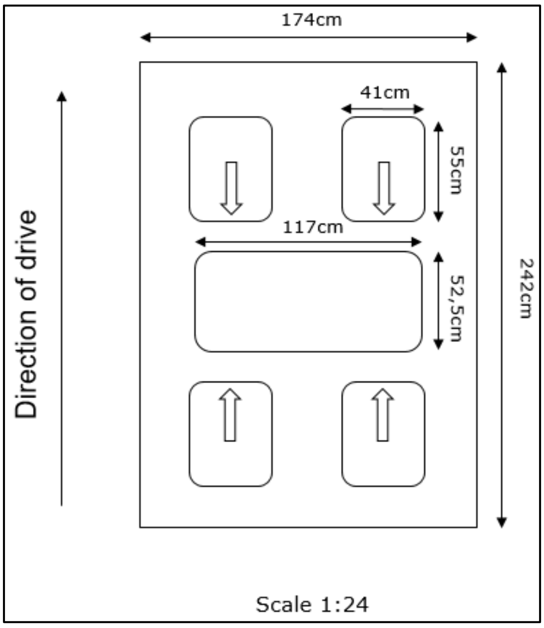


Figure 17 Interior setup of the rear part of the testing vehicle with measures

2.1.2.2 Route

For the user study, a standardized route was specified, ensuring to equally cover driving on a highway, on rural roads and within the city. The route illustrated in Figure 18 was driven twice. If, however, intense traffic due to rush hour or unforeseen events such as congestions on the highways occurred, the second round was shortened by taking a predefined shortcut.

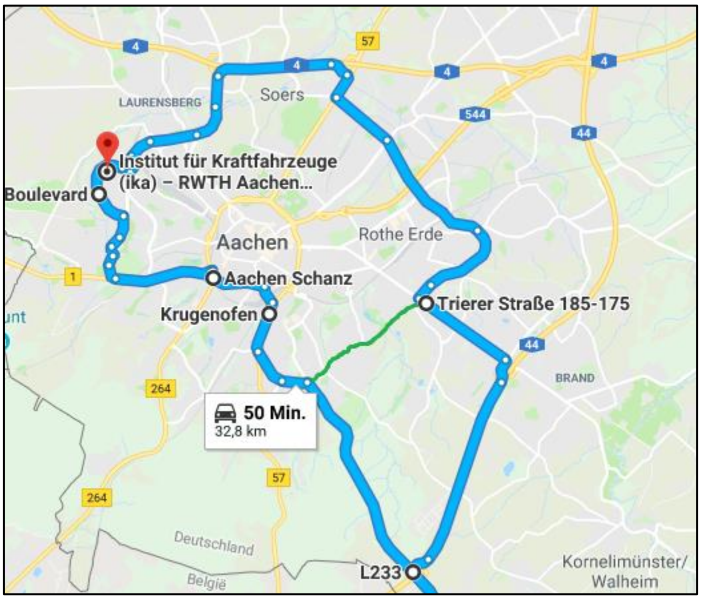


Figure 18 Route of the second study (blue) with short cut (green)

2.1.2.3 Camera Positioning

In total, nine cameras were placed in the vehicle (Figure 19). One was positioned on the windshield, recording the parkour from the drivers view. The remaining eight cameras were placed in the rear part of the vehicle, recording the participants. Every participant was recorded by two cameras, one camera having a frontal view and one having a lateral view, filming over the participants shoulder. This way it was ensured to have footage from different angles.

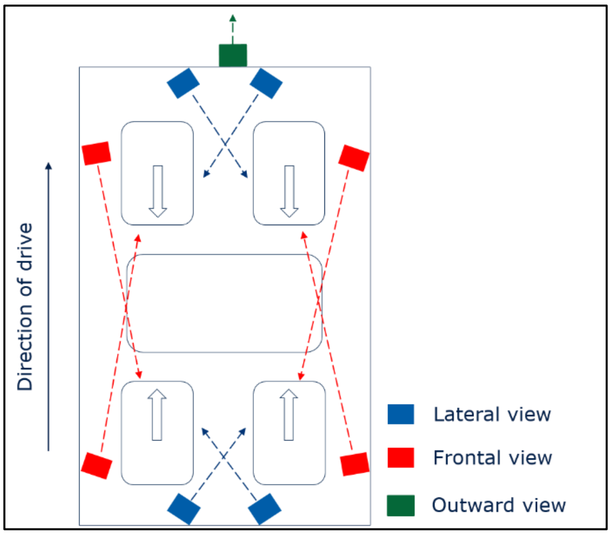


Figure 19 Camera positions in the testing vehicle

2.1.3 Design and Procedure

The second study was conducted with *N* = 51 participants, divided into 13 groups consisting of four people each, with the exception of one group which consisted only of three participants due to the non-appearance of one person. One group had to be excluded from data analysis because participants had to change seats or to cancel the ride due to motion sickness symptoms. Therefore, the final sample contained *N* = 47 participants, divided into 12 groups. Each group was engaged in a predetermined, given activity. The activities were sorted into seven use cases (see Figure 20), categorised by either peers or strangers, leisure or business and activities alone or in a group. In company of their peers, the participants were either working alone (business *N* = 7, leisure *N* = 8) or in groups (business *N*= 4, leisure *N* = 4). In the business condition, people were asked to bring something to work on, for example holding a meeting during the ride. In the leisure condition, they were given board games to play in order to control that they were actually engaged in an active activity together. When surrounded by strangers, the participants were either active alone (*N* = 8, asked to bring something to work on/read etc.) or visually passive, meaning that no other activity but listening to music was allowed. The visual passive groups were further divided by the time of the ride, as one group drove during the day (*N* = 8) and the other during the night (*N* = 8).

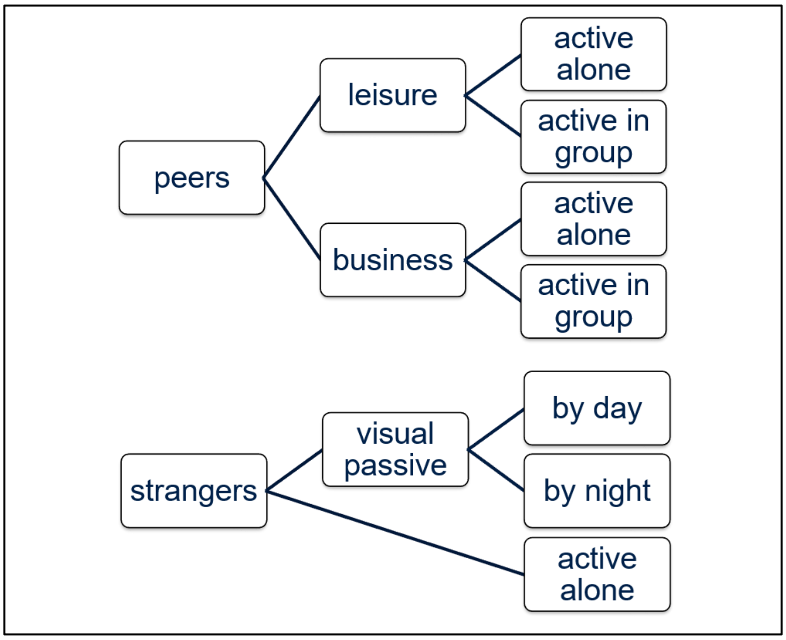


Figure 20 Specification of tested groups and use cases

Participants were greeted on the premises of the ika Aachen and led to the vehicle. Before the ride, a privacy statement on data protection, a confidentiality statement and test track regulations were handed out and explained to the participants, followed by a pre-questionnaire on demographic aspects.

Participants were tested in groups of four and were able to choose the distribution to the seats themselves, thus deciding whether they drove facing the front or back. Inside the vehicle, participants were explained their activities for the ride (see above) and, dependent on the activity at hand, asked not to engage in any contrary activities. Should any participant feel unwell or should want to discontinue the study, they were instructed to alarm the driver so that the ride could be interrupted. Afterwards, participants were asked to adjust the angle of their backrest to a position they felt most comfortable in and to buckle up. The angle of the backseat was measured twice for each seat individually, once before the departure and once after the arrival, in case a participant had readjusted the seat at any point during the ride.

The cameras had been turned on before the participants got on the bus and started recording just before the ride began, activated by a remote control. During the ride, the driver did not interact with the participants, as the feeling of an autonomously driving car was to be created. After arriving back on the ika Aachen premises, the participants filled out a post-questionnaire in order to give feedback on the ride and the study itself. Lastly, the participants were debriefed about the objectives of the user study and of the overall project. The entire experiment was executed in compliance with the project's ethics requirements.

2.2 Results and Discussion

The videos of the second user study were analysed using a distinct matrix displayed in Figure 21 assessing the relevant sitting postures and seat positions taken by participants in the several use cases throughout the second user study. The classification follows the system of similar studies, especially [3], [4], [5] and in part [6]. The learnings from these studies were complimented by discussion from the WP2 workshop held at IDIADA in November 2018. The results from these discussions are displayed in chapter 3.2.3.1 of the deliverable D2.1

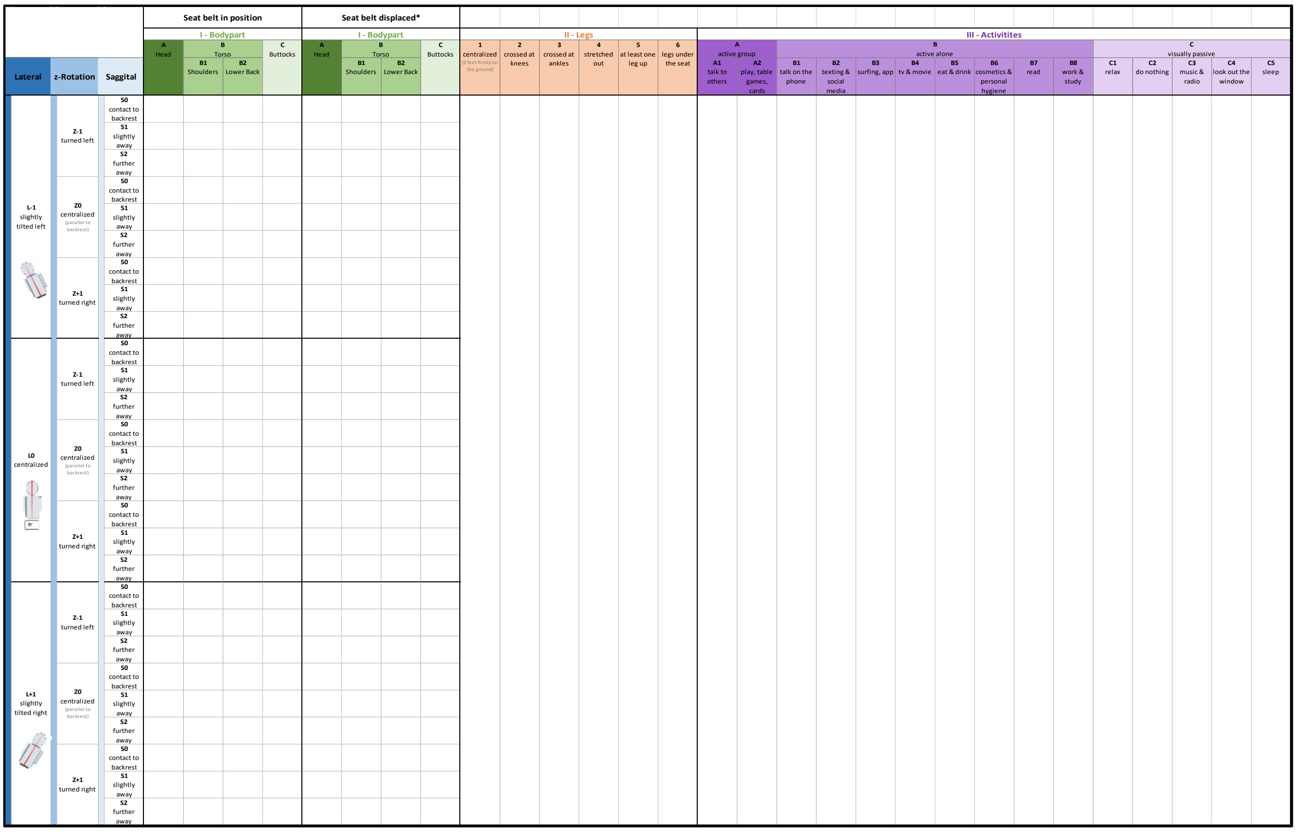


Figure 21 Detailed table for collection of seating positions in user study 2

For efficiency reasons, results for upper body postures, legs and activities are tracked individually. The videos of N = 47 participants were deemed suitable for the video analysis. As each participant was filmed by two cameras (see chapter 2.1.2.3) for a mean time of around 1.5 hours, the entire video material used for this study amounts to approximately 141 hours of video material. Each video was analysed according to the matrix in Figure 21. Decisions regarding the exact classification of the sitting posture were made by each interpreter following a joint scheme. However, if a participant moved between two postures, an individual decision was made by the interpreter. This could have led to small differences between the different interpreter’s choices. Nevertheless, the detailed matrix ensured a classification that is as exact as possible.

In the following, seat positions as chosen by participants in the tested use cases are described. Subsequently, the results for leg positions and sitting postures are displayed individually. For this, the results over all tested are shown before sitting postures for every use case are illustrated. The results in the text show only the most frequent postures.

2.2.1 Seat Positions

As explained in chapter 2.1.3, participants were asked to choose a backrest angle for their ride. The following Table 2 shows the mean backrest angle for each use case. A Welch test showed significant differences in mean values of the angle of backrest depending on group and activity (F(6,16.39)=4.01, p<.05), indicating that participants choose different backrest angles based on the use case .

Table 2 Backrest angles per use case

Group	Activity	Mean value
Peers	Business active in group	*M* = 17,50° (*SD* = 11.24°)
	Leisure active in group	*M* = 29.43° (*SD* = 3.65°)
	Business active alone	*M* = 21.29° (*SD* = 5.16°)
	Leisure active alone	*M* = 27.38° (*SD* = 4.66°)
Strangers	Active alone	*M* = 28.87° (*SD* = 2.85°)
	Visual passive by day	*M* = 31.25° (*SD* = 2.25°)
	Visual passive by night	*M* = 28.50° (*SD* = 5.88°)

2.2.2 Sitting Postures

Sitting postures were deducted from the videos taken of each participant. Figure 22 illustrates the applied categories and levels for sitting postures. For backrest positions, participants were allowed to vary the degree at the beginning of the ride and, if needed, once more during the ride. Backrest angles reclined more than 50° were not included in the user study due to safety reasons in the study conducted in real traffic. Furthermore, the backrest could only be reclined op to 34° due to space reasons in the testing vehicle.

This chapter illustrates the most frequent combinations of sitting postures for each category applied. Results are shown in percent of taken sitting posture over the entire time measured. Chapter 2.2.2.1 gives an overall overview, while chapter 2.2.2.2 splits the results up into use cases. Please note that the results for the different sitting postures are descriptive and have not gone through any analyses checking for significance. For choosing sitting postures for the test case matrix, the relative frequency was of interest.

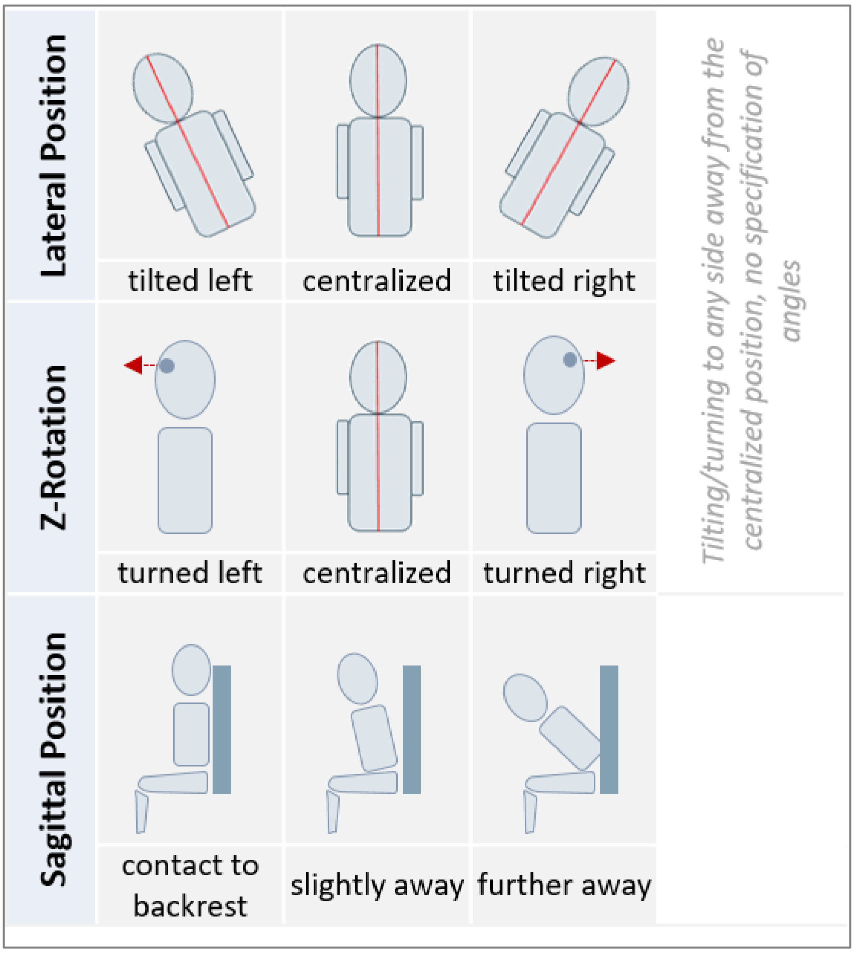


Figure 22 Detailed categories and levels of sitting postures

2.2.2.1 Overall Sitting Postures

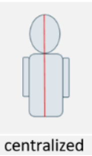
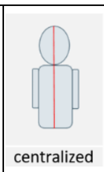
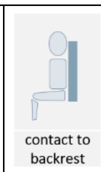
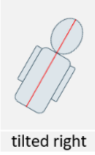
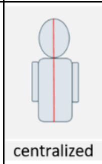
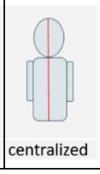
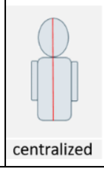
This chapter gives an overview over the most frequently obtained sitting postures over all participants. For this the categories “lateral”, “z-rotation” and “sagittal” have been combined to one overall posture for each body category. The body categories “lower back”, “shoulders”, “head” and “legs” were analysed separately in order to find the most frequently obtained position for each body part and deduct the most relevant cases for the test case matrix.

2.2.2.1.1 Lower Back

The three postures of the lower back taken most frequently over all participants are illustrated in Table 3. By far the most popular posture (85.04% of the time) was the one where people had their lower back fully centralized, in lateral, z-rotated as well as the sagittal position. This position should therefore be considered for the test case matrix. Even though the table shows two more postures for the lower back that were obtained the second and third most often, these were taken by far at a lower percentage of time. We therefore advice to not consider these lower back positions for the test case matrix.

Table 3 Most frequent lower back positions overall (in percent over time, *N* = 47)

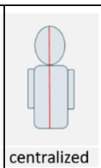
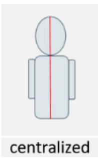
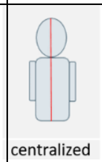
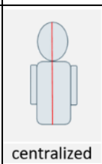
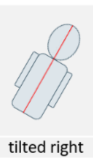
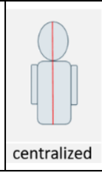
	position			percentage of time
	lateral	z-rotation	sagittal	

1	L0 centralized	 centralized	Z0 centralized	 centralized	S0 contact to backrest	 contact to backrest	85.04%
2	L+1 tilted right	 tilted right	Z0 centralized	 centralized	S0 contact to backrest	 contact to backrest	3.02%
3	L0 centralized	 centralized	Z0 centralized	 centralized	S1 slightly away	 slightly away	2.55%

2.2.2.1.2 Shoulders

The three postures of the shoulders taken most frequently over all participants are illustrated in table 4. Again, the most popular posture (65.43% of the time) was the one where people had their shoulders fully centralized, in lateral, z-rotated as well as the sagittal position. This position should therefore be considered for the test case matrix. The second most often taken position for the shoulders differs from the previously described position in the sagittal view and shows that participants' shoulders were fully centralized in the lateral and z-rotation view but were slightly away from the backrest (17.41% of the time). The posture for the shoulders ranging third shows an even less often percentage of time than the second and should therefore not be considered for the test case matrix. For this, the first posture combination should be considered first, even though the second one does hold relevance as well.

Table 4 Most frequent shoulder positions overall (in percent over time, *N* = 47)

	position						**percentage of time**
	lateral		z-rotation		sagittal		
1	L0 centralized	 centralized	Z0 centralized	 centralized	S0 contact to backrest	 contact to backrest	65.43%
2	L0 centralized	 centralized	Z0 centralized	 centralized	S1 slightly away	 slightly away	17.41%
3	L+1 tilted right	 tilted right	Z0 centralized	 centralized	S0 contact to backrest	 contact to backrest	2.66%

2.2.2.1.3 Head

The analysis for the head postures included the sagittal perspective only, meaning whether the head had contact to the backrest or not. The lateral view was excluded as head movement is usually quite fast and therefore hard to determine, especially as a posture was considered as such when a participant stayed in it for at least 5 seconds. This was scaled down to 2 seconds for the head in order to meet the more active nature of head movements. The same applies to the z-rotation of the head. Furthermore, head and shoulder posture are not independent from one another and results are in close correspondence.

Most of the overall time, participant's head had contact to the backrest (58.01%). However, the head was slightly (24.44%) or further (10.39%) away from the backrest, which is why we advise to include these for the test case matrix if distinct postures of the head will be considered for the test case matrix. As there is usually a large variety of head postures overall and among the use cases, integrating the head postures into the test case matrix can make this quite detailed. This should be considered when choosing the most relevant test cases within WP2.

Table 5 Head positions overall (in percent over time, *N* = 47)

	sagittal position		percentage of time
1	S0 contact to backrest		**58.01%**
2	S1 slightly away		24.44%
3	S2 further away		10.39%

2.2.2.1.4 Legs

The three postures of the legs taken most frequently over all participants are illustrated in Table 5. The most popular posture (52.49% of the time) were centralized legs with two feet firmly planted on the ground. This position should therefore be considered for the test case matrix. The second most often taken position for the leg differs features legs that are crossed at the knees (21.90% of the time). The posture for the shoulders ranging third were two legs/feet underneath the seat (13.93% of the time). This is a considerably lower percentage value than the posture ranging first but is not very far away from the second posture. Therefore, all three leg postures occurring most often should be considered for the test case matrix.

