Right of first publication: 28th Aachen Colloquium Automobile and Engine Technology, October 7-9, 2019, www.aachener-kolloquium.de/en

How Will We Travel Autonomously? User Needs for Interior Concepts and Requirements Towards Occupant Safety

Wie fahren wir autonom? Nutzerbedürfnisse für Innenraumkonzepte sowie Anforderungen an den Insassenschutz

M.Sc. Anna-Lena **Köhler,** M.Sc. Fabian **Prinz,** M.Sc. Lining **Wang,** M.Eng. Julian **Becker,** M.Sc. Gudrun Mechthild Irmgard **Voß,** Dr. phil. Stefan **Ladwig,** Univ.-Prof. Dr.-Ing. Lutz **Eckstein**
Institute for Automotive Engineering, RWTH Aachen University, Aachen, Germany

Dr.-Ing. Thorolf **Schulte,** Dr.-Ing. Nico **Depner**
fka GmbH, Aachen, Germany

Summary

In the context of autonomous driving, additional possibilities for passenger occupation arise. Parallel to this, vehicle concepts especially in the field of autonomous driving provide more degrees of freedom to apply novel interior concepts and seating configurations. To derive user requirements early on in the development process in this new field, three user studies in two research projects were conducted. As autonomous driving technologies take the focus away from the driving task, interior design in general and seating can be modified to allow different activities other than driving. A user study in the research project UNICAR*agil* focused on the interior design and seat arrangement of a highly automated shuttle concept. By bringing users close to the use case of riding in an autonomous shuttle in a workshop situation, an early user integration was achieved. In this vein, more degrees of freedom in seat arrangement lead to a need to review existing restraint systems regarding their applicability to the autonomous context. Moreover, two user studies were conducted with the EU H2020 project OSCCAR in order to provide input to a matrix for selecting the most relevant test cases. The goal isto derive and design novel safety principles for advanced, safe, and comfortable sitting postures. While one study focused on preferred seat rotations, the second study examined the impact of different user scenarios on preferred sitting postures in an artificial autonomous driving situation. Results provide insights into the perception of seat rotations and detailed sitting postures that are most likely to be obtained by occupants in future use cases. The results of the user studies of the two projects independently revealed valuable insights, which will help to derive requirements towards occupant safety in future vehicle concepts.

1 Introduction

Within the context of autonomous driving, technological advances in the automated driving functions lead to more degrees of freedom in driver vehicle interaction, but also with regard to the interior concept and resulting occupant protection requirements. With increasing level of automation, the user's role shifts from being an active driver to being a passenger. User involvement in the product development process is at least as crucial for autonomous vehicles compared to conventional vehicles. But as a passenger's focus is solely on the interior and not on a driving task anymore, this becomes even more important. In order to design and develop vehicles that fit user's requirements and make new technologies safe for use at the same time, users should be integrated early on in the development process [1] [2].

The interior of a vehicle is one of the main touch points between the passenger and the vehicle. First, the overall interior design is relevant, especially in the context of a disruptive technology such as autonomous vehicles: Vehicle concepts especially in the field of autonomous driving provide more degrees of freedom to apply novel seat configurations and follow different activities as a passenger, resulting in different sitting postures. Second and in line with such novel interior design concepts, there will be a need for advanced restraint systems in order to protect all occupants in future accident scenarios in the best way possible. Sitting postures and activities in vehicles that can be sufficiently protected with restraint systems are currently highly linked to the requirements of legal and consumer protection tests. In today's tests, apart from out of position situations, only upward and, forward facing occupant positions are considered [3], which are expected to occur frequently in a standard seating configuration within SAE level 0-2 vehicles [4].

The need for gaining user requirements for the interior design of highly automated vehicles (HAVs) is addressed within the project UNICAR*agil*, funded by the Federal Ministry of Education and Research of Germany and coordinated by the Institute for Automotive Engineering (ika) of RWTH Aachen University. In the scope of the project, four driverless vehicles will be developed and built in order to demonstrate the disruptive hardware and software architecture providing safety and security [5]. The present publication focuses on one of these concepts, the autoSHUTTLE. This concept car will be designed to complement public transport and offers, depending on the traffic situation's requirements, a comfort as well as a rush hour mode..

Advanced safety and restraint systems are the focus within the EU H2020 project "OSCCAR - Future Occupant Safety for Crashes in Cars". The project analyzes occupant safety requirements for HAVs and defines the technological advancements needed to enable the automotive industry to derive and investigate new safety systems for advanced, safe and comfortable sitting positions. In order to understand the potential of new sitting postures and seating positions in SAE level 4-5 vehicles, two empirical user studies were conducted to examine the impact of different scenarios on preferred sitting postures and orientations in a simulated autonomous driving situation. The results serve as input to a test case matrix of expected future crash scenarios in order to identify needs for future occupant restraint principles.

The two projects are independent of each other, but address relevant user centered research questions in the development process of autonomous vehicles and are therefore reported and analyzed jointly within this publication. First, the user study on interior design of fully automated shuttles within the UNICAR*agil* project is described, followed by the two user studies conducted in the OSCCAR project on occupant safety for autonomous vehicles on preferred seat rotations on the one hand, and sitting postures and activities of passengers on the other hand.

2 Study 1 - Seat Arrangement in Fully Automated Shuttles

Current public transportation is sometimes challenging. Many situations come along with unsatisfied excessive commuting demands during rush hours and low occupancy in off-peak hours [6] [7]. Thus, the vision of the autoSHUTTLE fleet within the UNICAR*agil* project is to operate as a supplement to the current public bus transportation system, which picks up and drops off passengers at defined bus stops. During a rush hour mode, the shuttle is planned to carry up to eight passengers standing. This operation mode mainly tends to relieve the pressure of excessive commuting demands of public transportation during rush hours. Furthermore, a comfort mode is planned to operate during the period of non-rush hours providing a maximum of six available seats. This mode aims for maximizing the passenger's well-being in the shuttle and optimizing the user experience in public transportation.