Table 6 Most frequent leg positions overall (in percent over time, *N* = 47)

	position	percentage of time
1	centralized	52.49%
2	crossed at knees	21.90%

3	legs under the seat	13.93%

2.2.2.2 Sitting Postures per Use Case

The results of this chapter show and interpret the postures of participants in the distinct use cases. Every sub-chapter gives an overview over the postures for all body parts. The tables indicate the most frequent postures that we advise to consider for the test case matrix if test case will be broken down to distinct use cases. The percentage of time given in each table refers to the overall time of this body part. The time of one body part spent in the different positions amounts to 100%, not the percentage of time in these overview tables.

When targeting sitting postures for the individual use cases, a more diverse picture unfolds, indicating that people are likely to take different sitting postures dependent on what they are doing in an autonomous vehicle. Please note that al leg positions were possible for all participants, including the fully stretched solution with legs of participants facing each other being put next to one another, as the interior of the testing vehicle provided enough space to do so.

We advise the following sitting postures to be considered for the test case matrix based on the results of the user study described in this appendix:

2.2.2.2.1 Peers – Business – Active Group

The positions taken most frequently in the use case in which N = 4 peers were actively interacting with one another in a business situation are illustrated in Table 7.

Table 7 Most frequent sitting postures in the use case “peers-business-active group”

Body part	Rank	position			Percentage of time
		lateral	z-rotation	Sagittal	
Lower back	1st	centralized	centralized	contact to backrest	86.26%
	2nd	centralized	centralized	further away	9.85%
Shoulders	1st	centralized	centralized	contact to backrest	85.43%
	2nd	centralized	centralized	further away	11.77%
Head	1st			contact to backrest	71.46%
	2nd			slightly away	16.64%
	3rd			further away	10.75%

Legs	1st	crossed at knees	43.84%
	2nd	centralized	25.81%
	3rd	legs under the seat	19.90%

By far the most popular posture (86.26% of the time) was the one where people had their lower back fully centralized, in lateral, z-rotated as well as the sagittal position. This position matches the overall results should therefore be considered for the test case matrix when looking at use case specific sitting postures. However, when interacting with other people, another posture seems to be relevant here, even though it was obtained much less often than the most frequent option. When talking to one another, participants leaned their lower back further away from the back rest, with the lateral and z-rotated view being centralised. Therefore, this posture holds relevance based on the results of this study and we advise to take it into consideration for the test case matrix.

When peers were active as a group for business (*N* = 4), **shoulders** were in the centralized position with contact to the backrest for the majority of the time (85.43%). This was followed by the same characteristics for lateral and z-rotated position, but with the shoulders further away from the backrest (11.77%), even though with a percentage that was by far lower than in the combination ranking first. As both options account to over 97% of the entire time, both should be considered for the test case matrix. Interestingly, the case where shoulders were further away from the backrest was occupied more often than shoulders being just slightly away from the backrest, which would have been a rather more intuitive option. The reason for this is that usually one person was protocolling the discussion on the computer, while the other participants in the group discussed without having to write anything down. Nevertheless, as participants were actively working and interacting with one another, they might have needed to pull farther away from the backrest when they moved at all, e.g. for writing something down on the table. This result is in line with the one for the lower back.

As explained above, the **head** of participants was in constant movement and therefore less often in a constant position than the other body parts. In close correspondence with the shoulders, the head had full contact to the backrest (71.46%). However, being slightly away (16.64%) or further away (10.75%) were relevant postures as well.

When looking at the **legs**, about half of the participants crossed them at the knees (43.84%), followed by a centralized position (25.81%) and legs under the seat (19.90%). Therefore, no choice out of these three most frequent leg positions can be made and all three should be considered for further analysis. The active leg movement can have come about because of the interaction throughout the ride and is in the line with the movement of the upper body.

2.2.2.2.2 Peers – Leisure – Active Group

A less clear picture unfolds when looking at peers interacting with one another in a scenario were a drive for leisure was simulated (see Table 8) with *N* = 4 participants.

Table 8 Most frequent sitting postures in the use case “peers-leisure-active group” (in percent over time)

Body part	Rank	position			Percentage of time
		lateral	z-rotation	Sagittal	

Lower back	1st	centralized	centralized	contact to backrest	25.48%
	2nd	centralized	centralized	further away	23.24%
Shoulders	1st	centralized	centralized	contact to backrest	27.35%
	2nd	centralized	centralized	slightly away	23.09%
	3rd	tilted left	centralized	contact to backrest	14.30%
Head	1st			further away	61.50%
	2nd			slightly away	26.70%
Legs	1st	legs under the seat			29.60%
	2nd	centralized			25.15%
	3rd	crossed at ankles			22.86%

The two postures for the **lower back** that were obtained almost equally often both showed a centralized position for the lower back for lateral view and z-rotation of the body, but people's lower back had either full contact to the backrest (25.48%) or was slightly away (23.24%). The lower back position ranking third follows closely with being taken 14.25% of the time with the lower back-part of the upper body tilted left, facing forward (centralized z-rotation) and contact to the backrest. As all three postures were taken to almost similar percentages of the entire time, we advise to include all three options in the test case matrix.

Similar to the "peers-business-active" group, the **shoulders** were in motion in this active group as well, and even more so in the leisure setting here. Therefore, not only the fully centralized position with contact of the shoulders to the backrest should (27.35%) be considered for the test case matrix, but also shoulders that are slightly away from the backrest (23.09%) and a lateral tilt to the left by the shoulders and an otherwise centralized and full contact to the backrest-like posture (14.30%).

As this use case was the one with most activity and therefore many different postures, the **head** was in a lot of movement as well. As participants rarely took a relaxing position and were focused on their board game. This is the reason why the most frequent position for the head was the head being further away from the backrest (61.50%), followed by the head being slightly away from the backrest (26.70%).

Again, the active nature of the use case resulted in a variety of **leg** positions, which is why the three most frequent should be considered for the test case matrix. Here, legs under the seat (29.60%) and the centralized position (25.15%) were among the most frequently obtained positions. Furthermore, legs crossed at the ankles adds to the three most frequent postures (22.86%). This difference is most likely due to individual differences in preferences of participants.

2.2.2.2.3 Peers – Business – Active Alone

A less diverse result can be seen when looking at peers interacting with one another in a scenario were a drive for leisure was simulated (see Table 9) with N = 7 participants.

Table 9 Most frequent sitting postures in the use case "peers-business-active alone" (in percent over time)

Body part	Rank	position			Percentage of time
		lateral	z-rotation	Sagittal	
Lower back	1st	centralized	centralized	contact to backrest	72.50%
Shoulders	1st	centralized	centralized	contact to backrest	47.97%
	2nd	centralized	centralized	slightly away	26.14%
Head	1st			slightly away	51.91%
	2nd			contact to backrest	27.61%
	3rd			further away	19.82%
Legs	1st	centralized			45.67%
	2nd	crossed at knees			35.46%
	3rd	crossed at ankles			12.40%

The posture for the **lower back** that was usually taken (72.50%) showed a centralized position for the lower back for lateral view and z-rotation of the body and full contact of the lower back to the backrest. The other two positions were taken far less often, which makes sense given that participants did not interact with one another and had therefore no reason to lean their lower back away from the backrest.

For the **shoulders**, results indicate two cases to be considered for further analysis, both the fully centralized option with full contact to the backrest (47.97%) and with shoulders slightly away from the backrest (26.14%). Putting this into the context of the use case. People were working on their own, which resulted in a forward-facing posture with people just sometimes slightly bending forward in order to e.g. write something down.

Especially because participants were working on their own and focused on working on their own (see chapter 2.2.3 of this appendix), the **head** was mostly slightly away from the backrest (51.91%). Nevertheless, full contact to the backrest (27.61%), e.g. while reading, or further away from the backrest (19.82%) were frequent head positions as well and should be considered further.

Considering individual preferences, the **legs** cannot be fully sorted into one category, resulting in three positions to be considered for a use-case specific test case matrix. These were either fully centralized (45.67%), crossed at knees (35.46%) or crossed at the ankles (12.40%).

2.2.2.2.4 Peers – Leisure– Active Alone

The choice is even more clear in this use case, where peers were seated in the vehicle for a trip purpose of leisure time, but being active alone, e.g. on the phone or reading a book (*N* = 8, two groups) as displayed in Table 10.

Table 10 Most frequent sitting postures in the use case "peers-leisure-active alone" (in percent over time)

Body part	Rank	position			Percentage of time
		lateral	z-rotation	Sagittal	
Lower back	1st	centralized	centralized	contact to backrest	99.31%
Shoulders	1st	centralized	centralized	contact to backrest	77.65%
Head	1st			contact to backrest	65.69%
	2nd			slightly away	32.43%
Legs	1st	crossed at knees			48.56%
	2nd	centralized			40.47%

When participants were not working but being active in a leisure situation by themselves, e.g. reading, the fully centralized position with full contact of the **lower back** to the backrest was preferred at 99.31% of the time, indicating to choose this position for further analysis

The same clear statement can be made for the **shoulders**, which were in the fully centralized posture with full contact to the backrest (77.65%) as well. This indicates that people riding in the simulated autonomous driving condition did not really have a reason to move their upper body away from the centralized position.

The **head** of participants in this use case was usually in contact with the backrest (65.69%) or just slightly away from it (32.43%). These are postures that are logical to be obtained when following an activity on their own like e.g. reading and not interacting with any of the other participants.

In this use case, the **leg** positions to be considered for further analysis can be reduced as well. With legs being either crossed at the knees (48.56%) or centralized (40.47%), this displays individual preferences for sitting in a relaxed way of the participants.

2.2.2.2.5 Strangers – Active alone

The results for strangers pursuing an activity on their own (*N* = 8) are displayed in Table 11.

Table 11 Most frequent sitting postures in the use case "strangers-active alone" (in percent over time)

Body part	Rank	position			Percentage of time
		lateral	z-rotation	Sagittal	
Lower back	1st	centralized	centralized	contact to backrest	95.88%
Shoulders	1st	centralized	centralized	contact to backrest	48.55%
	2nd	centralized	centralized	slightly away	47.43%
Head	1st			contact to backrest	55.27%
	2nd			slightly away	38.48%
Legs	1st	centralized			75.54%
	2nd	legs under the seat			18.43%

Here, the fully centralized position with contact of the **lower back** to the backrest is the most common posture (95.88%), with the following two combinations with such a low value, that they hold little relevance to the test case matrix.

When strangers were active but doing so on their own, their **shoulders** were, again, either fully centralized with contact to the backrest (48.55%) or slightly away from the backrest (47.43%) for the other half of the time. Again, they might have bent down slightly for reading or writing down something.

Similar to the shoulders and the previously described use case, the **head** was either in full contact to the backrest (55.27%) or slightly away from it (38.48%) for the same reason as described for the shoulders.

In this use case, the **leg** positions are clearer with being either centralized (75.54%) or, for about a fifth of the time, with legs under the seat (18.43%). This might again display individual preferences of the participants, but the high percentage of the fully centralized leg position indicates this to be the most relevant for the individual activities.

2.2.2.2.6 Strangers – visual passive – by day

For strangers riding in the simulated automated driving situation without doing anything or interacting with other by day, the results are shown in Table 12.

Table 12 Most frequent sitting postures in the use case “strangers-visual passive-by day” (in percent over time)

Body part	Rank	position			Percentage of time
		lateral	z-rotation	Sagittal	
Lower back	1st	centralized	centralized	contact to backrest	85.83%
Shoulders	1st	centralized	centralized	contact to backrest	71.66%
	2nd	centralized	centralized	slightly away	14.16%
Head	1st			contact to backrest	89.75%
	2nd			slightly away	9.87%
Legs	1st	centralized			50.44%
	2nd	legs under the seat			26.69%
	3rd	crossed at knees			12.60%

In the visual passive condition, again participants (*N* = 8) sat in the fully centralized position with full contact of the **lower back** to the backrest for the majority of time (85.83%). The subsequent two options have been obtained far less often with only 5.24% and 2.86% and therefore do not need to be considered for the test case matrix.

The **shoulders** had a similar outcome with the fully centralized position and full contact to the backrest by most participants (71.66%). Still, for a small amount of the time, shoulders of participants were slightly away from the backrest (14.16%). This could have been people looking out of the window and trying to change their sitting posture slightly, as 1.5 hours doing nothing besides being allowed to be listening to music can become boring and quite uncomfortable when remaining in the same position all the time.

In this passive use case, participant’s **heads** were mostly in full contact with the backrest (89.75%). However, a small amount of the time, the head was slightly away from it, e.g. for looking out of the window (please see chapter 2.2.3 for details).

Legs were fully centralized for about half of the observed time (50.44%), but some people seem to have found it comfortable to have their legs under their seat (26.69%) or crossed at the knees (12.60%) as well.

2.2.2.2.7 Strangers – visual passive – by night

Complimentary to the previous chapter, the results for strangers riding in the simulated automated driving situation without doing anything or interacting with other by day are shown in Table 13.

Table 13 Most frequent sitting postures in the use case “strangers-visual passive-by night” (in percent over time)

Body part	Rank	position			Percentage of time
		lateral	z-rotation	Sagittal	
Lower back	1st	centralized	centralized	contact to backrest	100%
Shoulders	1st	centralized	centralized	contact to backrest	87.81%
	2nd	centralized	turned right	contact to backrest	11.38%
Head	1st			contact to backrest	80.99%
Legs	1st	centralized			77.88%

Here, all participants (N = 8) sat in the fully centralized position with full contact of the **lower back** to the backrest the entire time (100%). As some people fell asleep or at least closed their eyes, this is not a surprising result because there was no reason for people to move their lower back to a different position.

The pattern of **shoulders** in the visual passive use case by night differ slightly from the other use cases. While people obtained the fully centralized position with contact to the backrest for most of the time (87.81%), some people turned their shoulders to the right with full contact to the backrest and being centralized from the lateral perspective (11.38%). This can be explained with people falling asleep in this condition, which they were not forbidden to do. This did not happen in the same use case during the day (see chapter 2.2.2.2.6), which can have come about because of people looking out of the window and nothing to see outside in this use case.

As reported for the lower back and the shoulders, the **head** was mostly in full contact with the backrest (80.99%). While participants in the visual passive use case during the day were also looking out of the window, this was just not an alternative in this use case riding in the dark.

The **legs** were mostly fully centralized in this condition (77.88%), indicating that people liked this best for a relaxed ride when other people were present. Further positions were obtained for far less than 10% and are therefore not recommended to be considered for the test case matrix. Even though they would have had the legroom for stretching out their legs, they could have refrained from this in order to be polite towards other participants. Behaviour when being alone in such a simulated autonomous driving situation in real traffic would be an interesting topic for further research.

2.2.3 Activities

The activities N = 47 participants engaged in varied with the different instructions per user case. In Table 14 below, the most often occurring activities across all participants are presented, along with the percentage of time spent on them, divided by groups. As the activities are highly dependent on the use case, no overall activity distribution was made as this would only have had limited informative value.

Participants in the use cases that were engaged in a group activity followed this activity all the time, as instructed. In use cases in which participants were engaged in an activity by themselves, participants mostly listened to music, worked, read something or were on their phones, either texting or on social media. In the visual passive-only conditions, participants followed only the allowed activities, such as listening to music, doing absolutely nothing, looking out of the window or even sleeping. The activities correspond to the sitting postures as reported in chapter 2.2.2.

Table 14 Most frequent activities in the different user cases (in percent over time)

Group	Activity	Percentage of time
Peers – Business – Active in group	talking to others	100,00%
Peers– Leisure – Active in group	playing table games	100,00%
Peers– Business – Active alone	work & study	91.43%
	texting & social media	0.06 %
Peers – Leisure – Active alone	music & radio	40.20 %
	reading	27.18 %
	texting & social media	8.07 %
Strangers – Business – Active alone	music & radio	43.75 %
	reading	20.75 %
	work & study	18.93 %
Strangers – visual passive – by day	music & radio	61.05%
	doing nothing	18.80 %
	looking out of the window	13.09%
Strangers – visual passive – by night	music & radio	68.99%
	doing nothing	17.82%
	sleeping	12.54%

2.3 Conclusion

In this chapter, a conclusion on which sitting postures should be considered for the test case matrix based on the present data is given. The user study on seat positions, sitting postures and activities in a simulated autonomous driving situation showed a variety of results that were discussed in detail in the previous chapter.

When looking at overall sitting postures, we advise the following sitting postures to be considered for the test case matrix based on the results of the user study described in this appendix 2.

Table 15 Most frequent sitting postures over all participants

Body part	Rank	position			Percentage of time
		lateral	z-rotation	Sagittal	
Lower back	1st	centralized	centralized	contact to backrest	85.04%
Shoulders	1st	centralized	centralized	contact to backrest	65.43%
	2nd	centralized	centralized	slightly away	17.41%
Head	1st			contact to backrest	58.01%
	2nd			slightly away	24.44%
	3rd			further away	10.39%
Legs	1st	centralized			52.49%
	2nd	crossed at knees			21.90%
	3rd	Legs under the seat			13.93%

The analysis of sitting postures in the individual use cases revealed a similar pattern of results but gave a deeper understanding on the circumstances and situations in which people took a certain posture in the study described in this appendix 2 of deliverable D2.1. We strongly advice to consider those results as described in chapter 2.2.2.2 of this appendix 2 for the test case matrix when a certain use case as tested in the present study will be considered there. However, these groups had a relatively low sample size as this factor was tested as a between-subject factor with N = 4-8 participants in order to control for different use cases at all. The focus of the study was gaining an overall impression of most frequent sitting postures, but this inevitably led to the manifestation of presumably some personal preferences of certain e.g. leg positions between the use cases and should be treated considerably and not as a universally given circumstance.

When considering activities, these can only give reliable insights in the context of the individual use cases. Furthermore, participants followed the instructions which can be concluded from the distinct analysis of the time following a certain activity. This analysis gives further insights into the reasons for presumably obtaining a certain sitting posture.

Summing up, the study was able to attain a dataset of verified sitting postures and seat positions within the setting of this user study. With these insights, justified statements can be made towards the probability of certain sitting postures in a simulated automated driving situation as carried out in this user study. Nevertheless, future studies should focus on elaborating the learnings further and transfer them to various vehicle concepts, use cases and settings, including a larger sample of participants in order to generalize the results to the upcoming challenges and chances of autonomous vehicles and their users.

3 REFERENCES IN APPENDIX 2

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APPENDIX 3 – BASE LINE STUDY: STATE-OF-THE-ART HUMAN BODY MODELS AND INJURY RISK EVALUATION

Author: Christian Mayer, Daimler

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Intro/objective

As outlined in chapter 3.2., the Individual Human Variation or injury risk evaluation dimension completes the Test Case Matrix and thereby the future safety assessment framework for occupant safety of HAVs. Computational techniques or at last Virtual Testing and the use of FE (Finite Element) or MBS (Multi Body Systems) HBMs are well addressed in the objectives of OSCCAR. They are already identified as enabling methodology for injury prediction and risk evaluation of HAV occupants related with the two other dimensions of the Test Case Matrix and now within this dimension, allowing the representation of individual human characteristics.

Nevertheless, current state-of-the-art HBM still have limitations or drawbacks when used within the above-mentioned framework and new seating configurations and seat positions. With the purpose to demonstrate the baseline respectively injury prediction capability of today's HBMs within pre-crash and crash applications a simulation study was performed. The results of this study will also be used as input data for the conceptual tasks 2.2, 2.3 and 2.4. Deficits concerning validation status, tissue modelling aspects and finally injury criteria are also formulated as research needs to be addressed by WP3.

Related with the intention to run this baseline study in the sense of the term state-of-the-art also exemplary load cases and seating postures were proposed and agreed in the WP2 WS. For the state-of-the-art load case definition, the hypothesis "ADAS operant on the road" was formulated.

Especially the findings of the EU project SafeEV [1] [2] were reviewed and preliminary results from WP1 ("ADAS effect") were considered. Five conflict scenarios were defined and described in more detail in the related subchapters below.

It should explicitly be stated, that these load cases are not a part of the crash configuration dimension respectively test matrix - but might be interpreted as "precursor".

To represent the occupant a selection of THUMS-D models were used. This was due to the fact, that only the OSCCAR Partner Daimler was designated to perform this baseline study and the related simulations. All these HBM are mainly based on the THUMS FE model (V3 or V4). Literature references are given, if equivalent models (e.g. GHBM) or similar modelling of respective human characteristics (Active HBM) are in place.

The "Generic Interior" model [40] was used to configure the interior and restraint environment. Within this baseline study the restraint and interior (seat, dashboard etc.) components of the Generic Interior were modelled in such a way, that they also represent state-of-the-art restraint and current vehicle interior concept.

This appendix 3 shows detailed information about the kinematics of the occupant in all five load cases, an extended injury risk evaluation and further criteria used within the post processing.

1 CASE 1 - HEAD ON AT INTERSECTION

1.1 Simulation set up

Case 1 is an oblique frontal impact with a preceding pre-crash manoeuvre, simulating an oncoming vehicle turning into path of the host vehicle, see Figure 1. A midsize male model is placed in the front passenger seat. An Active HBM (A-THUMS-D 3.3.5) was used within the avoidance manoeuvre (1g braking and lane change pulse applied to a vehicle travelling at approx. 50 kph), by the ADAS function in the host vehicle. A transition was made to the THUMS V4 for in-crash phase simulation of a 40 kph oblique frontal impact. Standard restraint systems of pre-triggered three-point belt, and passenger airbag were used. A crash pulse was taken from internal database.