As introduced before, occupants of automated vehicles no longer need to sit in a conventional car seat to accommodate driving tasks. This is because they are no longer needed as a driver and free to conduct non-driving related activities, depending on the level of automation. This results in additional degrees of freedom for the interior elements of autonomous vehicles, which should be designed to meet the user's requirements, resulting in the necessity to derive these requirements. When seats change, the question arises what the matching interior should look like and which specific requirements potential users have.

To approach especially seat arrangement and -specification, a user study was conducted within in the UNICAR*agil* project at ika in Aachen. The study focused on two research questions of the comfort mode. First, the study aims at assessing the preferred seat arrangement for a fully automated shuttle (1). The second research question addresses the ergonomic specifications the seats should have (2).

2.1 Methods

The research questions aim on a qualitative assessment and were addressed via workshops. As stated in [8], people usually have difficulties to come up with innovative ideas , especially in such a disruptive situation as a public and fully automated shuttle. People were therefore brought into relatable situations of their regular commute. They were asked to design and try out their preferred seat arrangements within this simulated situation, instead of merely having to think about these and then voice their ideas.

This chapter describes the methodological approach of the user study on interior design. First, the sample characteristics are described, followed by apparatus, task and stimuli, including the questionnaires used. The chapter concludes with the procedure.

2.1.1 Participants

N = 44 participants (*N* = 20 female) were tested. The mean age was *M* = 40.3 years with an *SD* = 18.7 years, ranging from 18 to 71 years. *N* = 28 (64 %) participants reported to live in a city, while *N* = 6 (14 %) lived in a small town, and *N* = 10 (23 %) lived in the countryside. *N* = 21 (48 %) participants did not own a car in the household and therefore used public transportation on a regular basis. *N* = 18 (27 %) owned one car, *N* = 7 (16 %) two cars and *N* = 4 (9 %) reported to have three cars available in their household. It was ensured that the sample was open towards technical innovation with N = 27 (62 %) participants stating new technology to be not or rather not frustrating on the questionnaire regarding openness towards technical innovation as described in chapter 2.1.2. Participants' mean height was *M* = 174.8 cm with an *SD* = 10.4 cm, ranging from 150 cm to 205 cm, where males had a mean of *M* = 180.7 cm with an *SD* = 8.0 ranging from 168 cm to 205 cm. Females had a mean height of 167.7 cm with an *SD* = 8.4 cm, ranging from 150 cm to 181 cm. For the 13 workshops, an average of *M* = 3.4 participants participated in a workshop, ranging from 1 to 6 participants. The group size of *N* = 6 was tested once, the group sizes *N* = 1, *N* = 2 and *N* = 4 were tested twice and the group sizes of *N* = 3 and *N* = 5 were tested three times. Participants were randomly assigned to the groups regarding age and gender.

2.1.2 Apparatus, Task and Stimuli

The workshops were executed in an empty static concept mock-up (length: 3910 mm, width: 1880 mm, height: 2480 mm, usable floor area: 2740 mm * 1880 mm, see figure 1) to simulate the real interior dimensions of the autoSHUTTLE. The body structure was assembled by SMT aluminum profiles with a MDF floor. Six seats made from cardboard were available for positioning inside the shuttle. The dimensions of the seats referred to the seat design recommendations by Reed [8], which satisfy the basic anthropometric accommodating requirements as shown in figure 1. The seat backrest was adjustable from 15° to 30°. In addition, the seat height was adjustable by adding 20 mm-thick plank boards under the seat structure. Three TV screens (165 cm each) with a video of a rear, front and left view of a car driving around the city of Aachen were part of the mock-up. A number of everyday requisites were used for interaction, such as bags with varying sizes and weights, coffee cups, an umbrella, laptop bags, a stuffed dog, big and small suitcases, and a bicycle. Questionnaires for assessing demographic data, openness towards technical innovation (on a 5-point Likert scale ranging from 1 = not correct to 5 = fully correct), personal preference of seating arrangements of four, five and six seats (for which participants had to draw an individual arrangement in a box representing the scaled dimensions of the shuttle), usage with strangers (on a 5-point Likert scale ranging from 1 = not at all to 5 = absolutely), motion sickness susceptibility on a 5-point Likert scale ranging from 1 = never to 5 = constantly), and further qualitative questions (e.g. "which additional items would you include in the shuttle?") were used to get a more detailed view of the participants' preferences. With regards to autonomous driving, motion sickness and the willingness to ride in a shuttle alone, with strangers, and without a driver are relevant aspects to assess.

Fig. 1: Left: Inside of the autoSHUTTLE mock-up structure with usable floor area in the middle of 2740 mm * 1880 mm and three screens (front, left and rear view), right: the adjustable mock-up seat

2.1.3 Procedure and Design

The N = 44 participants were divided into 13 workshop groups, with each workshop lasting three hours. Each group was engaged in a predetermined activity. The activities for each participant were sorted into four use cases, categorized by the reasons of travel, namely grocery shopping, going to work or university, and travelling. Upon arriving in a room where the mock-up was not present, all participants filled out a privacy statement on data protection and a confidentiality statement. On a short verbal instruction of the workshop's general goal, a brief demographic questionnaire followed. In company of the workshop leader, the participants transferred to the workshop room. The workshop itself was divided in three phases: The conception phase, a break, and a test drive. The conception phase started with a safety instruction and a detailed instruction about the goals of the workshop by the workshop leader in front of the mock-up in the experimental room. During this first phase, participants were initially asked to position a number of seats (maximum six seats, because the group size was maximum six participants) in a way that would create their preferred shuttle interior. There was no obligation to use all available seats but the precondition that every participant would be able to sit. Participants were instructed to design the interior for their group specifically.