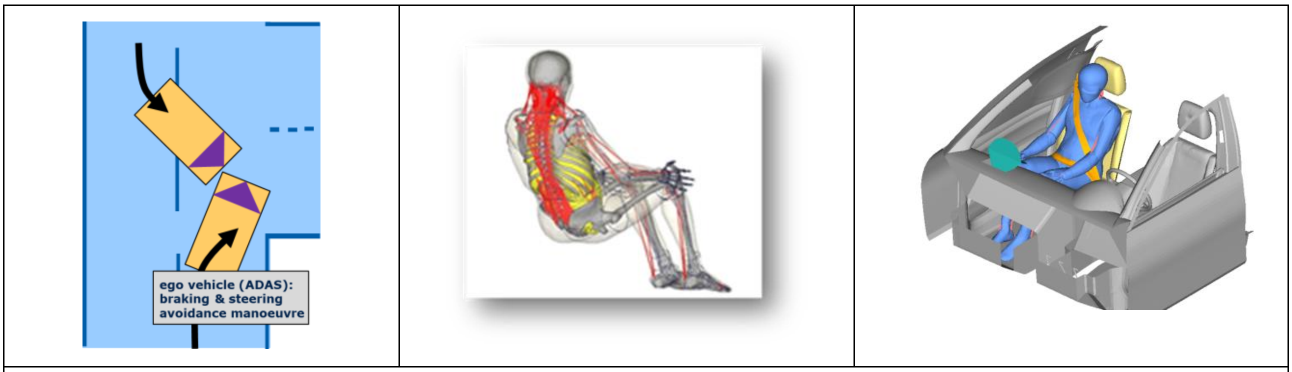


Figure 1 Case 1 - Head-on at intersection with avoidance manoeuvre of host vehicle, midsize passenger

The software tools utilized for conducting frontal crash simulations are listed below:

- **Pre-Processor:** Beta CAE ANSA v.18.1.0, LS-Pre-post v.4
- **FEM-Solver:** LS-DYNA V971 beta release R6.1.2 MPP, DP
- **Post-Processor:** Altair Hyperview v.12, LS-pre-post v.4, Animator 4
- **Occupant Positioning:** Positioning of Daimler FE Human Body Models were done using in-house developed simulation approach
- **FE Models**: Sled Model, THUMSv4 Occupant model
- **Injury Risk Prediction Post-Processor**: A post processing tool was developed by TU-Graz to assess injuries through human body models – Dynasaur

Table 1 Injury parameters for assessment using HBM in crash impact scenario

Body Region	**Injury Indicator/Injury Risk Assessment**	**THUMS v4**	**THUMS-TUC v3.01**	**THUMS-D v4 Obese (v1.0)**	**THUMS-D 5%ile Eastern Female**	**THUMS-D 50%ile Male**
Brain	Cumulative Strain Damage Measure used for THUMS V4.02 Injury Risk Curve of DAI AIS 4+	△	•	•		
	Cumulative Strain Damage Measure (No injury risk curve exists for female) >> 50th %ile injury risk considered with FPS of 15%				•	
	SUFEHM Criterion developed by University of Strasbourg					•
Neck / Spine	SUFEHN Criterion developed by University of Strasbourg (Probabilistic Force Based Criterion)					•
Thorax / Rib Fracture	Probabilistic (Forman criterion)		•	•		
	Deterministic Injury predictor (Burstein criterion developed for long bones but used for other skeletal areas/body regions)	△			•	•
Abdomen	No evaluation done / No detailed abdomen organs exists in the model					
Pelvic	Deterministic Injury predictor (Burstein criterion developed for long bones but used for other skeletal areas/body regions)	△	•		•	•
	Probabilistic injury criterion developd for THUMSv4 based on max. Principla Strain by Perese et al.			•		
Femur	Deterministic Injury predictor (Burstein criterion developed for long bones)				•	

1.2 Status HBM used

Within the case 1 scenario two HBM were applied, representing also a coupled pre-crash and in-crash simulation approach

A-THUMS-D 50th Male (3.3.5 - Daimler internal release):

This model respectively the methodological approach to develop two model derivatives for dedicated use in a pre-crash phase and in-crash phase including the implementation of a transition method was finally motivated by the fact, that the model should show valid characteristics and be effective

- in a relaxed (w/o muscle activity) state and therefore show valid soft tissues response in low g scenarios
- when implementing active muscles and human behaviour by taking optimisation of calculation time into account in parallel.

The model [3] is based on THUMS-D, which is already a derivative of THUMS V1.2 & V3. A-THUMS-D is currently capable to represent active occupant kinematics in frontal 1g braking pulse & lateral manoeuvres. Macroscopic validation for these application is mainly based on the OM4IS database which was published by Huber at al [4].

Active characteristics are currently achieved by implementation of a hybrid equilibrium point controller (hybrid controller) coupled with activation dynamics from Hatze [5] interacting with contraction dynamics from MAT_MUSCLE (MAT_156) in LS_DYNA [6].

Similar activities concerning soft tissue material characteristic in terms of valid behaviour under low g and implementation to the THUMS-VW (FE code VPS) are reported by Yigit et al [7]. Latest validation results and status of the reactive THUMS-VW under moderate lateral loading are reported by Sugiyama et al [8]. Lambda controller runs in the VPS solver via a user function. 600 muscles (Hill type) with 66 controllers are modelled.

Östh et al [9] have previously developed a finite element (FE) HBM with proportional integral derivate (PID) controlled Hill-type muscle system model. The neuromuscular feedback control was implemented also for the THUMS AM50 version 3.0 with some enhancements to the model [10]. The so called SAFER AHBM uses a 1D Hill-type model, as muscle representation, with muscles controlled by PID feedback, via stabilising muscle activation generated in response to external perturbation [11].

Application of the SAFER AHBM including its implementation to the above-mentioned crash/in-crash transition method could be found also in the reporting of SafeEV [38]. It should be mentioned that the SAFER AHBM also allows “single model” respectively continuously simulation of pre- & in-crash phase. Latest applications are reported by Östh et al [12].

Same methodological approach is applicable with the latest MBS MADYMO active human model [13]. Several publications on this subject can be found within relevant conference proceedings. Exemplarily and related with this use case the publication from Bosma et al should be mentioned [14]. Beside the application of the active HBM also the injury evaluation in comparison to latest ATDs (THOR & HIII) is discussed in this paper. The model is currently validated for frontal (forward and rear) and lateral pre-crash manoeuvres.

Another, commercially available FE model with ability to model active behaviour of a human in pre-crash and in-crash situations is the latest version of the THUMS model. This THUMS V5 currently exists in the configuration of an AF05, AM50 and AM95 [15] [16]. Two hundred and sixty-two (262) major skeletal muscles are currently represented by one-dimensional truss elements with Hill-type muscle model in THUMS V5. The active behaviour can be simulated by activating the muscle elements using prescribed parameters and functions. Matsuda et al presented the results of their study concerning the simulation of occupant posture changes due to evasive manoeuvres and effect on injury risk in vehicle frontal and side collisions at IRCOBI 2018 [17]. This recently published application of an active HBM is also quite close to this exemplary baseline load case. Finally, also THUMS V4 was used in a similar way within the crash phase and for injury risk evaluation.

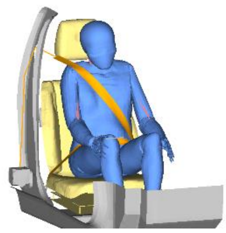
THUMS V4 was used to evaluate the injury risk in the in-crash phase. An in-house transition method was applied to transfer the physical parameters (posture and velocities) from the source (pre-crash) to the target (in-crash) model. A general description of the method can be found in the SafeEV deliverable D4.2 (see also SAFER AHBM above) [38]. Further activities on this topic are also foreseen in OSCCAR WP4.

Also, THUMS V4 is commercially available via JSOL coop. and several publications can be found within related literature and relevant conferences [18]. Comparable state-of-the-art FE human body model is represented by the GHBM (Global Human Body Model). J. Combest recently presented the latest development and project plan at the 7th HBM symposium 2018 in Berlin [19].

1.3 Results and observations

1.3.1 Precrash Phase

This section incorporates 1g braking and lane change pulse applied to a vehicle travelling at 50 kph. Figure 2 below illustrates occupant kinematics during the pre-crash avoidance manoeuvre phase. The existing virtual simulation sled model had seatbelts with pre-tensioner & load limiter and a passenger airbag. However, for the pre-crash scenario these systems were de-activated. Under the influence of the pre-crash pulse, the occupant moves away from the original posture & moves closer to the centre console. In the pre-crash phase, no contact with the centre console is observed.

	
0 ms	100 ms
	
200 ms	300 ms
	
400 ms	500 ms
	
600 ms	700 ms

	
800 ms	1000 ms

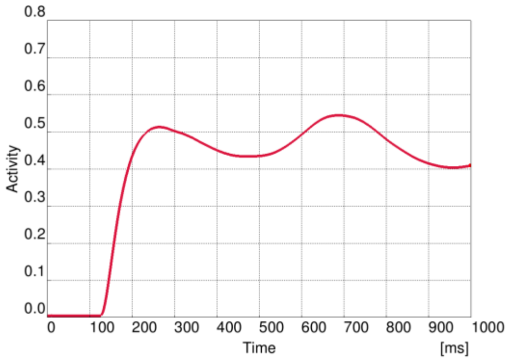
Figure 2 Occupant kinematics using ATHUMSD 3.3.5 50th percentile male active occupant

Muscle activities of 4 muscles were tracked which broadly represent neck lateral flexors, neck extensors, torso lateral flexors and torso extensors.

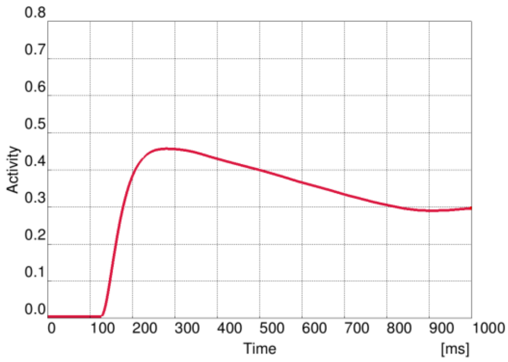
Table 2 Muscle activities tracked in case 1 manoeuvre

Muscle	Type
Levator Scapulae	Neck Lateral Flexor
Semispinalis Capitis	Neck Extensor
External Oblique	Torso Lateral Flexor
Erector Spinae Iliocostalis Thoracis Pars Thoracis	Torso Extensor

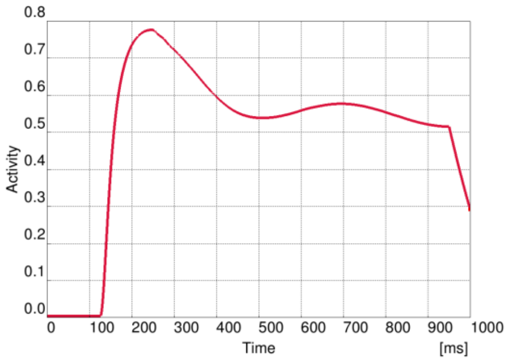
Model muscle activation for 4 representative muscles and body region excursions have been plotted in Figure 3 and Figure 4 below.



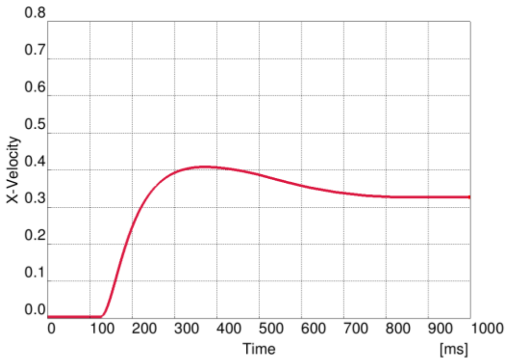
Levator Scapulae



Semispinalis Capitis

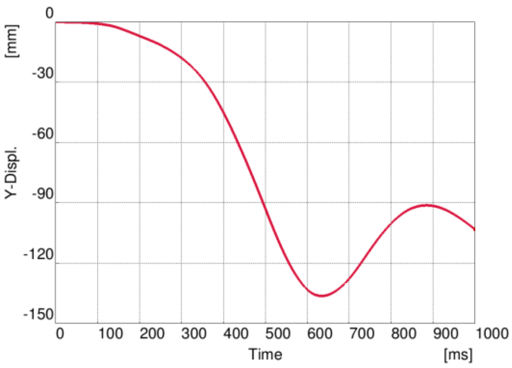


External Oblique



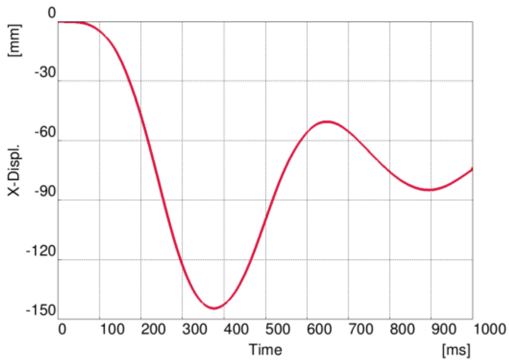
Erector Spinae Longissimus Thorcis Pars Thoracis

Figure 3 Activity levels of 4 representative muscle groups

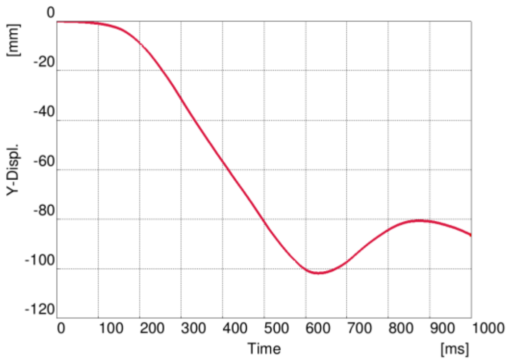


2

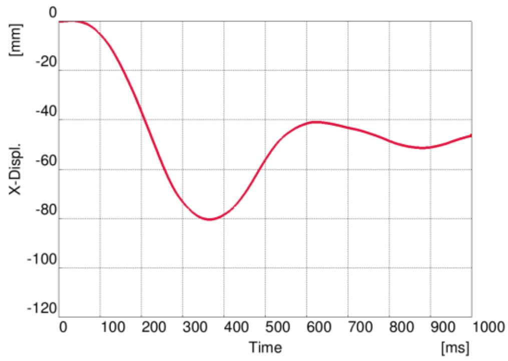
Head Y Excursion



Head X Excursion



Torso Y Excursion

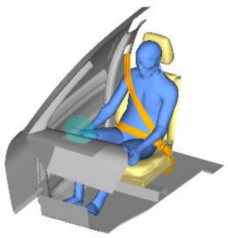
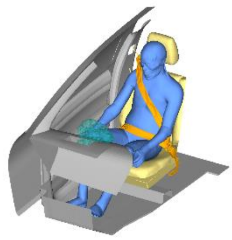


Torso X Excursion

Figure 4 Body region excursions

1.3.2 In-Crash Phase

Figure 19 shows the overall kinematics of the occupant in the in-crash phase. The same triggering time of the pre-tensioning and airbag system as used in a standard frontal load case have been considered. No real interaction with the passenger airbag is seen. Belt interaction loads the pelvis and rib cage both due to the oblique movement of the occupant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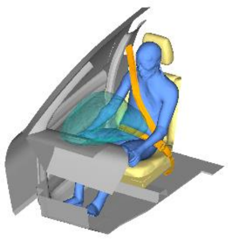
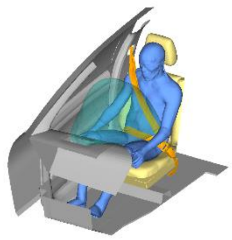
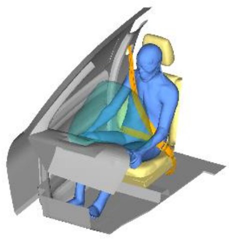
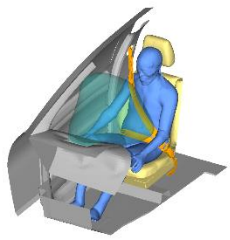
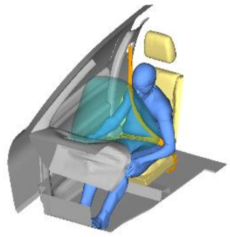
	
20 ms	30 ms
	
40 ms	50 ms
	
60 ms	70 ms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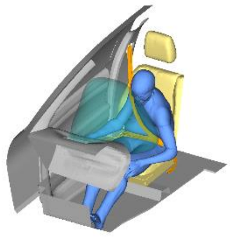	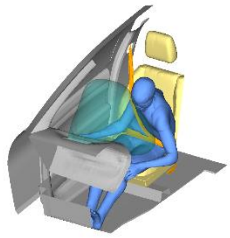
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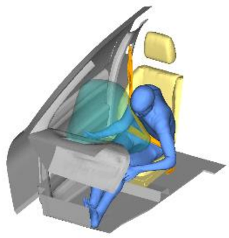
	
120 ms	130 ms

Figure 5 Occupant kinematics using THUMS version 4 50th percentile male occupant model

Low head injury risks are observed for this conflict scenario as illustrated in the Figure 6. No hard and grazing contact is observed with the occupant at 91 *ms* as illustrated in Figure 7 & Figure 8 below.

Ribcage injuries are predicted for this conflict scenario based on Burstein criterion. Figure 9 illustrates the contact forces between seatbelt and occupant which reach a peak value of ~9 kN at 82 *ms.* The belt interaction loads the pelvis and rib cage both. Ribcage injury risk is observed in right rib cage towards the posterior parts of the ribs (Figure 11). This might result in the occurrence of rib cage injury risk.

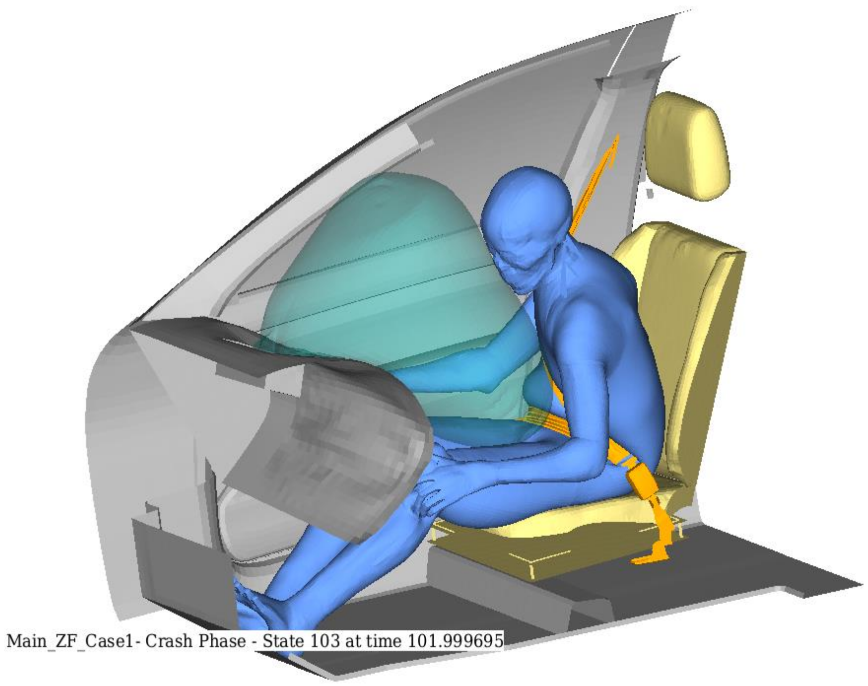


Figure 6 Passenger airbag interaction with occupant

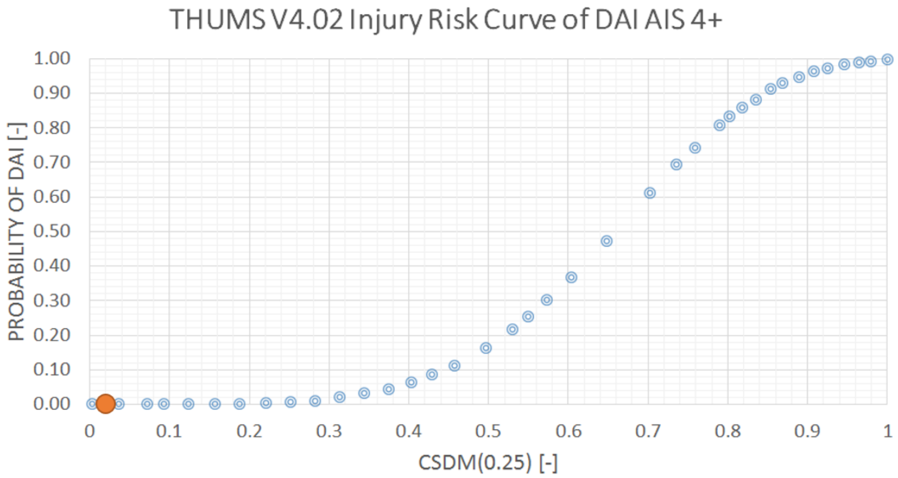


Figure 7 Head injury risk (Source: Toyota)

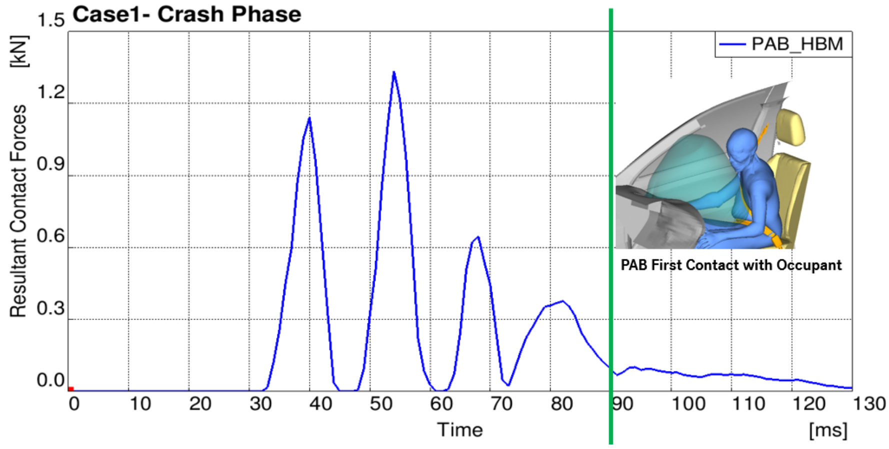


Figure 8 Passenger Airbag Contact Forces with Occupant

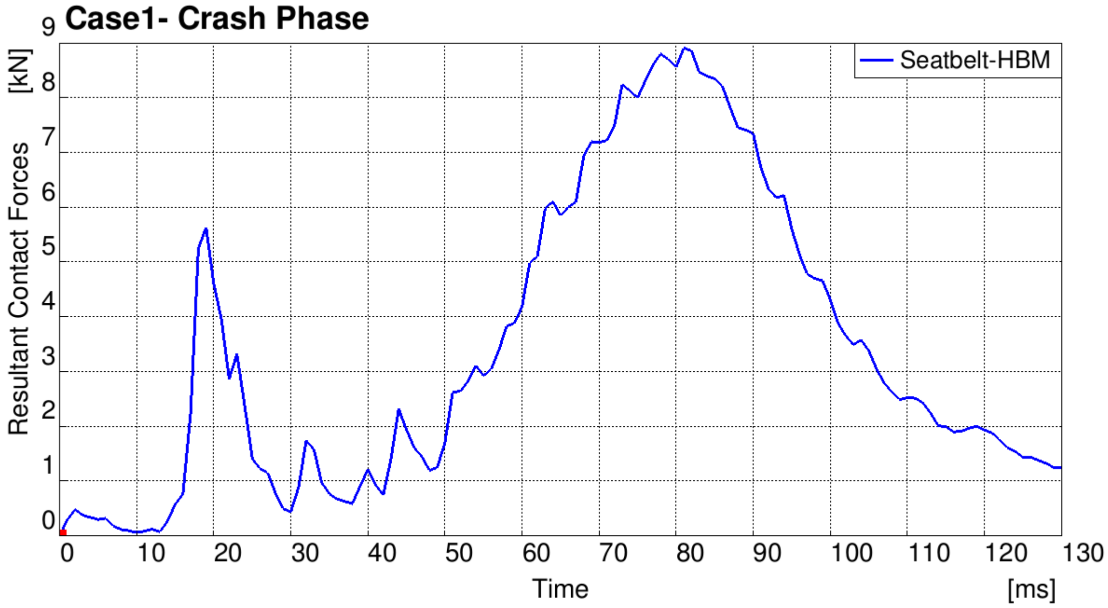


Figure 9 HBM – seatbelt contact forces

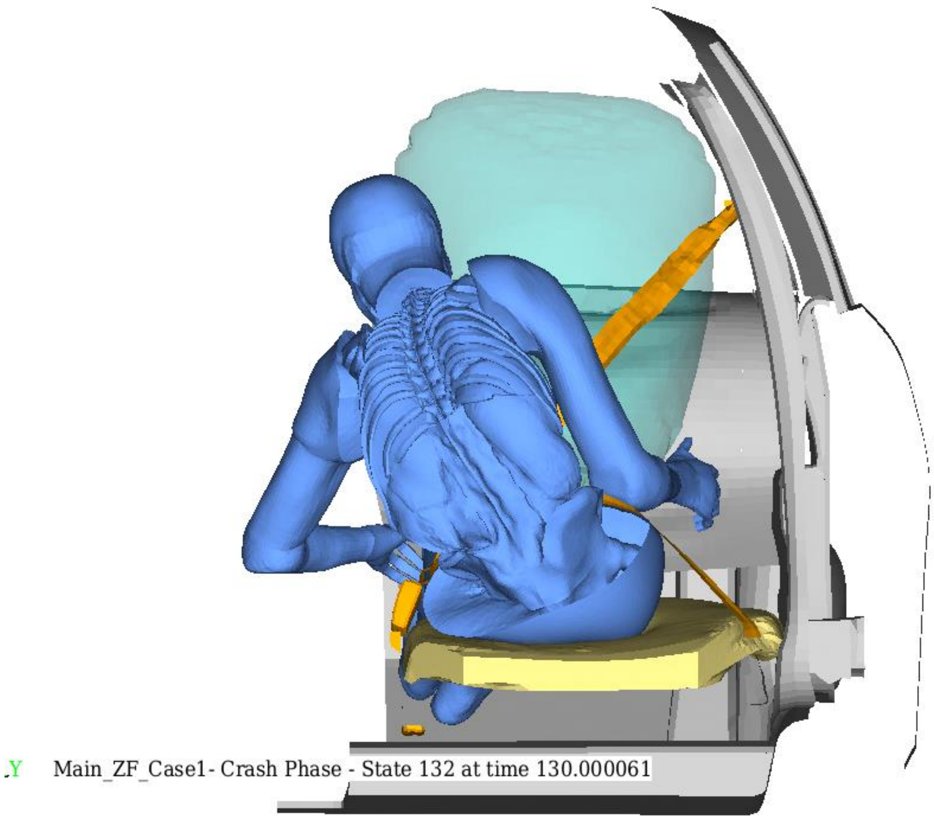


Figure 10 Response of ribcage at 130 ms

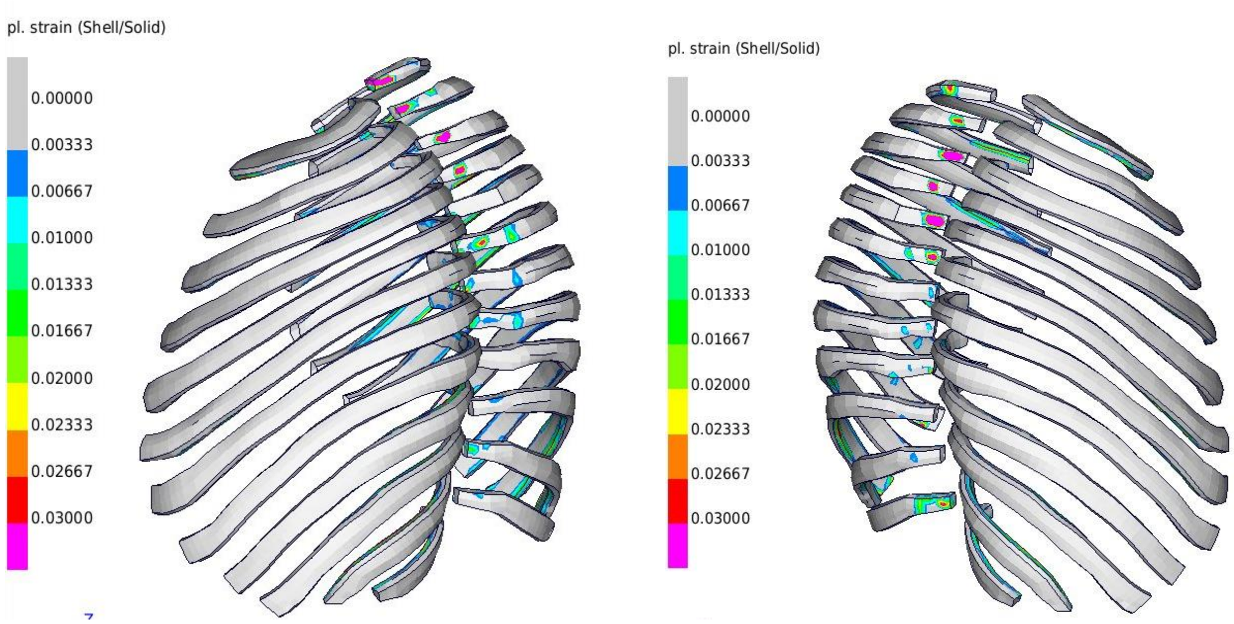


Figure 11 Plastic strains in ribcage at 130 ms

Pelvis injury risks for the 45-year-old occupant is 54.46% and can be considered that risk exists. The risk in pelvis is due to the loading from the belt and buckle. Figure 12 & Figure 13 illustrate the pelvic injury risk and rotation of the occupant towards the left pelvis leading to injury risks. This is a local effect and should be further investigated in later work packages.

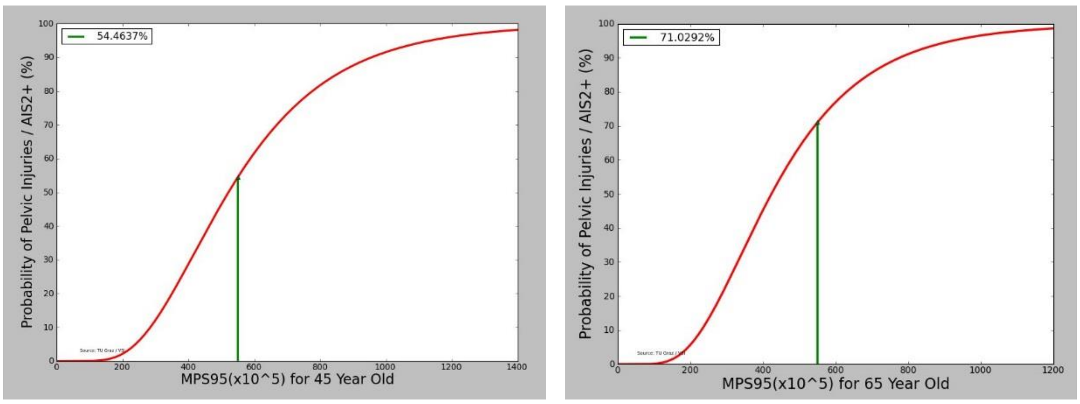


Figure 12 Pelvic injury risk

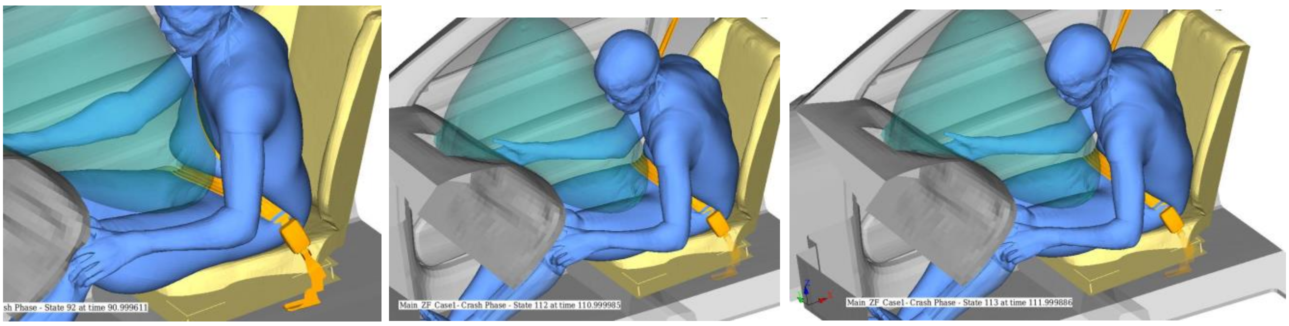


Figure 13 Seatbelt buckle interaction with occupant showcasing loading on pelvis

2 CASE 2 - CROSSING FAR SIDE

2.1 Simulation set up

Case 2 is a side impact at 40 kph on the passenger side exposing the midsized male driver (THUMS-TUC (3.01) to a far-side impact, see Figure 14. It represents an opponent vehicle running into the host vehicle in a crossing situation. No avoidance manoeuvre of the host vehicle due to obstructed view. Driver restrained by standard three-point belt and driver airbag. A crash pulse was taken from an internal database. This setup also represents exemplarily a possible “rotated seat” configuration of the UseCase dimension.

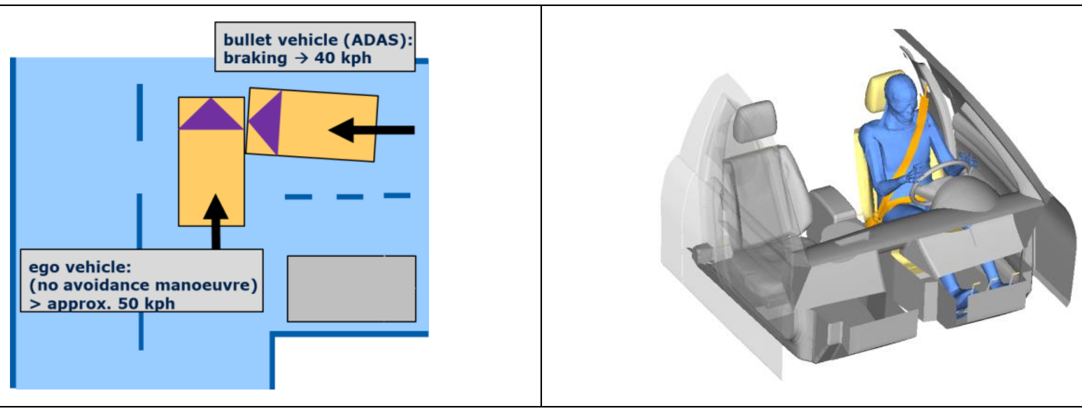


Figure 14 Case 2 – crossing far-side, midsize male driver

The software tools utilized for conducting side crash simulations are listed below:

- **Pre-Processor:** Beta CAE ANSA v.18.1.0, LS-Pre-post v.4
- **FEM-Solver:** LS-DYNA V971 beta release R7.1.3 MPP, DP
- **Post-Processor:** Altair Hyperview v.12, LS-pre-post v.4, SUFEHM IRA Tool, Animator 4
- **Occupant Positioning: :** Positioning of Daimler FE Human Body Models were done using Daimlers developed positioning tool named FETOOL.
- **FE Models**: Sled Model, THUMS-TUC v3.01 Occupant model
- **Injury Risk Prediction Post-Processor**: A post processing tool was developed by TU-Graz to assess injuries through human body models – Dynasaur, UVA developed Rib Fracture tool

Table 3 Injury parameters for assessment using HBM in crash impact scenario

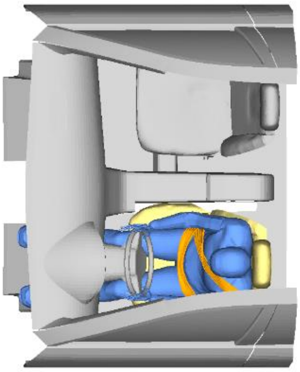
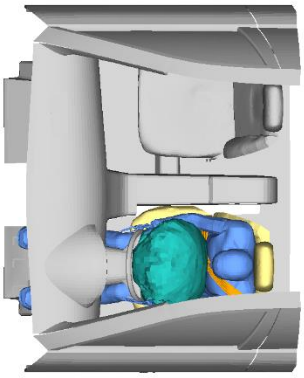
Body Region	Injury Indicator/Injury Risk Assessment	THUMS v4	THUMS-TUC v3.01	THUMS-D v4 Obese (v1.0)	THUMS-D 5%ile Eastern Female	THUMS-D 50%ile Male
Brain	Cumulative Strain Damage Measure used for THUMS V4.02 Injury Risk Curve of DAI AIS 4+	●	●	●		
	Cumulative Strain Damage Measure (No injury risk curve exists for female) >> 50th %ile injury risk considered with FPS of 15%				●	
	SUFEHM Criterion developed by University of Strasbourg					●
Neck / Spine	SUFEHN Criterion developed by University of Strasbourg (Probabilistic Force Based Criterion)					●
Thorax / Rib Fracture	Probabilistic (Forman criterion)		●	●		
	Deterministic Injury predictor (Burstein criterion developed for long bones but used for other skeletal areas/body regions)	●			●	●
Abdomen	No evaluation done / No detailed abdomen organs exists in the model					
Pelvic	Deterministic Injury predictor (Burstein criterion developed for long bones but used for other skeletal areas/body regions)	●	●		●	●
	Probabilistic injury criterion developd for THUMSv4 based on max. Principla Strain by Perese et al.			●		
Femur	Deterministic Injury predictor (Burstein criterion developed for long bones)				●	

2.2 Status HBM used

Within the case 2 scenario the latest version of the THUMS-TUC was used. This model is mainly based on THUMS V3 and was further developed within a collaborative activity of the THUMS User Community [20]. The status of the model was recently presented by Peldschus et al at the 7th HBM Symposium 2018 [21]. Modifications were mainly made in the shoulder, thorax and leg region. In general, also the robustness was improved by remeshing and revision of contacts etc. Finally, the probabilistic analysis method concerning evaluation of rib fracture risk, proposed and developed by Forman at al, was specifically adapted and implemented to this model. This method will be used within the post processing [22]. Latest applications of the THUMS-TUC are reported with reference to the SENIORS project. Here the model was also used as basis for further modifications to represent age-related (elderly) changes of rib cage anthropometry and rib fracture risk [23]. A detailed description of the THUMS-TUC model and its further improvement in terms of implementation also of active muscles can be found in the publication of E. Yigit [24].

2.3 Results and observations

Figure 15 (a) & (b) below illustrates occupant kinematics & trajectories during the impact.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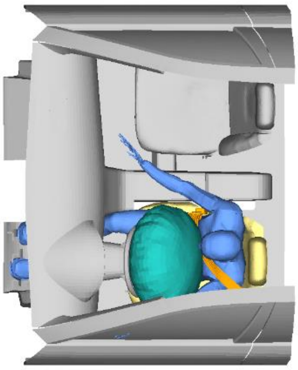
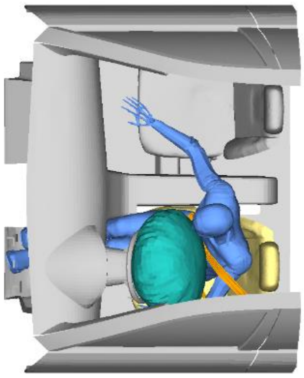
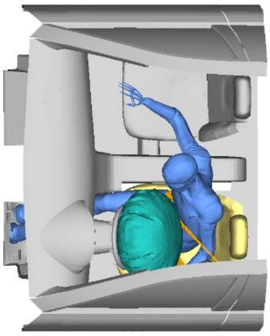
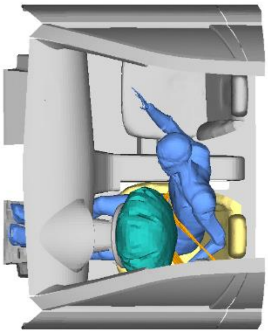
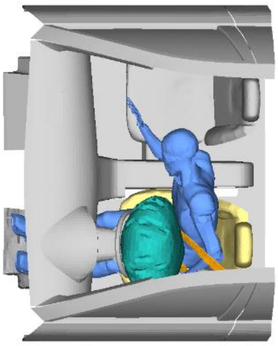
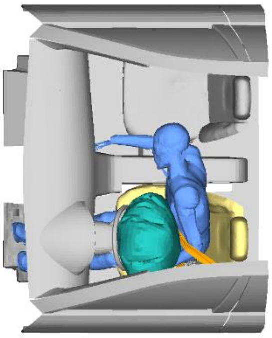
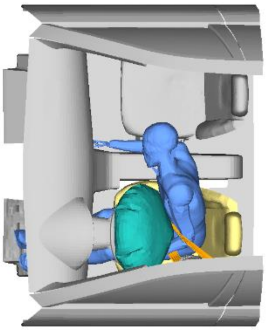
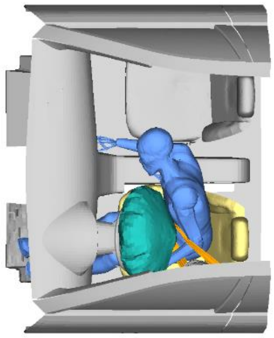
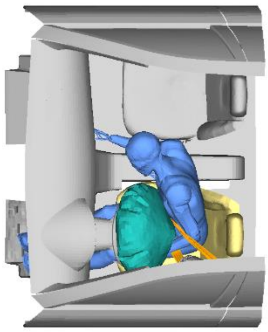
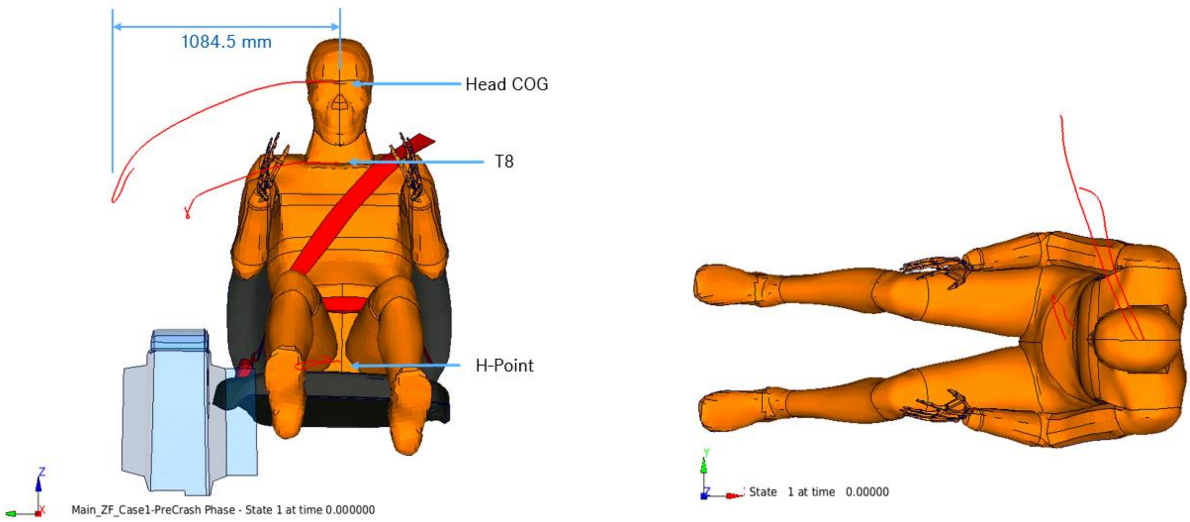
	
60 ms	90 ms
	
120 ms	150 ms
	

180 ms	210 ms
	
240 ms	270 ms
	
300 ms	

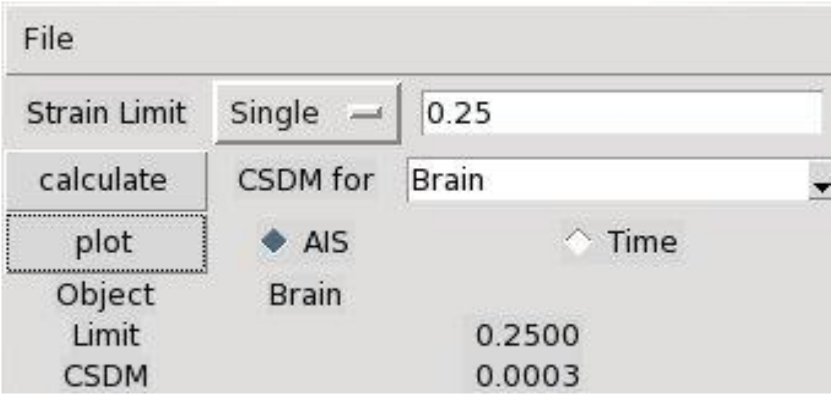
(a)



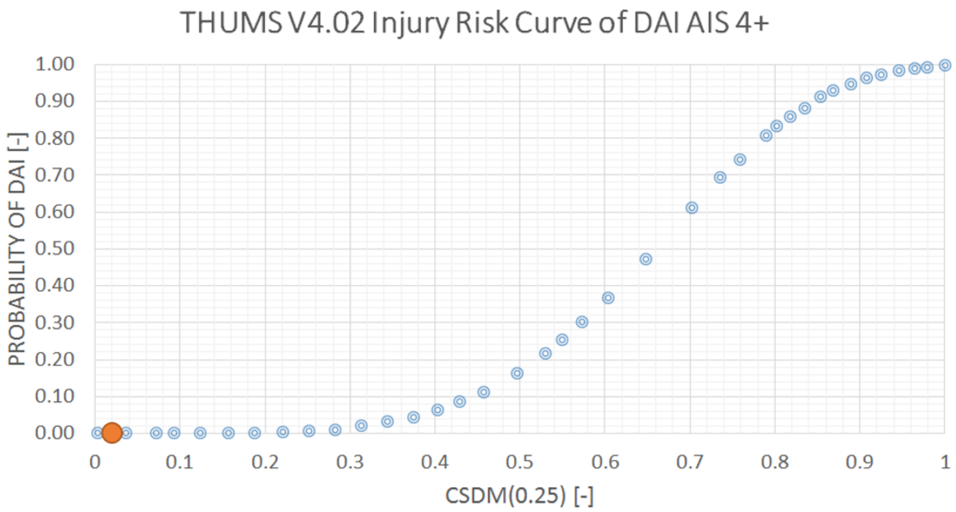
(b)

Figure 15 Occupant kinematics (a) & trajectories (b)

Figure 16 (a) & (b) below illustrates the risk of head injury which is computed through Cumulative Strain Damage Measure (CSDM) criterion. No risk of injury is predicted for the occupant head in this conflict scenario.