The conception phase was followed by a 15-minute break, in which individual ergonomic and anthropometric measurements of the participants were taken with the adjustable seats, so that the participants' preferred seat configuration could be assessed. Subsequently, a virtual test drive, during which the participants were asked to imagine a situation in which they would use the shuttle (e.g. a ride to university or shopping groceries) and take the appropriate requisites with them. This interaction was supposed to increase the participants' immersion, leading to more specific results regarding different age groups and reasons for travel, because the different participants could explain their specific needs in more detail (e.g. an old woman going grocery shopping and needing space and a safe spot to store her bag, or a young student needing a power socket to charge the smartphone). This virtual test drive around the city took approximately ten minutes and was executed by showing a video presented on three screens with rear, front, and left view. After the test drive, participants filled out a final questionnaire with open questions and the possibility to give comments. Within the final questionnaire, they were asked to sketch their three favorite shuttle interiors with four, five, and six seats. Dependent variables of this user study were the seat arrangement, the preferred seat height and backrest angle, and questionnaires for assessing demographic data, namely openness towards technical innovations, personal preference of seating arrangements of 4, 5 and 6 seats, usage with strangers, motion sickness susceptibility, and further qualitative questions.

2.2 Results

The results are structured according to the two research questions. First, the seat arrangements are described, followed by results on ergonomics.

In the user study, different seat arrangements were assessed for RQ 1. Depending on the group, the importance of different aspects varied (e.g. if participants wanted to communicate, a tight seating arrangement was chosen; if they were travelling with strangers, the focus was on personal space). Between four and six seats were arranged in each workshop ($M = 5.2$ seats). In four groups, participants favoured four seats, while two groups chose to put five seats into the shuttle. In the remaining seven groups, participants chose to put 6 six seats into the shuttle. Between two and three ($M = 2.5$) seats were arranged in the shuttle rear, between one and two ($M = 1.1$) seats in the shuttle middle and between two and three ($M = 1.6$) seats in the front of the shuttle. From the 13 workshops, 12 different seat arrangements were proposed with partly overlapping arrangements. The most preferred seat arrangement consisted of two to three seats in the rear of the shuttle facing to the front with a combination of one to three different other seats in the middle and front. 43 (64 %) of all 67 seats in all workshops were positioned in driving direction. The workshops did not reveal any preferences for certain numbers of seats or seat arrangements for different group settings.

The drawings in the final questionnaire matched the positioned seats in the workshop. When asked to arrange four seats inside the shuttle on a sketch, two to three seats in the rear were preferred by $N = 38$ participants (85 %). When drawing five seats, the three seats in the rear were preferred by $N = 29$ (66 %) of the participants. With six seats, $N = 38$ participants (86 %) preferred three seats in the rear. Overall, the composition of three seats in the rear was preferred most, with 84 (64 %) out of 132 drawings. Figure 2 sketches the aggregated design recommendation based on the preferred seating compositions with arrows indicating the direction participants were facing in.

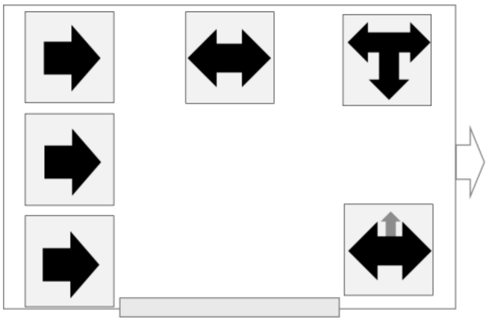


Fig. 2: Aggregated design recommendation from user study based on the preferred seating compositions. Arrows are indicating the directions participants were facing in Design recommendation from user study

Figure 3 shows the participants' preferred seat height and preferred backrest angle. *N* = 33 (75 %) of the *N* = 44 participants chose a seat height between 380 mm and 400 mm. While the results for the preferred backrest angle range from 15° to 27°, the most preferred angle is at 22°.

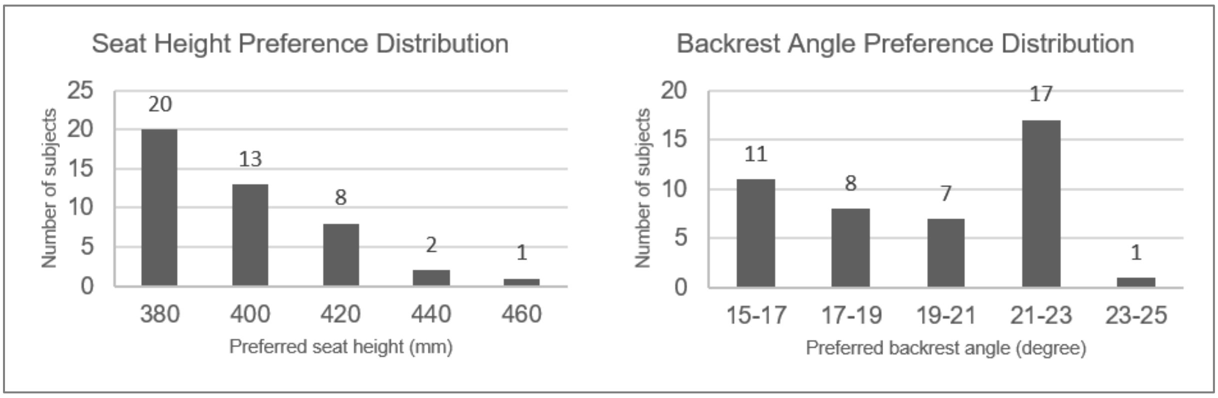


Fig. 3: Distributions of participants' preferred seat heights (categorized into 20 mm steps) and preferred backrest angles

2.3 Discussion

In this user study on the comfort mode of the autoSHUTTLE, the main focus was on the interior arrangement by passengers in groups of one to six people. The two research questions (RQ) were focusing on preferred seat arrangement (1) and ergonomic specifications (2). For this reason, user centered workshops were conducted.

The results regarding seat arrangement (RQ 1) suggest that most seats should be facing forward as this was the most desired seating position. Many people feared to suffer from motion sickness when not facing in the driving direction. This might have influenced the seat arrangements strongly. There should be two to three seats in the rear of the shuttle, as most participants favored this arrangement. Following the open comments of the final questionnaire, especially passengers who knew each other wanted to be able to communicate easily with each other. This could be realized through seating positions that are close together and/or facing each other. Results indicated for the seats in the front and middle of the shuttle to be rotatable, according to the user's personal preference and need for personal space.