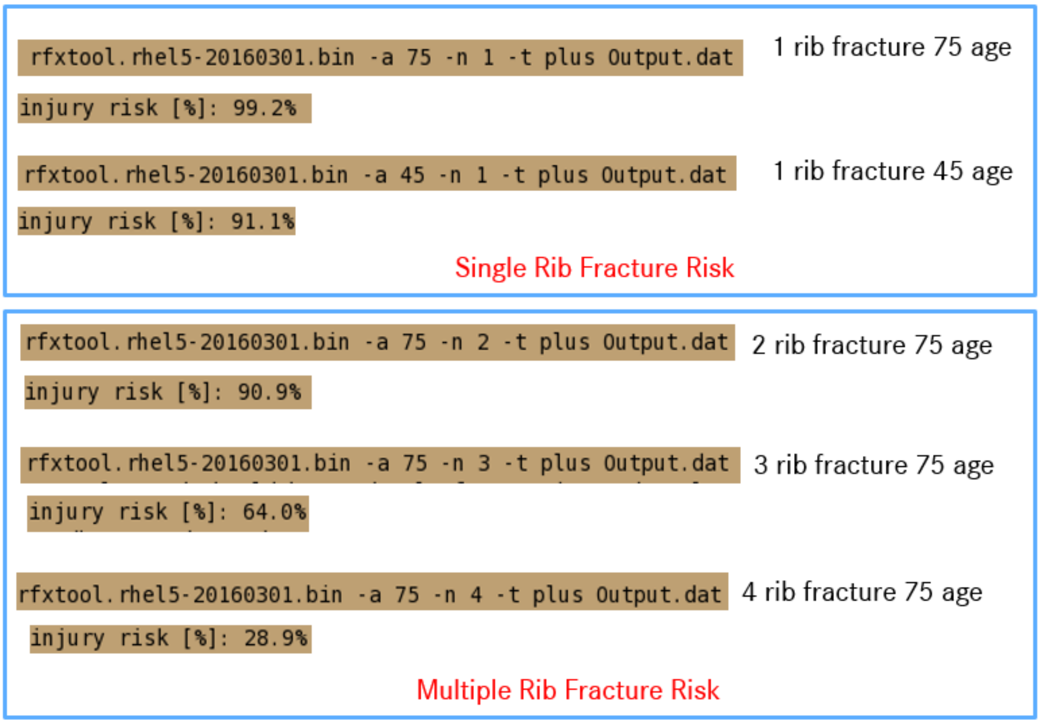
(a) CSDM Calculation from Dynasaur



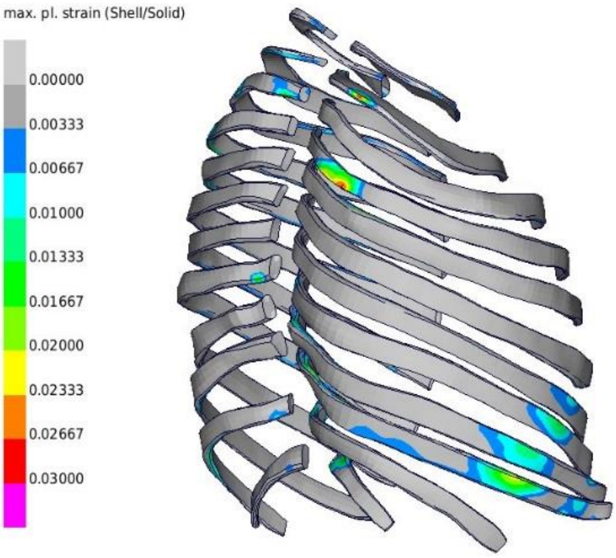
(b) Injury risk of head based on CSDM (Source: Toyota)

Figure 16 head injury risk

Risk of rib fractures is predicted using the Forman criterion. Forman criterion and method has been implemented in a tool from University of Virginia, USA (UVA) and the injury is predicted in the format below (Figure 23- a) with multiple rib fractures & age being considered. The method was explicitly adapted and implemented to the THUMS-TUC model. Single rib fracture risk > 90% is observed for both age groups of 45 & 75 years. However, the tool needs to be further developed for incorporating the actual location of rib fracture risk (as shown in additional max. strain plot and post-processed with Burstein criteria – Figure 17- b) computed in the model. Furthermore, a verification concerning computed strain processed in the rib fracture risk predictor of the tool is needed (will be addressed in WP 3).



(a)



(b)

Figure 17 Rib fractures based on (a.) Forman criterion & (b.) Burstein criterion

No pelvis fracture is observed in this load case. Plastic strains developed in the pelvis are below the Burstein injury indicator (3% Strain Threshold). Currently, no criterion exists for the THUMS-TUC model for the pelvis. However high seatbelt buckle loading is observed on the iliac crest at 200 ms. The contact forces measured between seat belt and the occupant is 2.02 kN. Figure 18 & Figure 19 illustrates the plastic strains developed in the pelvis region & contact forces between the seatbelt & occupant.

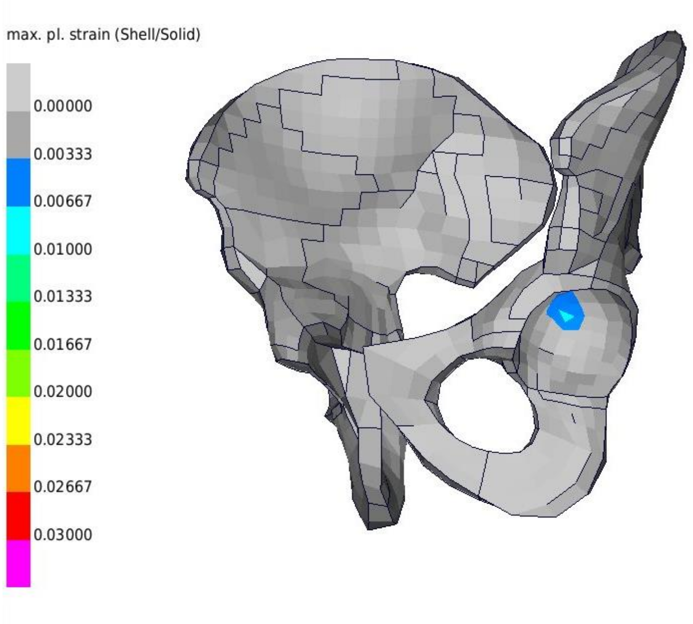


Figure 18 Plastic strain plot for pelvis region

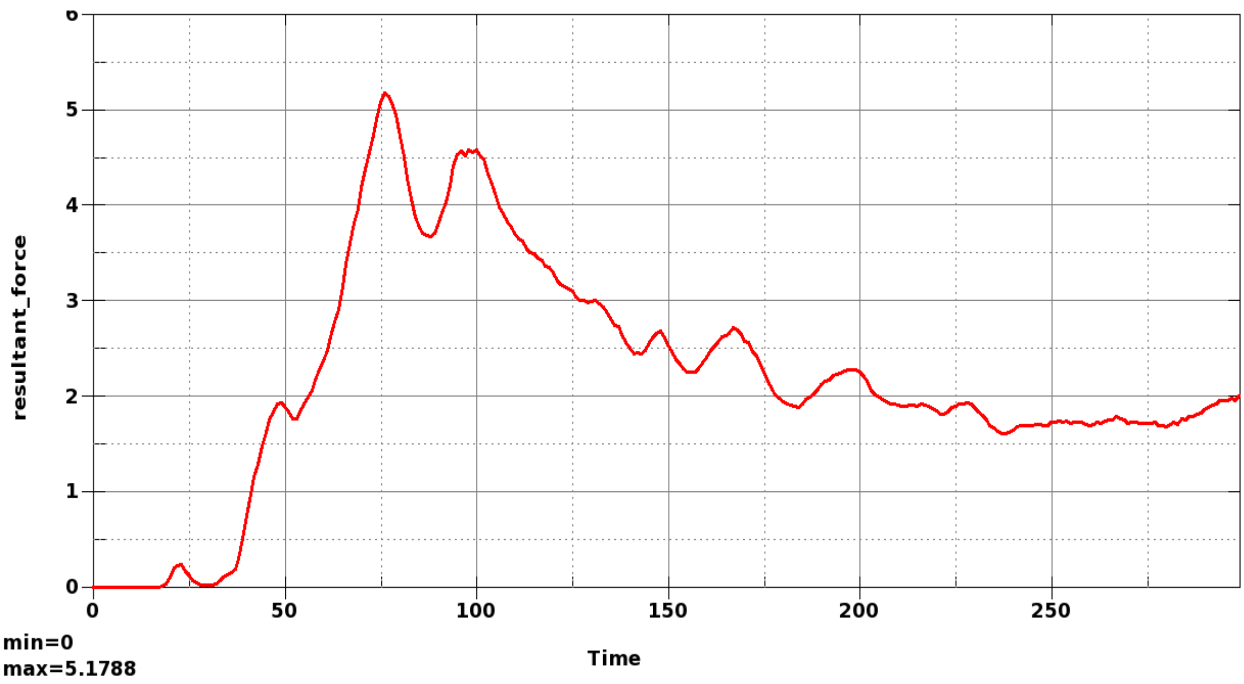


Figure 19 Contact force between seatbelt & occupant

3 CASE 3 – HEAD ON / OBESE PASSENGER

3.1 Simulation set up

In Case 3, an obese (BMI 35) front seat passenger (THUMS-D V4 Obese) placed in a moderate reclined seat is exposed to a frontal impact in 40 kph, due to an unexpected cut-in manoeuvre causing a rear end collision, see Figure 15. It is assumed that the host vehicle is performing a pre-brake manoeuvre. However no pre-crash phase was simulated due to the fact that this HBM version currently does not have active muscles implemented. Standard seat belt and passenger airbag are used. Crash pulse was again taken from internal database.

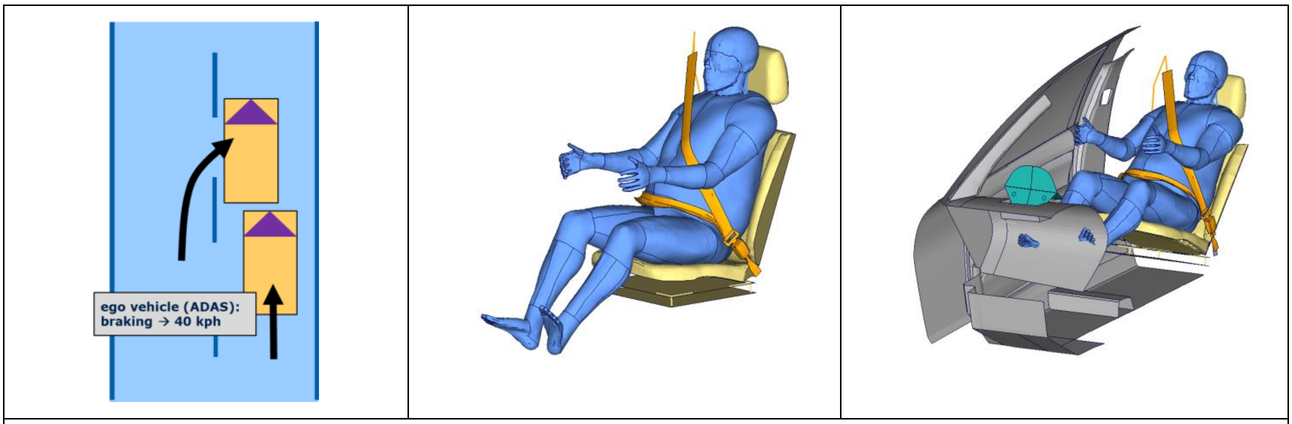


Figure 20 Case 3 – Rear-end / Head-on (“cut-in” highway scenario), obese passenger

The software tools utilized for conducting frontal crash simulations are listed below:

- **Pre-Processor:** Beta CAE ANSA v.18.1.0, LS-Pre-post v.4
- **FEM-Solver:** LS-DYNA V971 beta release R7.1.3 MPP, DP
- **Post-Processor:** Altair Hyperview v.12, LS-pre-post v.4, Animator 4
- **Occupant Positioning:** Positioning of Daimler FE Human Body Models were done using in-house developed simulation approach
- **FE Models**: Sled Model, THUMS-D v4 Obese (v1.0)
- **Injury Risk Prediction Post-Processor**: A post processing tool was developed by TU-Graz to assess injuries through human body models – Dynasaur

Table 4 Injury parameters for assessment using HBM in crash impact scenario

Body Region	Injury Indicator/Injury Risk Assessment	THUMS v4	THUMS-TUC v3.01	THUMS-D v4 Obese (v1.0)	THUMS-D 5%ile Eastern Female	THUMS-D 50%ile Male
Brain	Cumulative Strain Damage Measure used for THUMS V4.02 Injury Risk Curve of DAI AIS 4+	•	•	△		
	Cumulative Strain Damage Measure (No injury risk curve exists for female) >> 50th %ile injury risk considered with FPS of 15%				•	
	SUFEHM Criterion developed by University of Strasbourg					•
Neck / Spine	SUFEHN Criterion developed by University of Strasbourg (Probabilistic Force Based Criterion)					•
Thorax / Rib Fracture	Probabilistic (Forman criterion)		•	△		
	Deterministic Injury predictor (Burstein criterion developed for long bones but used for other skeletal areas/body regions)	•			•	•
Abdomen	No evaluation done / No detailed abdomen organs exists in the model					
Pelvic	Deterministic Injury predictor (Burstein criterion developed for long bones but used for other skeletal areas/body regions)	•	•		•	•
	Probabilistic injury criterion developd for THUMSv4 based on max. Principla Strain by Perese et al.			△		
Femur	Deterministic Injury predictor (Burstein criterion developed for long bones)				•	

3.2 Status HBM used

A Daimler in-house created derivative of THUMS V4 was used within case 3 of the baseline study. THUMS V4 male AM50 was morphed to represent a corpulent person. The target anthropometry of this model was based on the corresponding RAMSIS obese manikin (121 kg, BMI 38.2; Database SizeGermany). The target anthropometry from RAMSIS showed also good consistency with UMTRI database surface model representing an occupant of 125 kg. Modelling and distribution of visceral and subcutaneous fat were done in accordance with published data and related literature. It has to be stated that this model is still under development and was not extensively validated prior to this study. The status concerning the validation set-up of Forman 2009 and Foster 2008 are described in the Appendix. A brief description of the creation process and an application of the model within a reconstruction of a real accident can be found in the publication by Mayer et al [25].

Comparable development of a THUMS V4 AM50 representing an obese occupant (BMI 35) was presented by Kitagawa et al at IRCOBI 2017 [26]. In the study the validation of the model against PMHS data was discussed and different methods for post-processing and injury risk evaluation were shown comparing non-obese and obese occupant. The HBM models were applied in a frontal collision and a pole side impact scenario.

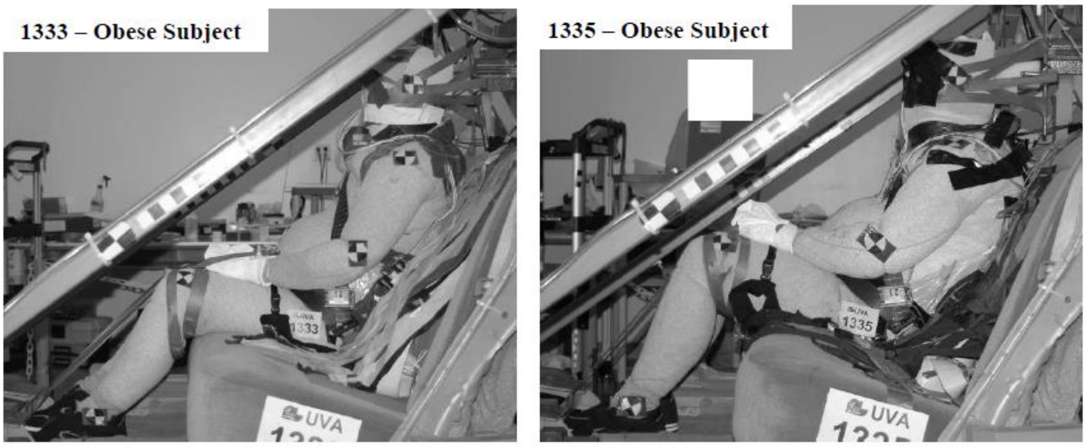
A similar approach for an obese model development is also reported by GHBMC [19].

The model was validated based on 2 load cases from Forman et al [2009] and Foster et al [2006]. The load cases set-ups were developed as a part of TUC Catalogue and are accessible through THUMS User Community.

1. **<u>Rear occupant front impact validation load case :</u>**
    a. 2 Obese PMHS subjects (>30 BMI) tested. Figure 21 (a) & (b) illustrates the obese subjects tested and characteristics of the subjects.

b. Figure 22 illustrates the acceleration pulse used in the actual tests

c. Reduced sled model was created using Daimler vehicle for the validation study & hence, differences in the interiors & restraint systems are expected.



(a)

Table 1: Test Matrix and Subject Characteristics

Test #	Subject #	Age/Gender	Stature (cm)	Mass (kg)	BMI* (kg/m^2)	ΔV (km/h)
1333	404	54/M	189	124	35	48.7
1335	400	53/M	182	151	45	48.2
1386	429	67/M	175	69	23	48.2
1387	444	69/M	171	67	20	49.6
1389	457	72/M	183	72	22	49.4

(b) Subject Characteristics

Figure 21 Obese subjects tested by Forman et al. [2009]

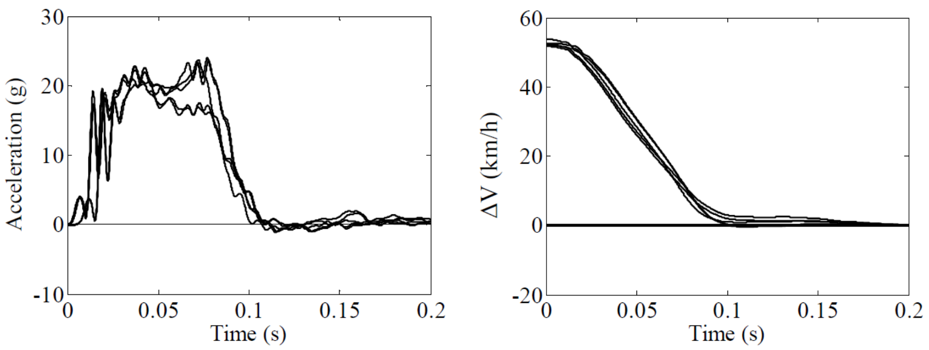


Figure 22 Composite plots of sled accelerations (left) & changes in velocity (right) for all tests

d. Figure 23 shows the overall kinematic behaviour of the obese model when subjected to this pulse.

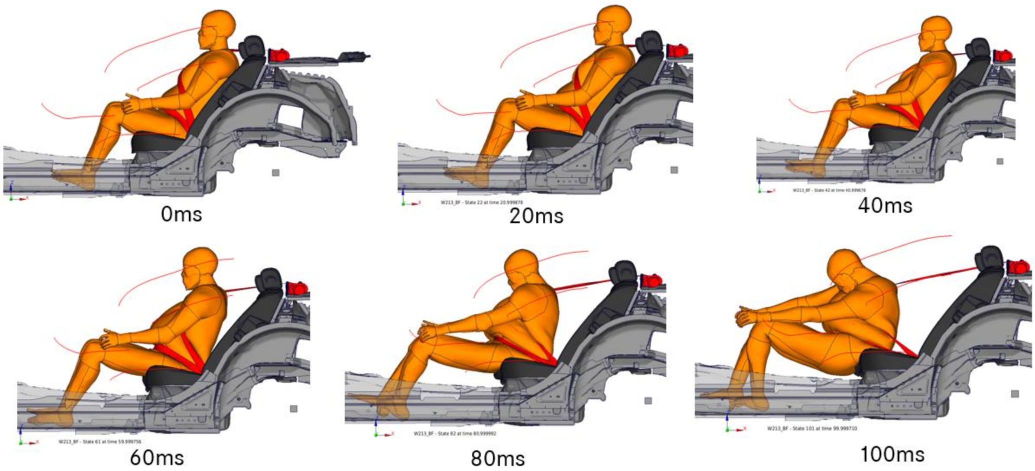


Figure 23 THUMS-D v4 obese model kinematics

e. Figure 24 shows overall kinematic comparison of THUMS-D v4 Obese (v1.0) with trajectories of the obese subject.

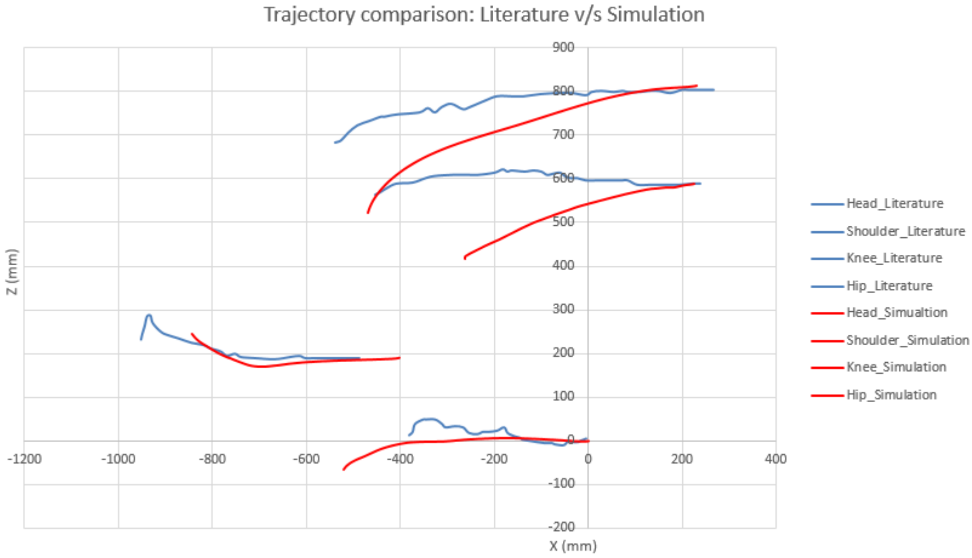


Figure 24 THUMS-D v4 obese model trajectories vs tests

f. It is observed that the THUMS-D v4 Obese (v1.0) shows a fair kinematic correlation with the tests, however, further improvements in the model are required as the virtual simulation model is softer compared to actual tests.

2. **<u>Abdomen high speed lap belt validation load case:</u>**

   a. High speed abdomen seatbelt tests were conducted by Foster *et al.* [2006]

   b. The subject test set-up is illustrated in Figure 25 and comprises of an occupant on whom a seat belt of width 50 *mm* is wound around the umbilicus.

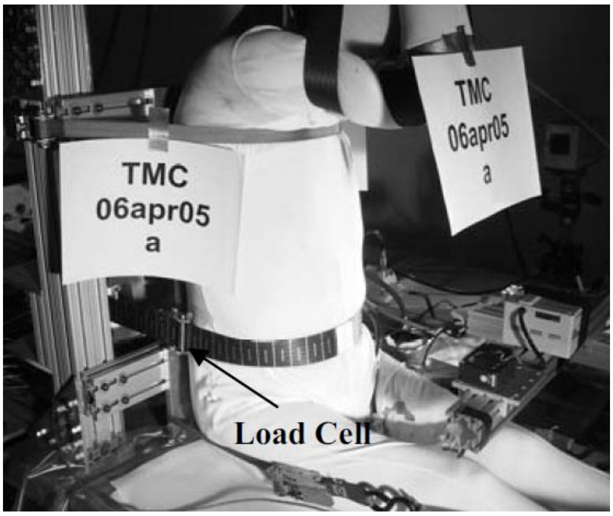


Figure 25 Experimental test setup – top view (Foster et al. 2006)

c. Figure 26illustrates the imposed displacement on lap belt

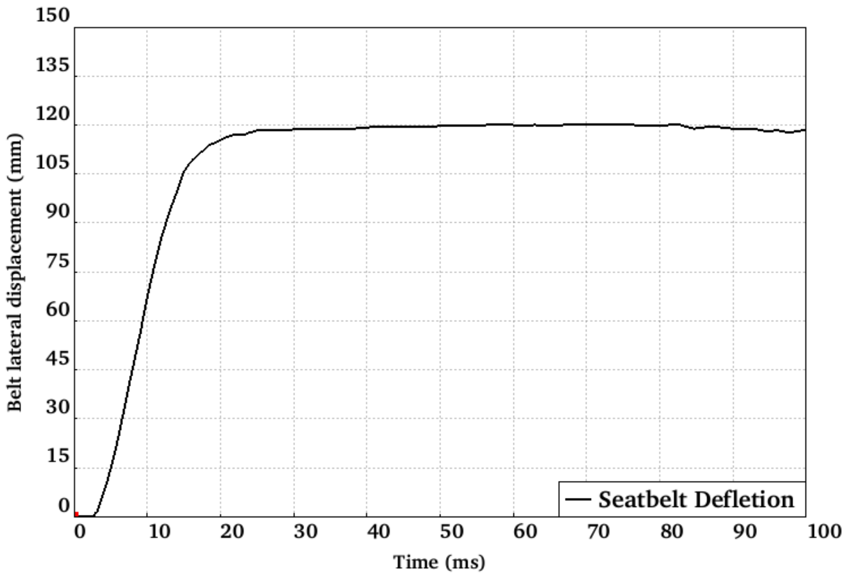
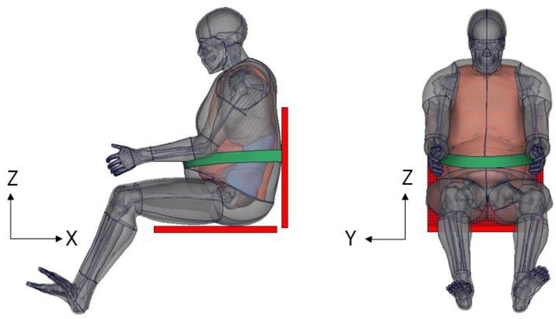


Figure 26 Imposed displacement in lap belt

d. Figure 27 below shows the set-up with THUMS-D v4 Obese (v1.0) and kinematics.



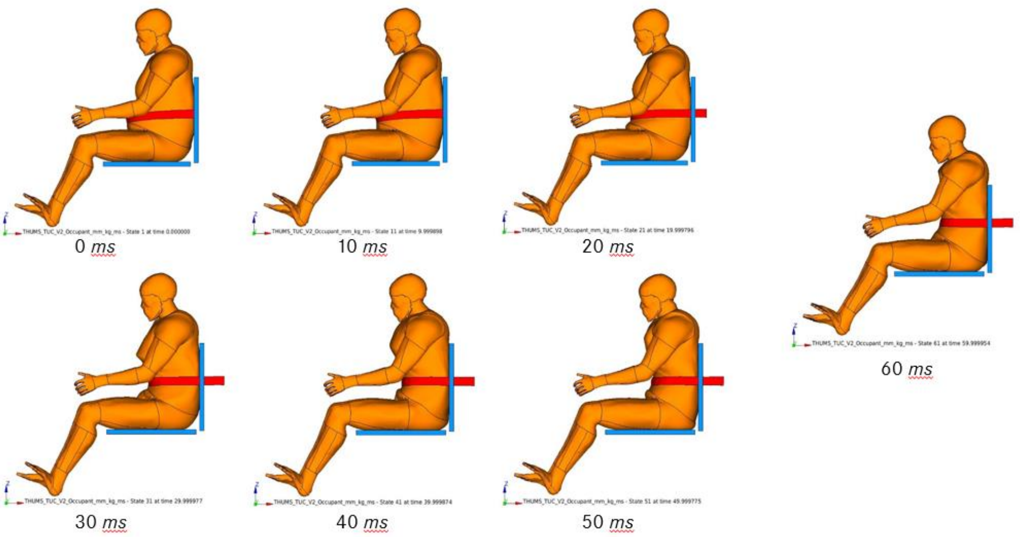


Figure 27 Load case Simulation Deck & Occupant Kinematics

e. Figure 28 below illustrates the response of the obese model against the subjects. A good correlation is achieved between the tests and virtual simulations. However, further improvements are required in the model in the latter part of the unloading where it behaves stiffer compared to the subjects.

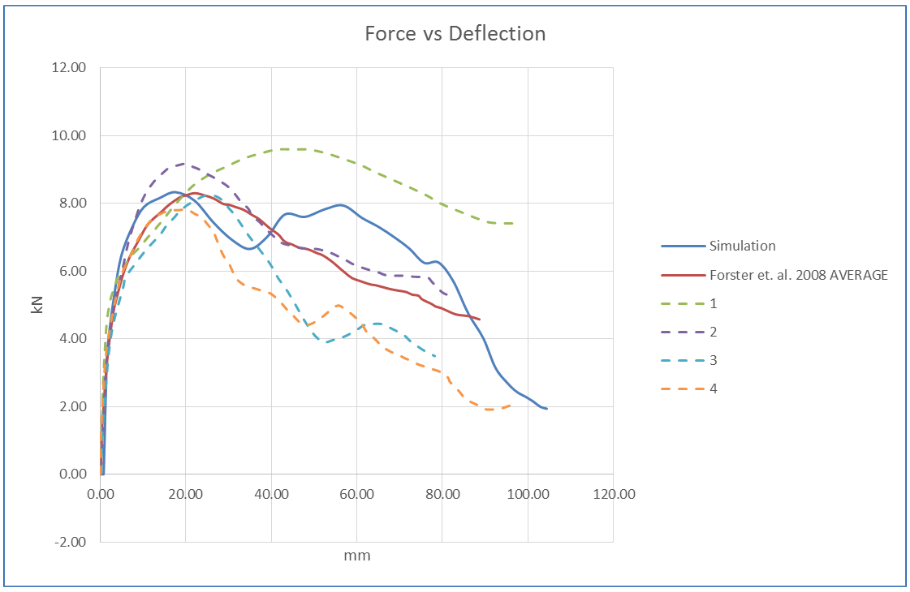
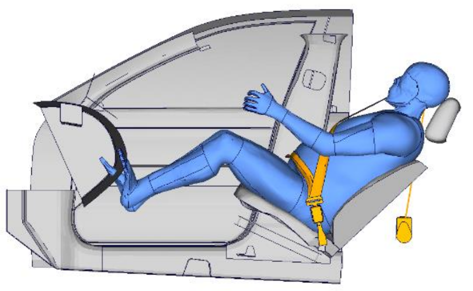
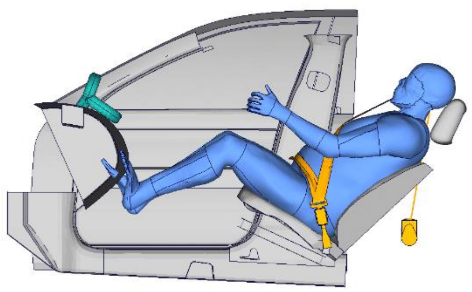
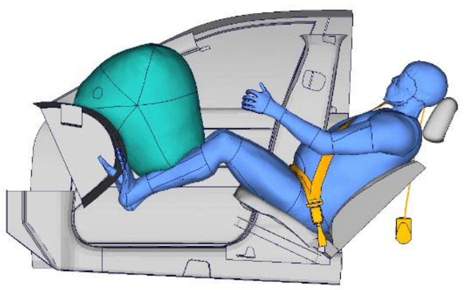
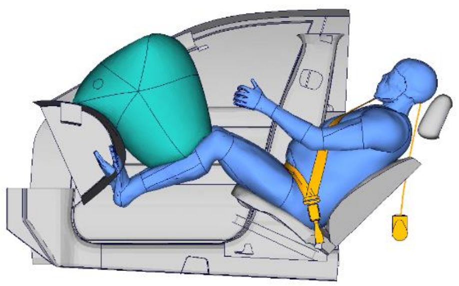
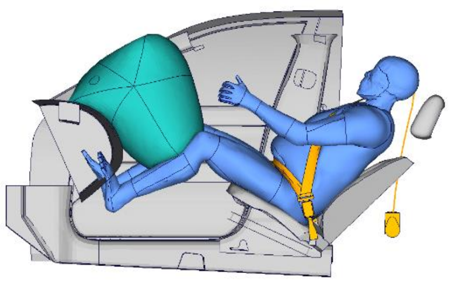
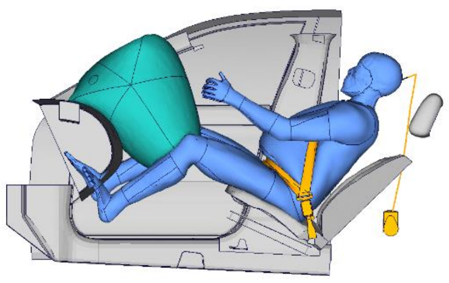


Figure 28 Response of obese occupant based on PMHS data

3.3 Results and observations

This section incorporates the overall evaluations of the unexpected cut-in manoeuvre leading to a frontal collision. Figure 29 below illustrates the overall kinematics of the occupant in such a scenario

	
0 ms	20 ms
	
40 ms	60 ms
	
80 ms	100 ms

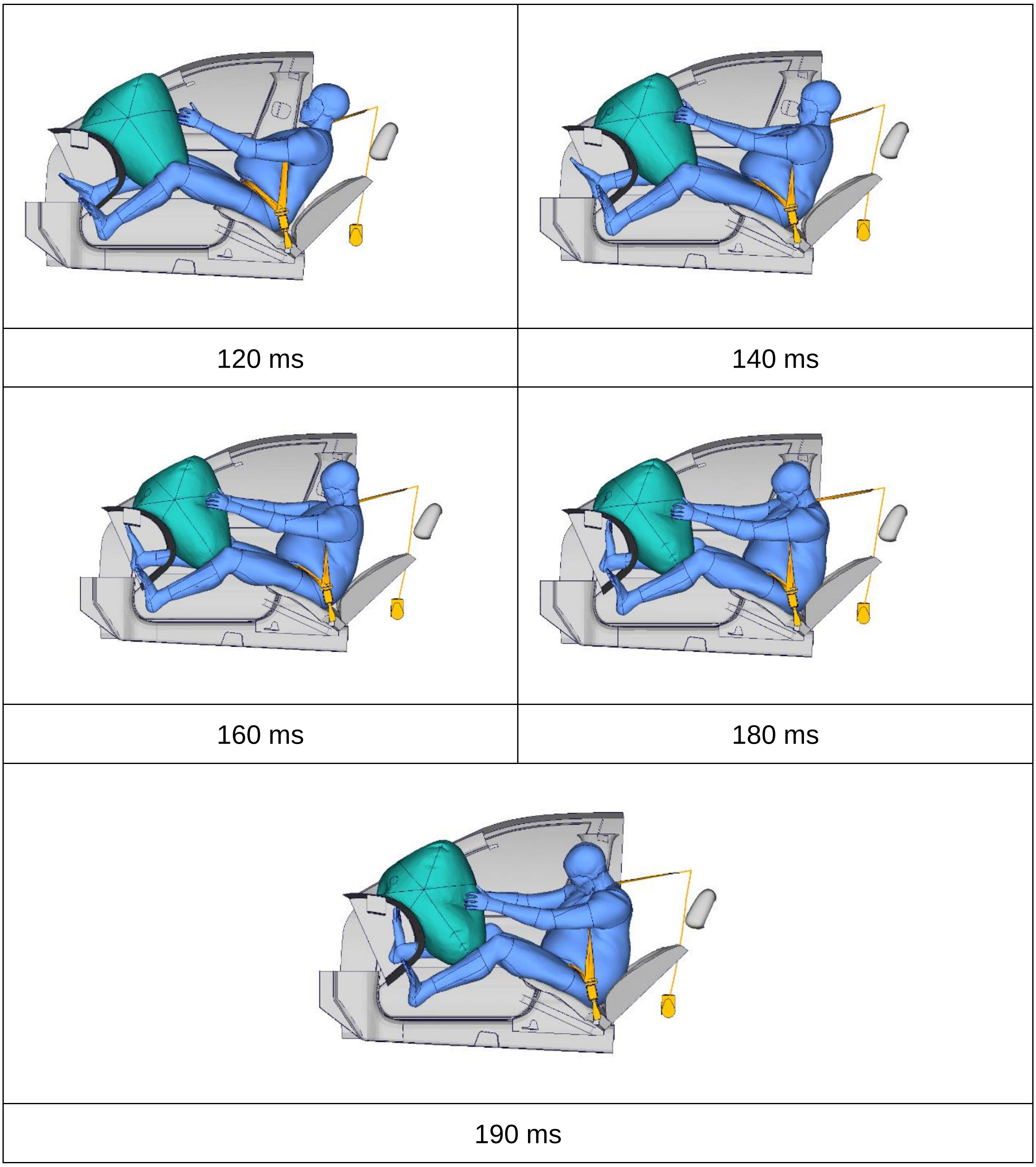
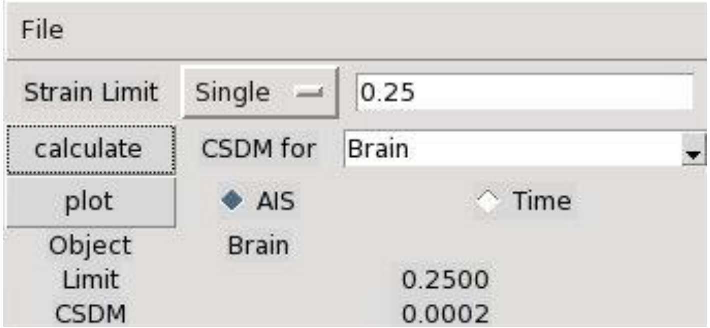


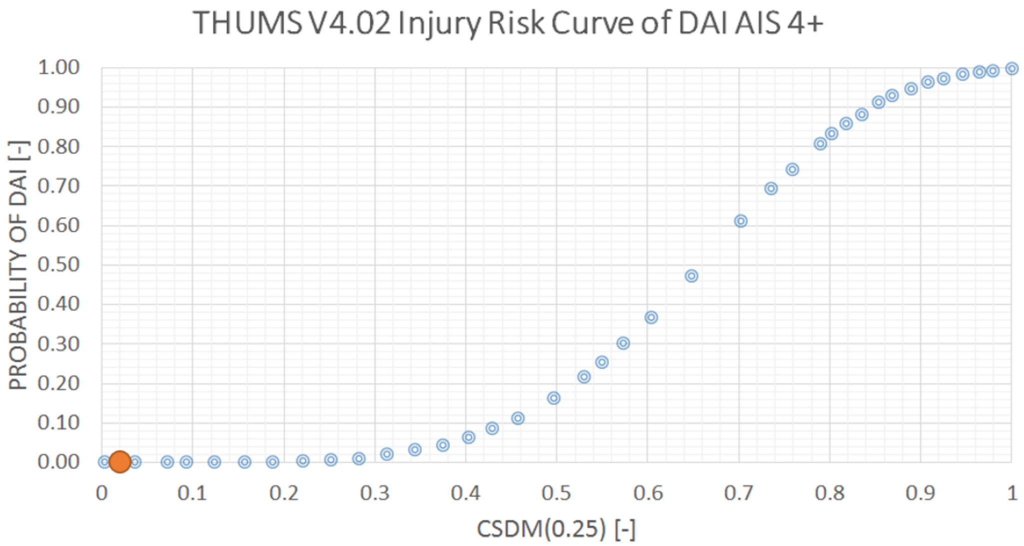
Figure 29 Occupant kinematics for obese

Observations from the kinematic evaluation suggests the following:

1. No interaction with the passenger airbag is seen and is hence, the safety benefit offered by position of airbag requires evaluation. Figure 30 shows the head injury risks computed for the load case. A low injury risk is observed for the conflict scenario and is in line with the overall kinematics.



(a) CSDM Calculation from Dynasaur



(b) Injury Risk of head based on CSDM (Source: Toyota)

Figure 30 Head Injury assessment of THUMS-D v4 obese (v1.0)

2. Current simulations consider that the seat structure below the pan as rigid. However, considering weight of the obese the seat structure design would be a challenge and would influence the overall kinematics.
3. High seatbelt forces contact forces (10.68 kN) are experienced by the occupant at approx. 130 ms and this could lead to potential rib fracture risks, abdominal injuries and pelvic injuries. However, as illustrated in the Figure 31 below rib fracture risks are significantly low and is contradictory to seat belt forces. Therefore, it seems that the existing Forman criterion needs to be consolidated for use with THUMS V4 to ensure that the criterion becomes valid for this model as it is a model dependent one. Dynasaur might create misleading output as it was not adapted to THUMS-V4 so far. Figure 32 illustrates the pelvic injuries risks computed for the load case. A significant risk of injury is observed in the elvis region and aligns with the loading from the seatbelt.

Part	Max. Strain	Element	Prob. age 25		Prob. age 45		Prob. age 75	
Left Ribs								
89003600	0.384086764123	89196177	100.0	%	100.0	%	100.0	%
89004101	0.00818746268843	89012507	0.0	%	0.0	%	0.0	%
89004201	0.0103346061385	89012787	0.0	%	0.0	%	0.0	%
89004301	0.0114211075073	89013226	0.0	%	0.0	%	0.0	%
89004401	0.0064061916509	89014152	0.0	%	0.0	%	0.0	%
89004501	0.00647961715716	89014817	0.0	%	0.0	%	0.0	%
89004601	0.00292172609522	89015099	0.0	%	0.0	%	0.0	%
89004701	0.0074728577636	89015635	0.0	%	0.0	%	0.0	%
89004801	0.00381504789518	89016750	0.0	%	0.0	%	0.0	%
89004901	0.00370612625506	89017389	0.0	%	0.0	%	0.0	%
89005001	0.00281822928335	89017632	0.0	%	0.0	%	0.0	%
89005101	0.00155164422999	89018145	0.0	%	0.0	%	0.0	%
89005201	0.00142008376665	89018318	0.0	%	0.0	%	0.0	%
Right Ribs								
89503600	0.164691088367	89374027	100.0	%	100.0	%	100.0	%
89504101	0.0063426973893	89071026	0.0	%	0.0	%	0.0	%
89504201	0.00292116689634	89071501	0.0	%	0.0	%	0.0	%
89504301	0.00826134022944	89072004	0.0	%	0.0	%	0.0	%
89504401	0.00823837225904	89072365	0.0	%	0.0	%	0.0	%
89504501	0.0153019023378	89073306	0.0	%	8.6	%	16.9	%
89504601	0.0106589806399	89073737	0.0	%	0.0	%	0.0	%
89504701	0.00895894974126	89074448	0.0	%	0.0	%	0.0	%
89504801	0.00422944188741	89075433	0.0	%	0.0	%	0.0	%
89504901	0.00354690561242	89075857	0.0	%	0.0	%	0.0	%
89505001	0.00339445221243	89076467	0.0	%	0.0	%	0.0	%
89505101	0.00181178576697	89076844	0.0	%	0.0	%	0.0	%
89505201	0.00150898363	89076910	0.0	%	0.0	%	0.0	%
Multiple Fractures								
		#	Prob. age 25		Prob. age 45		Prob. age 75	
		0	0.0	%	0.0	%	0.0	%
		1	0.0	%	0.0	%	0.0	%
		2	100.0	%	91.4	%	83.1	%
		3	0.0	%	8.6	%	16.9	%
		4	0.0	%	0.0	%	0.0	%
		5	0.0	%	0.0	%	0.0	%
		6	0.0	%	0.0	%	0.0	%
		7	0.0	%	0.0	%	0.0	%

Figure 31 Thoracic injury assessment of THUMS-D v4 obese (v1.0) via Dynasaur

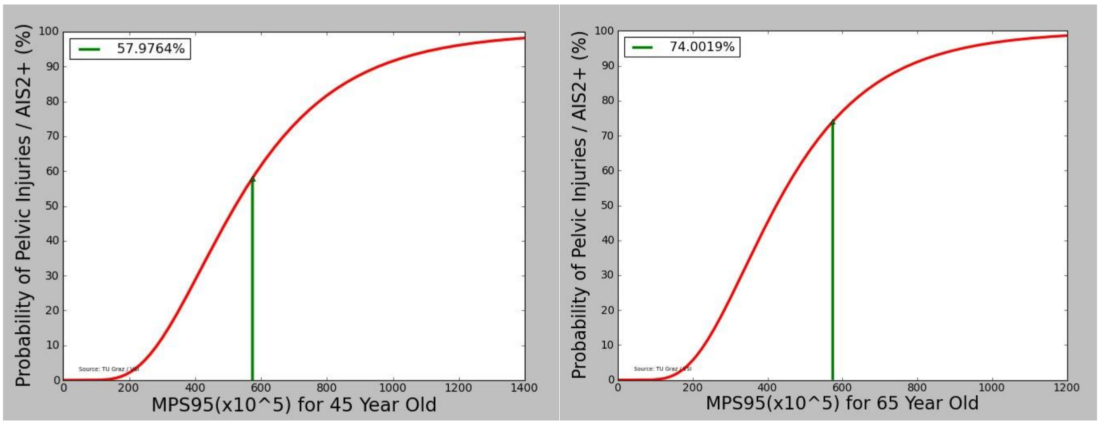


Figure 32 Pelvic injury risk for THUMS-D v4 obese (v1.0)

An additional set-up / parameter variation was simulated and now shown in Figure 33. It addresses the fact that often in such a relaxed position passengers place their feet on the instrument panel. In the first Case 3 simulation set-up, occupant feet are intersecting with the instrument panel and constraints are applied to ensure that the feet during the entire crash duration are remain at the original position ("feet on instrument panel"). Removing the constraints with the instrument panel does not change the upper torso kinematics significantly (“seat position with no occupant interaction with instrument panel” > e.g. represent relaxed passenger in rear seat).