The ergonomic results (RQ 2) indicate that the seat height should be around 380 mm to 400 mm, which satisfies the recommended ergonomic accommodating height [9]. This could be adopted as a rough guideline for seat design that is likely to satisfy most occupants in autonomous vehicles. However, it indicates that participants tend to sit more straight in this setup and scenario. Results could vary slightly in other setups and scenarios like a very short trip of two to five minutes, where an almost upright standing position could be more comfortable. Therefore, a final seat design should consider all situations. Results furthermore indicated for seats to have an adjustable backrest, so the preferred backrest angle can be realized for a range of passengers.

Please note that the results are rather focusing on younger people and college students who are mostly open towards technical innovations, due to the sample characteristics. Realizing a modular approach would allow for combining the preferred seat arrangements of several groups of participants. Overall, the results of the user study on seat arrangements and seat design of a fully automated shuttle provided valuable insights on user requirements towards seat arrangements and design. By bringing participants into the situation of interacting with the shuttle, we were able to derive detailed results for our sample. These findings serve as a basis for the product development process of the autoSHUTTLE's interior within the UNICAR*agil* project.

3 Study 2: Preferred Seat Rotations for Autonomous Vehicles

The first user study reported above was conducted within UNICAR*agil* focused on user requirements regarding interior elements and seat arrangements for the development of an autonomous shuttle concept. The second user study reported next in this paper was conducted within the OSCCAR-project and takes a closer look at occupant safety, specifically in the context of autonomous driving.

When a driver is not required to execute 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 conveniently. A 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. This first user study aims at assessing preferences and the subjective feeling of discomfort of participants in different seat rotations in a safe environment on the test track.

3.1 Methods

This chapter describes the methodological approach of the user study. First, the sample characteristics are described, followed by apparatus, task and stimuli, including the questionnaires used. The chapter concludes with the procedure.

3.1.1 Participants

N = 31 participants (*N* = 12 female) with age ranging from 19 to 66 years and a mean age of *M* = 31.52 (*SD* = 14.05), 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). 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 a mobile phone (*N* = 16; 10.32 %). Other participants stated that they like to look 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 %). *N* = 8 participants (5.16 %) stated to prefer other activities and *N* = 3 participants prefer doing nothing (1.94 %).

Participants were screened according to their prevalence for motion sickness. Participants were tested in pairs, ensuring to control for motion sickness prevalence as one person who had experienced motion sickness before and one person who had not were always tested in the same rotation. This way, possible differences between rotations could not be attributed to motion sickness prevalence of participants. *N* = 15 participants had experienced motion sickness before, *N* = 16 participants had not.

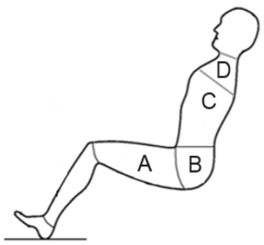
3.1.2 Apparatus, Task and Stimuli

The testing vehicle used for the study was a Ford Transit with seven seats (FT300, KW 92, 2.2l). The vehicle was driven by the test coordinator, creating an artificial autonomous driving situation for the passengers. Only two drivers conducted the experiments in order to keep the influence of different drivers as low as possible. 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, on which up to four seats can be placed freely. Each seat is equipped with foldable armrests and a seatbelt, and can be turned clockwise in steps of 30°. For the study, two seats were placed on the middle rail in the rear of the vehicle for two participants to be tested at once without the participant’s perception and rating of discomfort being distorted by the side of the vehicle where the seat was placed. This way, both participants experienced the same lateral 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 instructed to not use the armrests in order to make sure they experienced the vehicle dynamics in the seat with their entire body and did not distort this feeling by using their arms as support. The seatbelts were always used. Figure 4 shows an exemplary setting of the seats in the vehicle and gives a close up of one of the seats.

Fig. 4: Seats and exemplary seat configurations. Seats turned forward (1), 90° sideways (2) and full view of one seat (3)

The user study was executed on a restricted test track of ika in Aachen. The test track is 400 m long and has two circular areas. The larger circle is 100 m wide, the smaller is 40 m wide. Figure 6 in the subsequent chapter shows the parkour used for testing on the test track. The user study followed the projects' ethics requirements.

For each rotation, participants were first asked whether this would be an acceptable rotation for them to travel in. Furthermore, for assessing their perceived discomfort of each rotation, the CP50 scale according to [10] was adjusted to a 26-point scale, with a rating of 26 indicating maximal discomfort (see figure 5). The rating scale was shortened from 50 items to 26 options in order to give people a better understandability and overview of the questionnaire. Participants were asked to rate the extent of discomfort which arises from their seating position separately for both body halves and individually for each body part. The questionnaire assessed subjectively perceived discomfort of certain body parts, namely the thigh, buttocks, the back, and the shoulders/neck. The rating was compared between rotations for each body part individually.



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

Fig. 5: Adjusted CP50 scale. Rating scale shortened from 50 to 26 options

3.1.3 Procedure and Design

Participants were welcomed at the start/finish as shown in figure 6. 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 different randomizations of seat rotations according to the test plan: Each participant started in a different seat rotation and experienced seven rotations (random sequence, not fully crossed). One group of participants was rotated clockwise between 0° and 180° (right-wing), the other group counter-clockwise (left-wing). The participants sat in the rear of the vehicle.

Figure 6 illustrates the sequence of manoeuvres. Each trial started with a test driver accelerating the vehicle to 45 km/h, followed by a double lane change. Afterwards, the driver stopped before turning right. While driving in the big roundabout as displayed on the right of figure 6 the driver drove at a maximum speed of 20 km/h. After this, the driver turned left twice 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 right, as can be seen on the right side of figure 6. Subsequently, the test driver sped up to 45 km/h and drove two double lane changes. Then, the driver again slowed down to 20 km/h and drove into the curve displayed on the left of figure 6 in order to expose people to just left-side tilts, additionally to the previous right-side tilts in longer curves. After this, the driver returned to the start/finish mark. One trial lasted about 2 minutes. The drivers paid attention to not drive abrupt or harsh manoeuvers but rather to simulate a normal ride in a car and followed a balanced and smooth driving style.

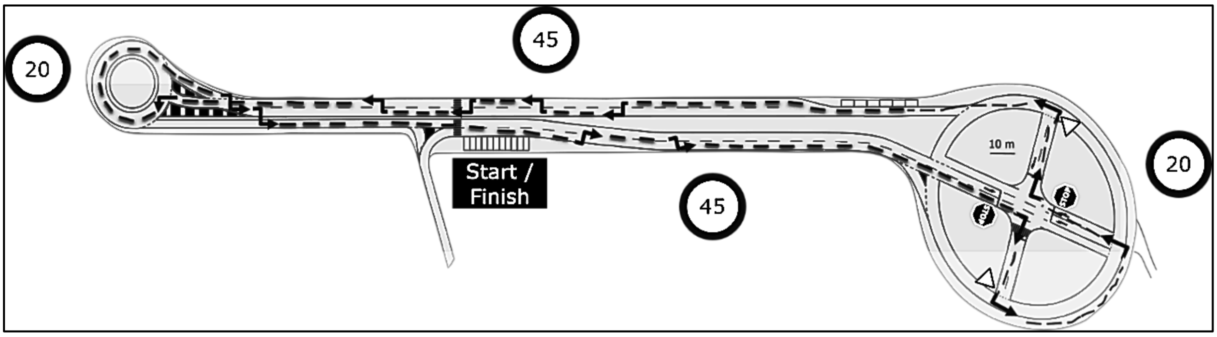


Fig. 6: Testing parkour on the test track including sequence of manoeuvres. The test track is 400 m long and has one circular area on the left (40 m wide) and one elliptical area on the right (100 m wide)

Participants were asked directly after each trial whether the rotation they had just experienced would be acceptable for them. They could reply either with yes or no. If they answered negatively, their reasoning was documented. After each ride with a certain seat rotation, participants filled in the adjusted CP50-scale on their perceived discomfort in different body parts, as described in chapter 3.1.2. Therefore, dependent variables were participant's overall acceptance of each rotation on the one hand and the rating of discomfort with the adjusted CP50-scale on the other hand.

3.2 Results

After each rotation ride on a standardized parkour on the test track, participants' acceptance of each rotation was assessed. Figure 7 shows the percentage value of "yes"-replies to the question, if the rotation participants had just experienced would be acceptable to them.

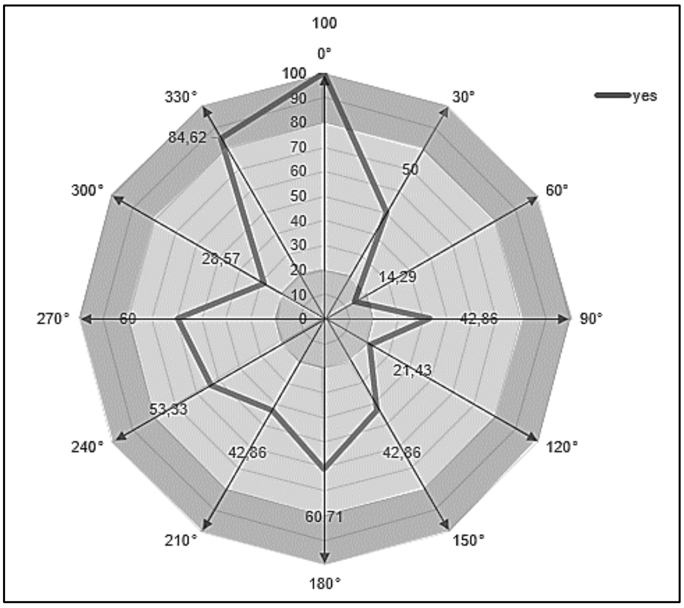


Fig. 7: Percentage of participants agreeing that the seat rotation is acceptable for an autonomous vehicle depending on the seat rotation. 0° means that no rotation was applied in relation to the driving direction. Note: Mann-Whitney

U-tests for opposing pairs of rotations showed a significant difference between 30° and 330° (z = -2.111, p = .035). All other comparisons were only marginally or not significant.

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). For both rotations, participants without motion sickness prevalence accepted each rotation more often than participants who had experienced motion sickness before. For the other rotations, no significant difference was observed between the two motion sickness prevalence groups.

After each ride with a certain seat rotation, participants filled out a questionnaire to assess their perceived extent in discomfort in different body parts. Each body part, such as the thighs, the buttocks, the shoulder/neck, and the back, was assessed individually. Participants reported the highest discomfort for the 60°-rotation for the thighs (M = 9.34, SD = 8.35), the buttocks (M = 9.72, SD = 7.95), and the back (M = 11.5, SD = 7.4). For the shoulders, no rotation had a higher peak than others. However rotating right (rotations between 30° and 150°) caused a higher overall discomfort rating (M = 9.33, SD = 6.45) for the shoulders than rotating left (rotations between 210° and 330°; M = 6.13, SD = 6.15). These results are only descriptive and results for both individually assessed body halves were merged in order to gain a better overview. For details, please see [11].

3.3 Discussion

In this user study within OSCCAR, different seat rotations were assessed in an equipped testing vehicle on a closed test track, evaluating overall acceptance of seat rotations and general discomfort. The results show preferences of certain rotations and feed into future research steps of the OSCCAR project in order to select the most relevant test cases to derive novel safety principles for advanced, safe, and comfortable sitting postures. Within this chapter, the overall acceptance of the distinct rotations is discussed first. Subsequently, the rating of subjective discomfort of each assessed body part is targeted, before a summary is given and limitations are discussed.