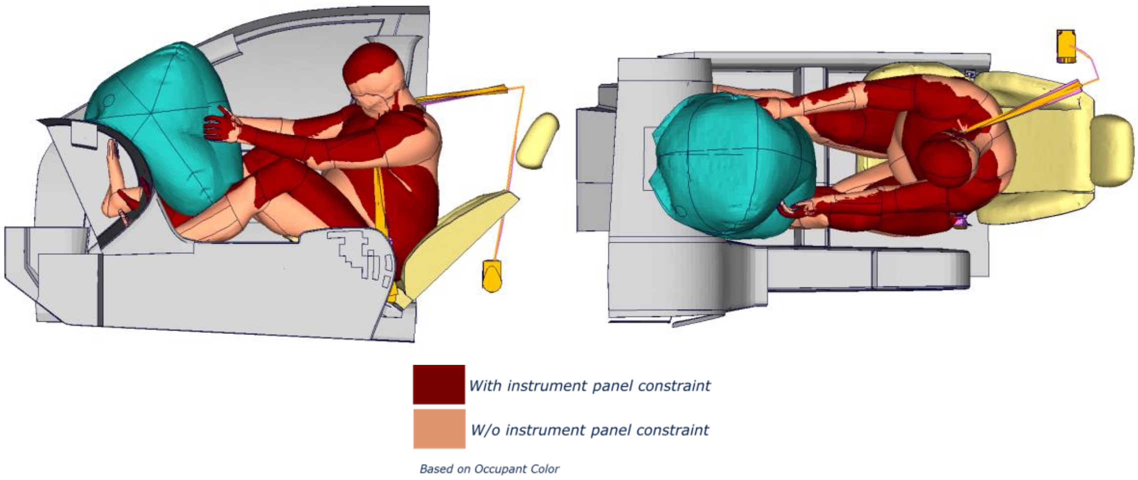
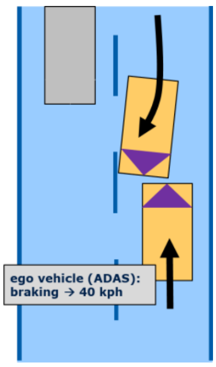


Figure 33 Kinematic comparison at 190 ms with and without instrument panel constraint

4 CASE 4 – HEAD ON / EASTERN FEMALE

4.1 Simulation set up

In Case 4, a small female driver (THUMS-D-F05-Asian (5.0)) is exposed to a partial offset frontal impact in 40kph due to a head-on collision, e.g. unexpected overtaking manoeuvre, see Figure 16 34. Sitting posture in accordance with ergonomic sitting position related to Asian anthropometry. Standard three-point belt and driver airbag are activated, and internal crash pulse was used.



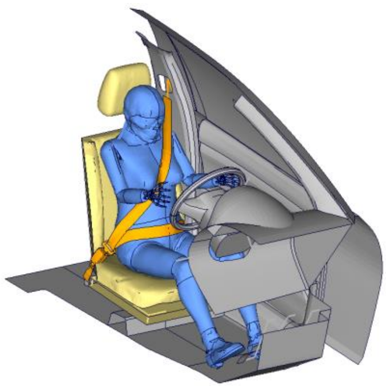


Figure 34 Case 4 – Head-on

The software tools utilized for conducting frontal crash simulations are listed below:

- **Pre-Processor:** Beta CAE ANSA v.18.1.0, LS-Pre-post v.4
- **FEM-Solver:** LS-DYNA V971 beta release R7.1.3 MPP, DP

- **Post-Processor:** Altair Hyperview v.12, LS-pre-post v.4, Animator 4
- **Occupant Positioning :** Positioning of Daimler FE Human Body Models were done using Daimlers developed positioning tool named FETOOL.
- **FE Models**: Sled Model developed, THUMS-D 5th Percentile Eastern Female
- **Injury Risk Prediction Post-Processor**: Post processing tool was developed by TU-Graz to assess injuries through human body models – Dynasaur and standard post-processing in LS-PrePost.

Table 5 Injury parameters for assessment using HBM in crash impact scenario

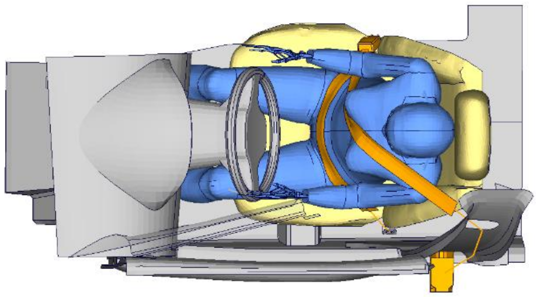
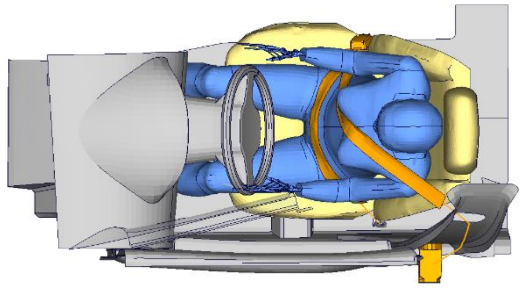
Body Region	Injury Indicator/Injury Risk Assessment	THUMS v4	THUMS-TUC v3.01	THUMS-D v4 Obese (v1.0)	THUMS-D 5%ile Eastern Female	THUMS-D 50%ile Male
Brain	Cumulative Strain Damage Measure used for THUMS V4.02 Injury Risk Curve of DAI AIS 4+	•	•	•		
	Cumulative Strain Damage Measure (No injury risk curve exists for female) >> 50th %ile injury risk considered with FPS of 15%				△	
	SUFEHM Criterion developed by University of Strasbourg					•
Neck / Spine	SUFEHN Criterion developed by University of Strasbourg (Probabilistic Force Based Criterion)					•
Thorax / Rib Fracture	Probabilistic (Forman criterion)		•	•		
	Deterministic Injury predictor (Burstein criterion developed for long bones but used for other skeletal areas/body regions)	•			△	•
Abdomen	No evaluation done / No detailed abdomen organs exists in the model					
Pelvic	Deterministic Injury predictor (Burstein criterion developed for long bones but used for other skeletal areas/body regions)	•	•		△	•
	Probabilistic injury criterion developd for THUMSv4 based on max. Principla Strain by Perese et al.			•		
Femur	Deterministic Injury predictor (Burstein criterion developed for long bones)				△	

4.2 Status HBM used

In case 4 another derivative of THUMS-D was used to represent a 5% female with Asian anthropometry. This 5th percentile female of eastern population was developed based on the THUMSD-F05 model using an appropriate geometry scaling method. To ensure the two HBMs have comparable biofidelity, the eastern 5th percentile female HBM was validated against frontal as well as lateral load cases. Scaling factors for the HBM were calculated using the dimensions of the THUMSD-F05 model and that of the eastern 5th percentile female derived from latest China National Institute of Standardization (CNIS) database. Scaling process and a first use case including post-processing and injury risk metric applied was reported by Yang et al at IRCOBI Asia in 2016 [27].

4.3 Results and observations

Figure 35 below illustrates occupant kinematics during the impact for the Eastern female.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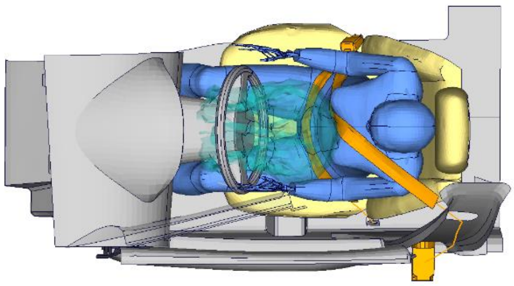
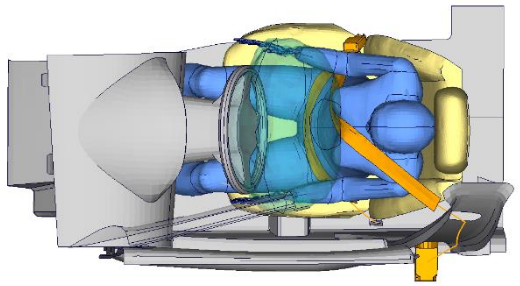
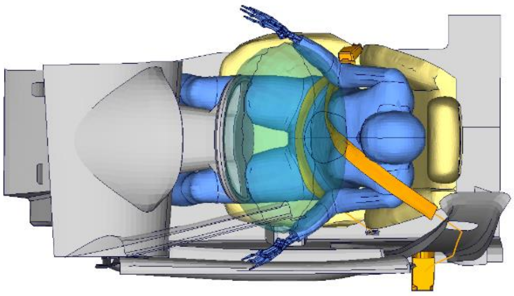
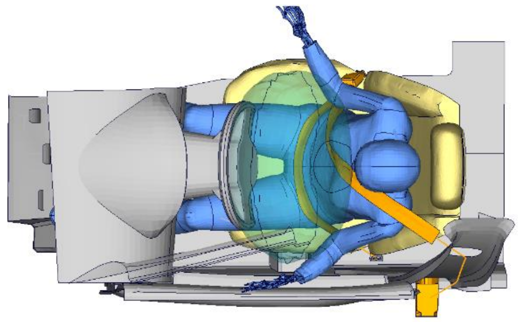
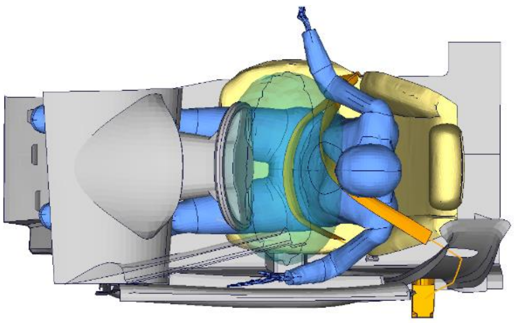
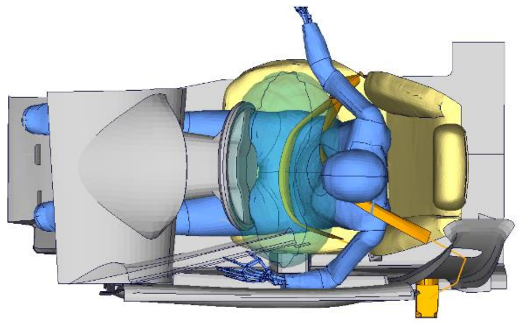
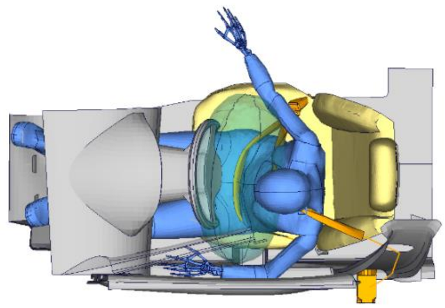
	
20 ms	30 ms
	
40 ms	50 ms
	
60 ms	70 ms



84 ms

Figure 35 Occupant kinematics for eastern female

Figure 36 below illustrates the risk of head injury which is computed through Cumulative Strain Damage Measure (CSDM) criterion incorporated in Dynasaur. Based on the injury risk it could be seen that in such a scenario, a low risk of head injury can be envisaged. This is complemented by the low head angular velocities of the head as shown in Figure 37.

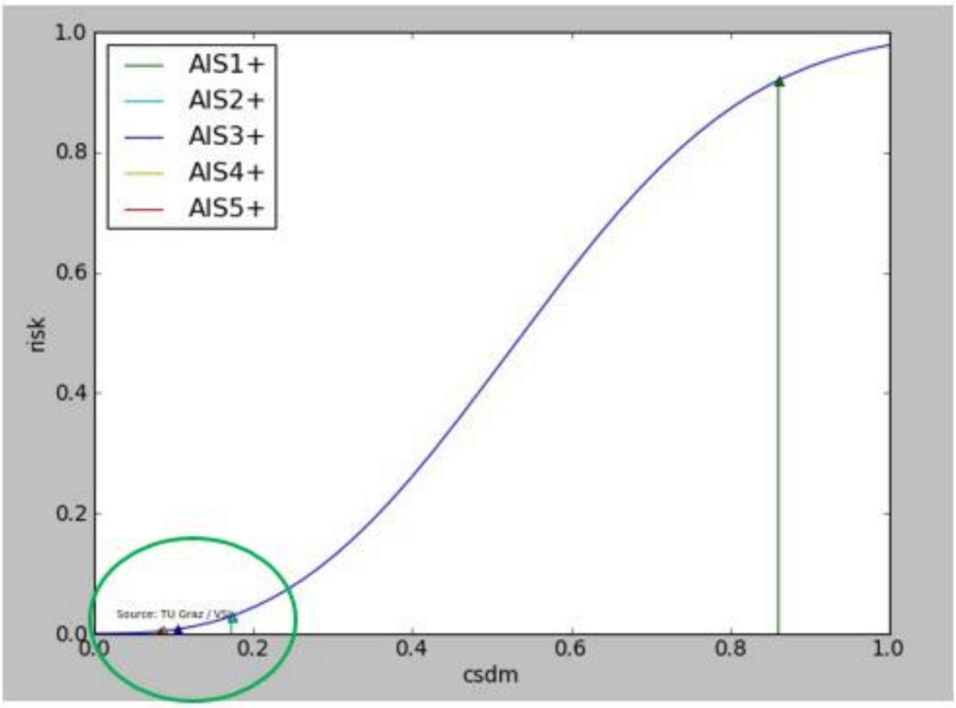


Figure 36 Head injury risk for eastern female (risk curve showing AIS4+, Takhounts 2011)

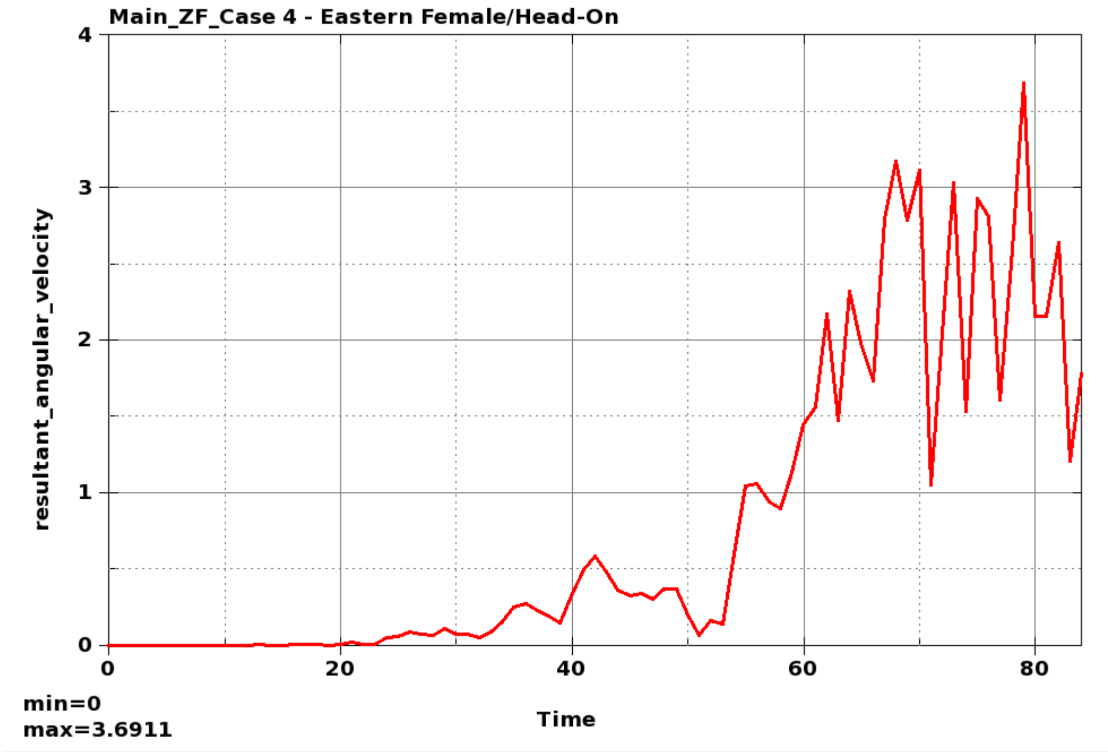


Figure 37 Head angular velocity for eastern

Female Rib fractures are observed in the left side (9th and 11th ribs) for the Eastern female. No injury risk curve respectively probabilistic method is available for the current model. Hence, also an injury indicator based on max. plastic strain is used for computing the risk. It should be stated that the current Eastern female model is well conforming to the anthropometric requirements of the eastern population. However, the material properties are taken from original “Western” model and should be considered for further research and updates to represent also eastern population characteristics.

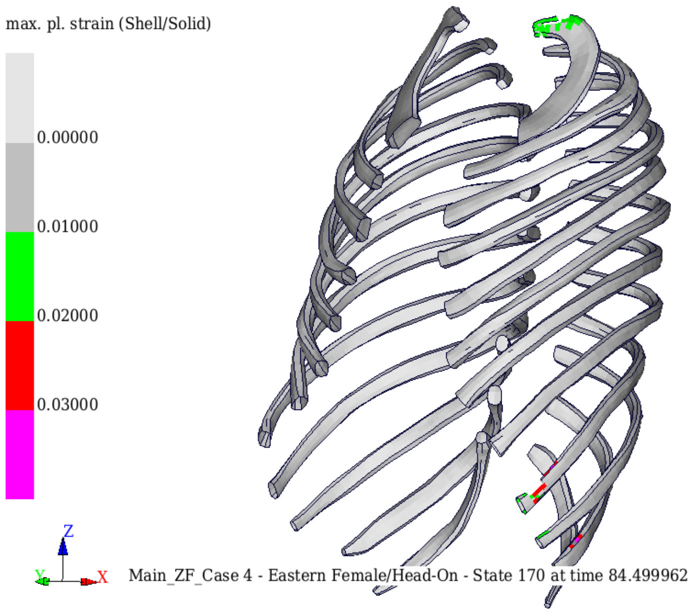


Figure 38 Rib fracture prediction for eastern female

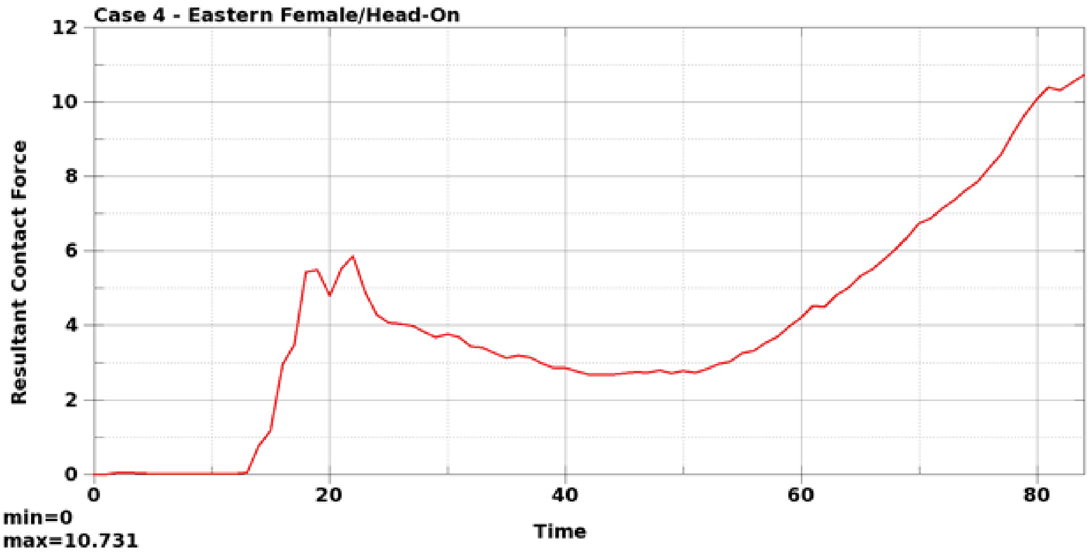


Figure 39 Seatbelt contact forces for eastern female

Analysis of injury risk for pelvis and femur are illustrated in Figure 40, Figure 41and Figure 42. This body region was specifically examined due to the fact that the female is sitting closer to the steering wheel and instrument panel. However, in this generic environment no severe contact with the instrument panel was observed. So, no risk of pelvic fracture is predicted in this load case. Plastic strains of approximately 1.7% are observed in the iliac crest which is driven mainly by loading from the seat belt system. Also, no risk of femur fracture is predicted in this load case. As injury indicator for predicting the fracture again the Burstein injury indicator of 3% plastic strain is used.