The descriptive values of the overall acceptance rating as displayed in figure 7 suggest that left-wing rotations were preferred, while the number of right-hand turns and left-hand turns was balanced. Rotations to the right (30°-150° clockwise) were descriptively accepted worse than the rotations to the other side. However, statistically significant results could only be reported for the direct comparison of 30° and 330°. These descriptive results were supported by the rating for discomfort 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 reported 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. Regarding the influence of motion sickness prevalence, chi-square tests suggested that motion sickness did only have limited influence on the overall acceptance of seat rotations. This should be investigated further in follow-up studies, e.g. with larger sample sizes.

Overall, the rotation of the seat seems to induce a difference in the perception of general discomfort, especially when rating the discomfort for the back, which showed the highest discomfort rating for the 60° rotation. 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.

Regarding the discomfort rating, the overall results indicate that the back plays a crucial role in the subjective assessment of discomfort for different seat rotations. One reason for this could be the missing armrests, nevertheless this was the case for all rated body parts.

For all statistically significant results, the right-hand rotations (30°-150°) were negatively rated compared to left-hand rotations (210°-330°). The subjective assessment of discomfort 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 will need further investigation in order to understand the effects properly, to learn how and why the statistically significant and not-significant differences have come about, and whether these can be replicated.

Summing up, the results of the study give a first overview on 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 discomfort 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 of this user study are subject to certain limitations. 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 participant's behavior in this study could be a subjective feeling of control when looking in the direction of travel. This should be targeted in future studies. Furthermore, people were not engaged in any activity, so we cannot make assumptions about the preferences for a certain rotation when people are actually sitting next to one another or if they are engaged in further activities such as reading or talking to one another. In close correspondence to this, the third study reported in this publication investigated sitting postures in different use cases further and will be explained in the following.

4 Study 3: Preferred Sitting Postures and Activities

While the second study focused on preferred seat rotations, the third study (also conducted within the OSCCAR project) was on occupant safety and therefore focused on 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 on seats facing each other and limiting the view on the driver of the vehicle, creating an artificial 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 deduction of novel restraint systems. This chapter describes the methodological approach and discusses the results of this study.

4.1 Methods

The following chapter gives an overview of the methodological approach. First, the sample characteristics are described, followed by apparatus, task and stimuli, including the questionnaires used. The chapter concludes with the procedure.

4.1.1 Participants

In the third study, *N* = 51 participants (*N* = 29 female) with age ranging from 18 to 58 years and a mean age of *M* = 26.86 (*SD* = 10.26), participated in this experiment. On average people spend *M* = 4.53 times per month as a passenger on longer drives of about 2 hours (*SD* = 6.11). 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 %).

4.1.2 Apparatus, Task and Stimuli

As in the second user study on seat rotations, the testing vehicle was a Ford Transit with seven seats (FT300, KW 92, 2.2l). All modifications in the way they were used in this study are TÜV-approved and judged safe to use in public traffic. The two test coordinators were seated on the driver seat and one of the two front passenger seats. The vehicle was driven by one of the test coordinators, creating an artificial situation of an autonomous driving situation for the passengers. This was done by separating the front seats from the rear of the vehicle with black cloth, leaving only a small part in the middle free for the driver being able to use the rear view mirror inside the vehicle and for the test conductor to be able to communicate with the participants if needed. 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 four seats was placed, two facing in the direction of driving and two facing the rear window so that two participants sat directly opposite to each other (see figure 8). A fixed table was positioned in the rails in the middle of the passengers. 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 autonomous ride.

Fig. 8: Interior of the testing vehicle. Backward facing seats with table (1), all rear seats with folded table (2), forward facing seats with table (3)

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, 32.8 km long in and around Aachen, 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. Drivers followed the speed limits (following the suggestion of 130 km/h on the highway) and adjusted their speed to the traffic situation. The user study followed the projects' ethics requirements.

Nine cameras were placed in the vehicle (figure 9). 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.

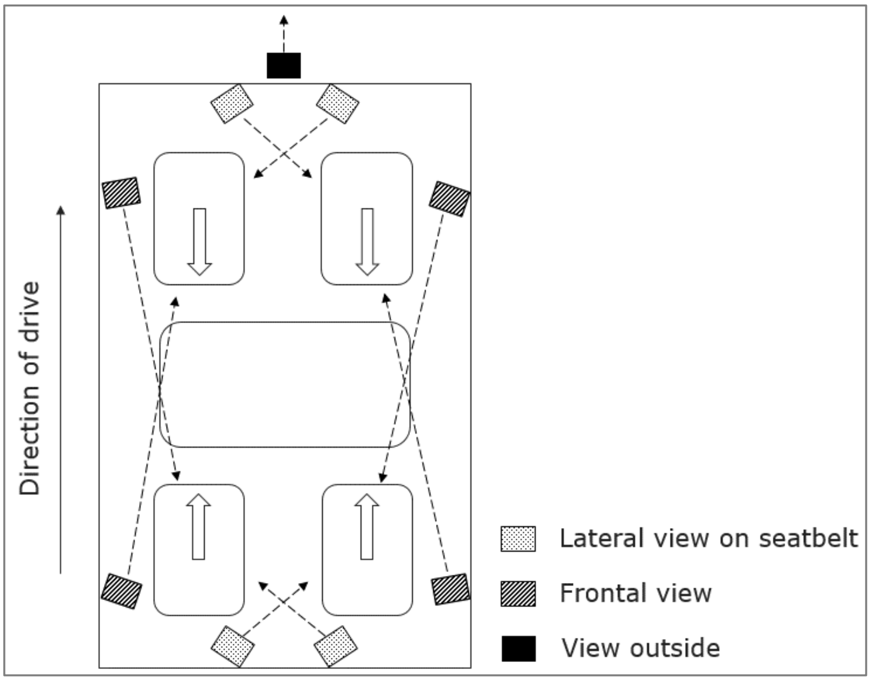


Fig. 9: Camera positions in the testing vehicle. Four cameras filming the lateral view on participant's seatbelt, four cameras filming each participants from the front and one camera facing in driving direction.

4.1.3 Procedure and Design

The third user study was conducted with *N* = 51 participants, divided into *N* = 13 groups consisting of *N* = 3-4 people each. One group had to be excluded from data analysis due to not completing the testing. 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, categorized 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 10 illustrates the use cases.

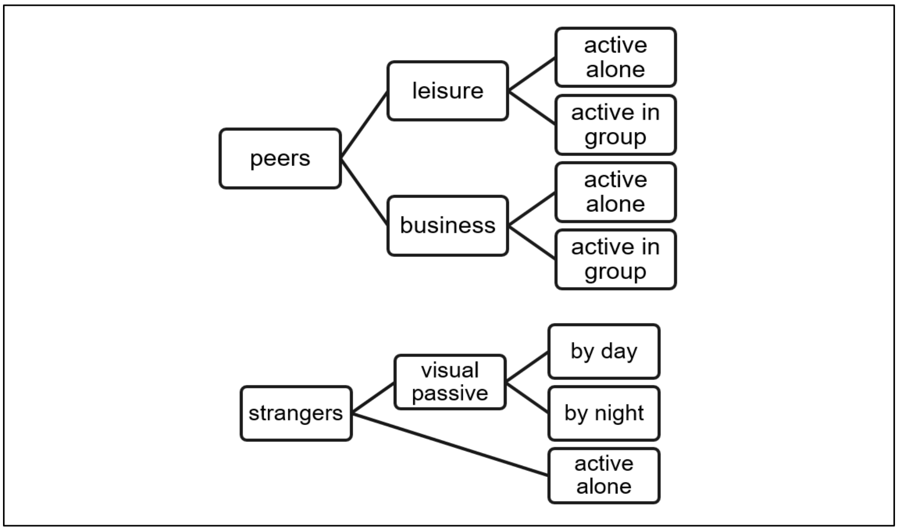


Fig. 10: Camera positions in the testing vehicle. Use cases for peers divided into leisure and business and again divided into being active in a group or alone. Use cases for strangers divided into two visual passive scenarios, one by day and one by night, and being active alone

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

Participants were able to choose the distribution to the seats themselves, thus deciding whether they drove facing to the front or back. Inside the vehicle, activities for the ride (see above) were explained to the participants. Afterwards, participants were asked to adjust the angle of their backrest to a position they felt most comfortable in and to buckle up. The backrest could only be reclined up to 34° due to space reasons in the testing vehicle and due to safety reasons because of the study being conducted on public roads.

The cameras had been turned on before the participants entered the bus and started recording just before the ride began. During the ride, the driver and the test conductor did not interact with the participants. After arriving back on ika premises, the participants filled in a qualitative 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. Dependent variables of this explorative user study were the filmed and classified sitting postures and the performed activities.

4.2 Results

The videos of the second user study were analyzed using a distinct matrix 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 [10], [13], [14] and in part [15]. The classification is illustrated in figure 11 below.

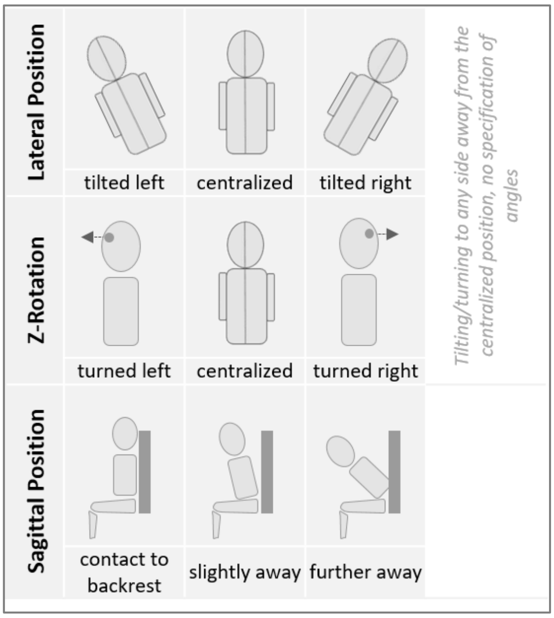


Fig. 11: Detailed categories and levels of sitting postures divided into lateral position (tilted to the left, the right, or centralized), z-rotation (turned to the left, to the right, or centralized), and sagittal position (contact to the backrest, slightly away, or further away).

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. Each video was analyzed according to the matrix by one of four decoding persons. Decisions regarding the exact classification of the sitting posture were made by each decoder of videos following a joint scheme. Each video was analyzed by one decoder. In case of unclear decoding, decoders consulted each other in order to make the same decisions. 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 the classification to be 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 use cases are shown before sitting postures for every use case are illustrated. The results show only the most frequent 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.

4.2.1 Sitting Postures: Overall Results

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. For choosing sitting postures for future research within OSCCAR, the relative frequency was of interest. Table 1 indicates the most frequent postures as described in figure 11.

Tab. 1: Most frequent sitting postures over all participants. Percentage of time given in each table refers to overall time of video material of each 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. Ranks show all postures that were taken for at least 10 % of the time.

Use Case	Body part	Rank	Posture: lateral	Posture: z-Rotation	Posture: Sagittal	Percent-age of time
overall	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 %

4.2.2 Sitting Postures: Results in Individual Use Cases

As described in chapter 3.2.1.3, the workshop groups followed individual use cases. Table 2 shows the most frequent sitting postures for every use case.

Tab. 2: Most frequent sitting postures in the individual use cases. Percentage of time given in each table refers to overall time of video material of each 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. Ranks show all postures that were taken for at least 10 % of the time.