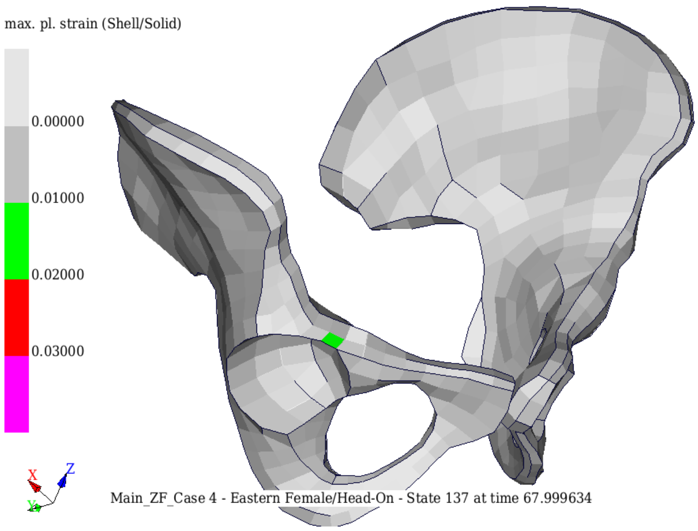


Figure 40 Pelvic fracture prediction for eastern female

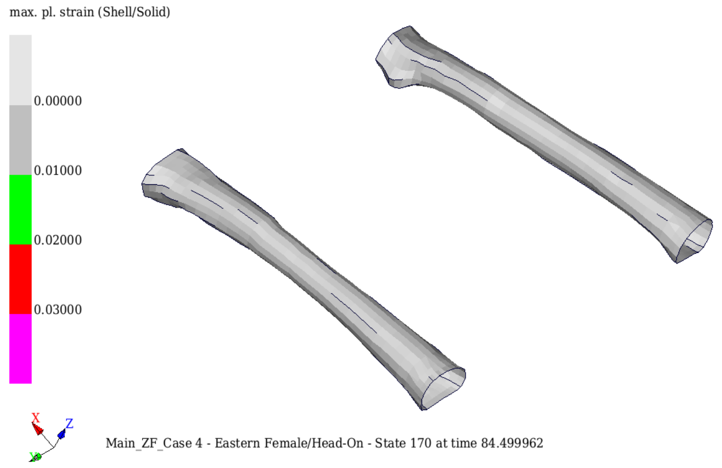


Figure 41 Femur fracture prediction for eastern female

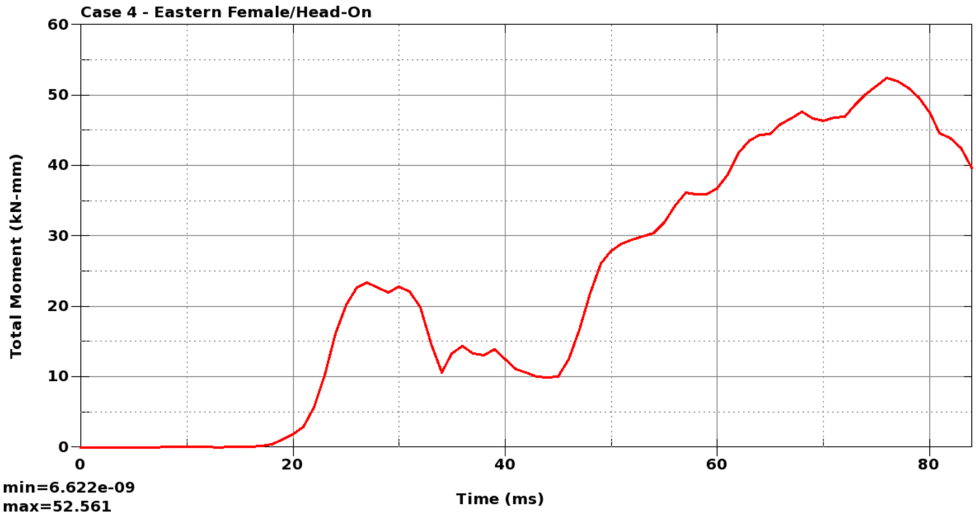


Figure 42 Femur bending moments for eastern female

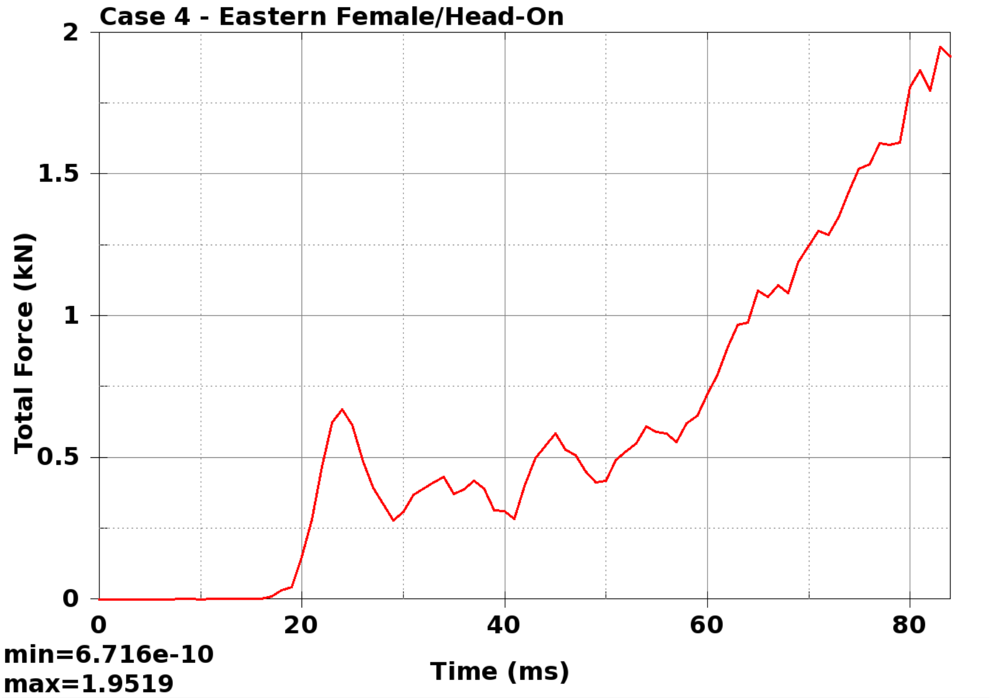


Figure 43 Femur cross section forces for eastern female

5 CASE 5 – REAR END OBLIQUE

5.1 Simulation set up

In Case 5, a midsize male driver (THUMS-D-SUFEHN (3.2)) is exposed to a rear end oblique impact in 15 kph due to a sudden stop of the host vehicle triggered by an AEB function and opponent vehicle running into host vehicle, see figure 44. Standard three-point belt is used. No airbags triggered. Crash pulse from internal database. Set-up also exemplarily represents a possible “rotated seat” configuration of the UseCase dimension.

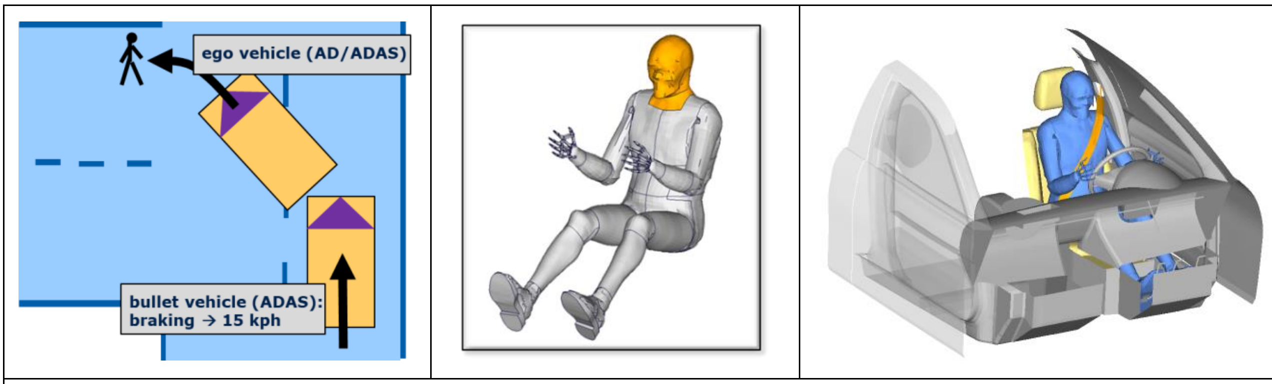


Figure 44 Case 5 – rear-end oblique

The software tools utilized for conducting frontal crash simulations are listed below:

- **Pre-Processor:** Beta CAE ANSA v.18.1.0, LS-Pre-post v.4
- **FEM-Solver:** LS-DYNA V971 beta release R7.1.3 MPP, DP
- **Post-Processor:** Altair Hyperview v.12, LS-pre-post v.4, SUFEHM IRA Tool, Animator 4
- **Occupant Positioning:** Positioning of Daimler FE Human Body Models were done using Daimlers developed positioning tool named FETOOL.
- **FE Models**: Sled Model, THUMS-D-SUFEHN Occupant model
- **Injury Risk Prediction Post-Processor**: A post processing tool was developed by TU-Graz to assess injuries through human body models – Dynasaur

Table 6 Injury parameters for assessment using HBM in crash impact scenario

Body Region	Injury Indicator/Injury Risk Assessment	THUMS v4	THUMS-TUC v3.01	THUMS-D v4 Obese (v1.0)	THUMS-D 5%ile Eastern Female	THUMS-D 50%ile Male
Brain	Cumulative Strain Damage Measure used for THUMS V4.02 Injury Risk Curve of DAI AIS 4+	•	•	•		
	Cumulative Strain Damage Measure (No injury risk curve exists for female) >> 50th %ile injury risk considered with FPS of 15%				•	
	SUFEHM Criterion developed by University of Strasbourg					⚠
Neck / Spine	SUFEHN Criterion developed by University of Strasbourg (Probabilistic Force Based Criterion)					⚠
Thorax / Rib Fracture	Probabilistic (Forman criterion)		•	•		
	Deterministic Injury predictor (Burstein criterion developed for long bones but used for other skeletal areas/body regions)	•			•	⚠
Abdomen	No evaluation done / No detailed abdomen organs exists in the model					
Pelvic	Deterministic Injury predictor (Burstein criterion developed for long bones but used for other skeletal areas/body regions)	•	•		•	⚠
	Probabilistic injury criterion developd for THUMSv4 based on max. Principla Strain by Perese et al.			•		
Femur	Deterministic Injury predictor (Burstein criterion developed for long bones)				•	

5.2 Status HBM used

THUMS-D V3.2 was also the basis for the implementation of the SUFEHM and also the SUFEHN. This modified THUMS was now applied within this baseline case 5. The coupling of the Strasbourg University Head Model (SUFEHM) to THUMS-D and its validation was already published at ESV Conf. 2009 [28].

This Strasbourg University Finite Element Head Model (SUFEHM), which is a 50th percentile FE model of the adult human head, was developed under Radioss software (Kang et al., 1997) [29] and transferred to LS-DYNA (Deck and Willinger, 2008) [30].

It has to be stated that the SUFEHM is available under three different codes (PAMCRASH/VPS, RADIOSS and LS-DYNA) and that it has been validated against existing experimental head impact data available in the literature in terms of brain pressure, brain deformation and skull fracture under the three codes. The model has been used for extensive real-world head trauma simulation in order to derive model-based head injury criteria for three different injury mechanisms, neurological injuries, subdural hematomas and skull fracture. In order to ensure an easy use of the model, a SUFEHM dedicated IRA-tool (Injury Risk Assessment tool) has been developed. This post-processing tool permits an automatic analysis and risk assessment.

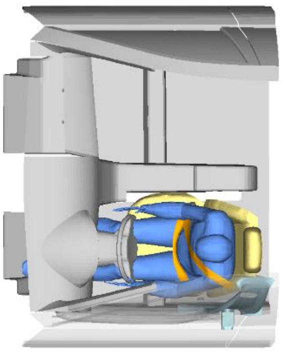
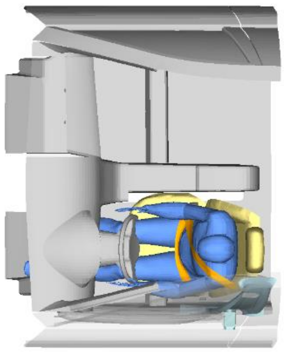
In 2004, Meyer et al. [31] presented a finite element neck model and its original validation and coupled it in 2012 with the existing Strasbourg University Finite Element Head Model and which is referred to as SUFEHN now. Latest development was presented by Meyer et al at carhs HBM Symp. 2018 [32].

Several FE Head Models exist and were published in recent years which have some tolerance limits to specific injury criteria: SIMon models developed by NHTSA and Takhounts et al. [33], KTH model developed by Kleiven et al. [34] and WSU model developed by Zhang et al. [35].

Latest applications of the THUMS-D with SUFEHM and as well THUMS-VW with SUFEHM in VPS are also extensively reported in the EU research project SafeEV [36] [37] [38].

5.3 Results and observations

Figure 45 below illustrates occupant kinematics during the impact. In the baseline simulation the contact between the head and the b-pillar was de-activated as structural contacts were not in focus. This was also primarily done to capture the complete kinematics of the head neck complex.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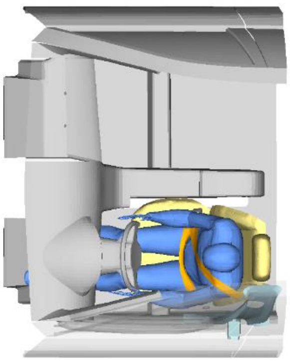	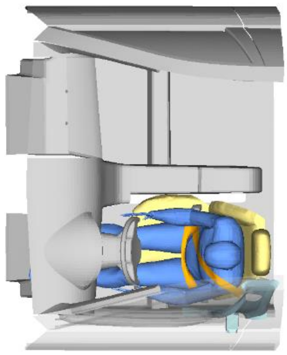

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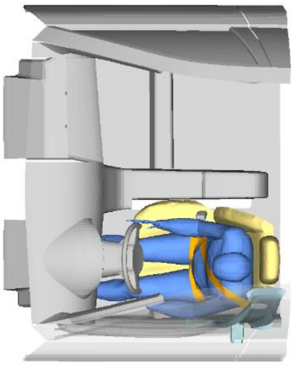	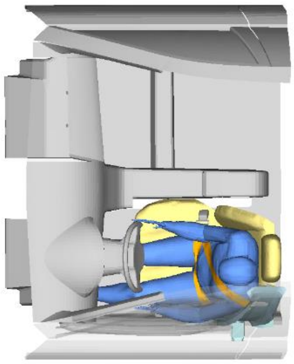
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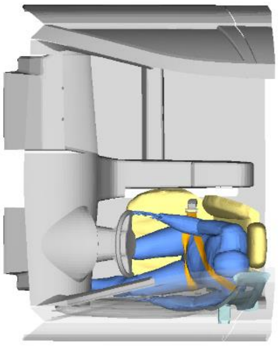
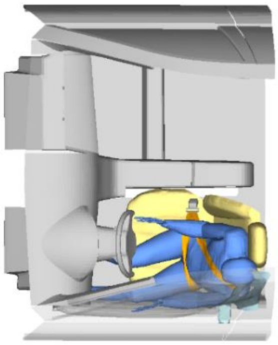
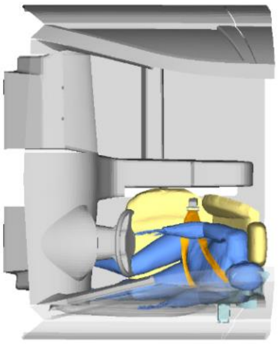
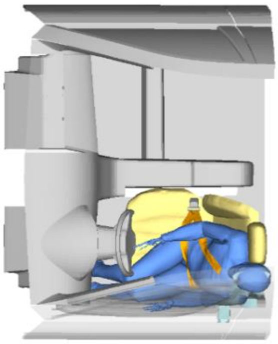
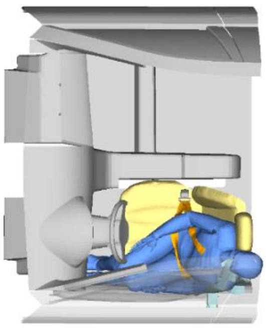
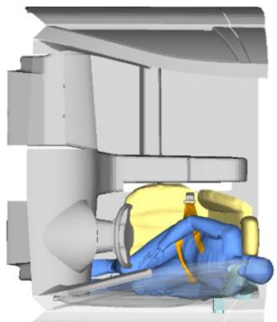
	
60 ms	70 ms
	
80 ms	90 ms
	

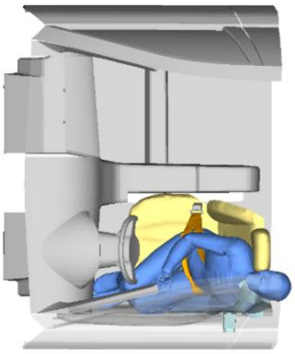
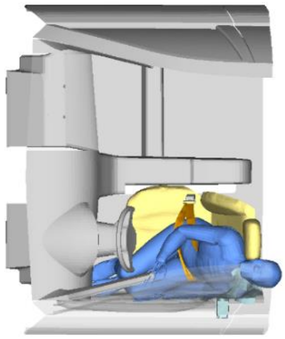
100 ms	110 ms
	
130 ms	138 ms

Figure 45 Occupant kinematics using THUMSD 50th percentile male occupant model

Head injury assessment is done based on SUFEHM IRA tool. Figure 46 shows the injury risk curves for head. Risk of DAI (neurological injury) is 9.3 % / is low. The injury risk for the head in general is low because of limited interaction with any of the structural components.

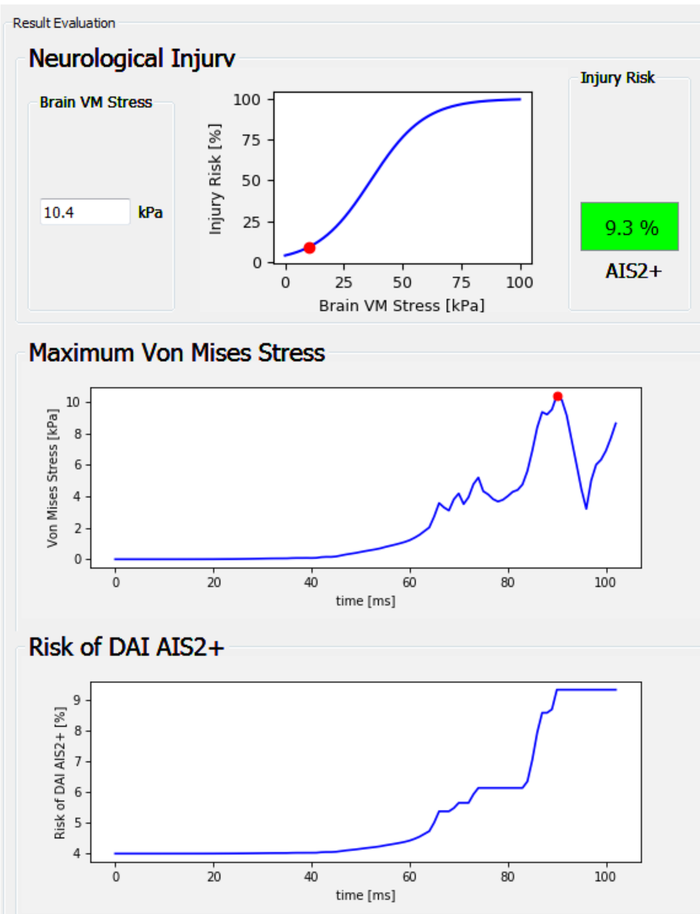


Figure 46 Injury risk evaluation and IRC for head using SUFEHM IRA tool

A risk of neck injury primarily whiplash was observed in this configuration. This evaluation is based on a peak shear force of 1.06 kN experienced at Occipital Condyle. Figure 47 illustrates the neck injury evaluation for the occupant. The reason foreseen for the whiplash risk is the absence of head restraint support due to lateral component of the pulse. However, kinematic evaluations also provide further insights that lateral guidance of the seat i.e. the depth of the seat bolsters and belt interaction with the occupant are areas which are influencing occupant kinematics.

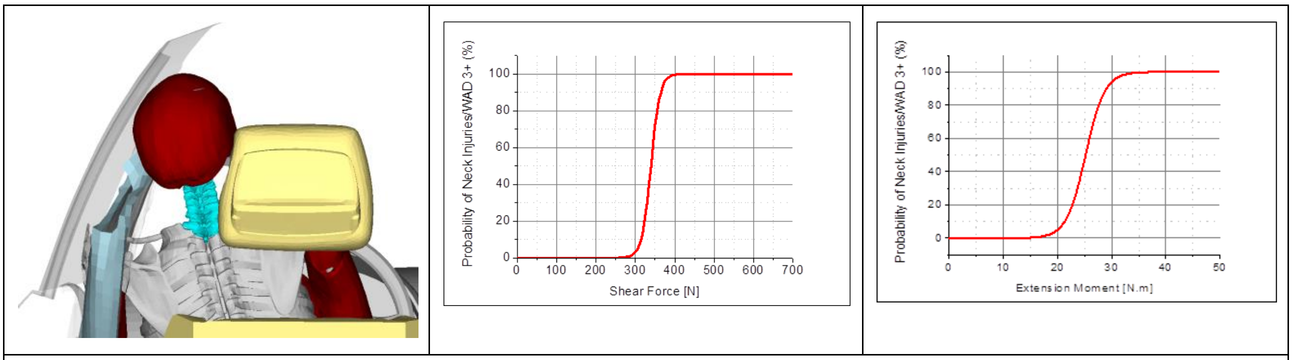


Figure 47 Head-Neck kinematic at 138 ms (left); injury risk curve for neck shear force and extension moment (right)

6 REFERENCES IN APPENDIX 3

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APPENDIX 4 – DEFINITIONS OF TERMS

Term	Definition
Test Case Matrix	A three-dimensional matrix, comprising the three dimensions; Individual Human Variations, Crash Configurations, and Occupant UseCases. See further in Chapter 3.2.
Test Case	A Test Case contains a combination of the three dimensions, with specification to allow for a crash test or simulation. See further in Chapter 3.2.
Demonstrator Test Cases	A Test Case selected for further study. See further in Chapter 3.2.
Occupant UseCases	In this report, 'Occupant UseCases' defines one of the dimensions of the Test Case Matrix. It contains combinations of some defined seating configurations, seat positions, sitting postures and interior features. See further in Chapter 3.2.3.1.
Crash Configuration	In this report, the Crash Configuration is one of the dimensions of the Test Case Matrix. It contains combinations of host and opponent collision angles, opponent yaw angle in addition to host and opponent collision velocity. See further in Chapter 3.2.3.2.
Pre-pre-processes and Pre-processes	Steps to filter out non-relevant combinations, when applying the matrix. Pre-pre-processes relate to more than one dimension of the Matrix. Pre-processes relate to one Dimension only. See further in Chapter 3.2.3.
Process of Grading	A process developed for grading a Test Case, and to compare some relevant aspects between different potential Test Cases. See further in Chapter 3.2.4.
Seating Configuration	In this report, Seating Configuration describes how the seats are positioned inside the vehicle, in terms of number of seats, seat location relative to the direction of travel and also seat occupancy. See Chapter 3.2.3.1.1.
Interior Feature	Interior features include information on relevant interior space and interior design details that may affect the outcome in case of a crash. See Chapter 3.2.3.1.2.
Seat Position	In this report, Seat Position includes information on the seat position adjustability in terms of seatback angle and seat pan tilt. It also includes examples of seat design features such as leg support and articulated seatback. See Chapter 3.2.3.1.3.
Sitting Posture	Sitting Posture included information on how the person is sitting in the seat, relating different body parts to the seat, in sagittal and lateral direction. See Chapter 3.2.3.1.4.