Use Case		Body part	Rank	Posture: lateral	Posture: z-Rotation	Posture: Sagittal	Percent-age of time
Peers	Business – Active in a Group	Lower back	1st	centralized	centralized	contact to backrest	86.26 %
		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 %
	Business – Active Alone	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 %
	Leisure – Active in a Group	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 %
	Leisure – Active Alone	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 %
Strangers	Active Alone	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 %
	Visual Passive by Day	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 %
	Visual Passive by Night	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 %

4.2.3 Activities

The actions *N* = 47 participants engaged in varied with the different instructions per use case. In table 3 below, these are split up into the actual activity people were executing while following the use cases. Here, most often occurring activities across all participants are presented, along with the percentage of time spent on them, divided by groups. As the executed activities are highly dependent on the use case, no overall activity distribution without considering use cases was made, as this would only have had limited informative value.

Tab. 3: Most frequent activities in the different use 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 b 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 %

4.3 Discussion

This third user study within the present paper focused on sitting postures and activities of participants in an artificial autonomous driving situation. For this, participants were sorted into different use cases and their activities and postures were assessed in an explorative design in an equipped vehicle on public roads. As in the user study on preferred seat rotations within this project as described in chapter 3.1, the results feed into the test case matrix of the OSCCAR project in order to select the most relevant test cases to identify novel safety principle needs for advanced, safe, and comfortable sitting postures. First, the overall results are discussed, before the results of the individual use cases are in the focus of the discussion. Chapter 3.2.3 concludes with the discussion of the results regarding activities.

4.3.1 Overall Sitting Postures

The by far most frequent sitting posture, independent of the use case, was a centralized lower back with contact to the backrest. Figure 12 illustrates this posture. This position should therefore be considered for future research within OSCCAR. Regarding the shoulders' position, the centralized with contact to the backrest posture was also the preferred sitting posture, indicating that this is the most common position. 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.

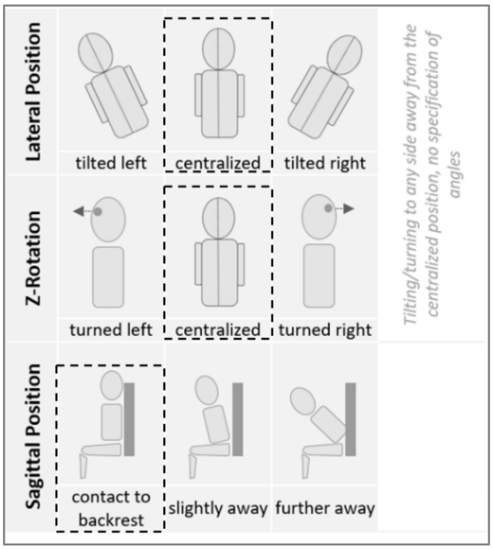


Fig. 12: Most frequently taken posture was the participants being laterally centralized, not rotated around the z-axis, and having full contact to the backrest

For head postures, 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 participants stayed in it for at least 5 seconds. This was scaled down to two 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 each other and results are in close correspondence. Most of the time, participant's head had contact to the backrest. However, the head was also observed to be slightly (or further) away from the backrest, which is why the authors advise to include these in future research, 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 can make this quite detailed.

For legs, the most frequent posture was centralized legs with two feet firmly planted on the ground. This position should therefore be considered for future research. The second most often taken position features legs that are crossed at the knees. The posture for the legs ranging third was two legs/feet underneath the seat. 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 future research.

4.3.2 Sitting Postures in Individual Use Cases

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.

The favored head posture is more difficult to determine as there is normally a variety of head postures overall and among the use cases. The preference for contact between the head and the headrest is different in each group: In the peer business group when participants were active in a group it was most often followed by the peer leisure group and in the two use cases where they had to share the shuttle with strangers. For other peer group use cases, a sitting posture with the head being slightly away from the backrest and a sitting posture with the head being further away from the backrest, was preferred, respectively. The favored leg position was also uniform for all use cases with strangers and the business group (active alone), where a centralized leg posture was generally preferred. The posture in which the legs are crossed at the knees was the most frequently observed posture in the business group where participants were active in a group and the leisure group (active alone). Holding the legs under the seat was the most frequent posture in the leisure group.

The analysis of sitting postures in the individual use cases revealed a similar pattern of results but gave a deeper understanding of the circumstances and situations in which people took a certain posture in the study. 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 in certain use cases.

4.3.3 Activities

As described in chapter 3.2.1, activities participants followed were assessed as well. The participants in the use cases who were engaged in a group activity followed this activity the entire 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.

4.3.4 Conclusion

With the insights from this third user study, justified statements can be made towards the probability of certain sitting postures in a simulated autonomous driving situation as carried out in these user studies. 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.

5 General Discussion

Autonomous vehicles provide more possibilities for the occupation of users. Depending on the level of automation, the role from an active driver shifts to a passenger. Consequently, this leads to more degrees of freedom regarding the interior design of such vehicles, especially regarding seat arrangement and specification. This goes hand in hand with the need for updated safety systems.

The present publication addresses two projects and three user studies. Study 1 was on user requirements regarding the seat arrangement and ergonomics of an autonomous shuttle (autoSHUTTLE) within the UNICAR*agil* project. The results provide recommendations for further refinement of the interior, especially regarding seat arrangement and seat design, of the autoSHUTTLE. Furthermore, study 2 and 3 focussed on preferred seat rotations on the one hand and sitting postures and activities of passengers on the other hand, aiming at finding the most relevant test cases to derive novel safety systems for the autonomous driving context. Despite both projects in which the user studies were conducted being independent of each other, they all address relevant user-centered research questions in the development process of autonomous vehicles.

Study 1 on seat arrangement of fully automated shuttles identified relevant seat arrangements for 13 different user groups for the comfort mode of the autoSHUTTLE. Three seats in the rear were identified as a key result together with foldable seats in the middle and front for a modular approach. Summing up, the results of the user study on interior design of autonomous vehicles provided valuable insights into user needs of interior designs for autonomous vehicles in the future. This again stresses the valuable insights gained by an early user involvement.

User study 2 and 3 aimed assessing on occupant safety aspects and had a similarly explorative scope but with a different focus. These were on the one hand assessing what seat rotations are preferred by passengers, and on the other hand gathering on detailed sitting postures and activities of occupants in an artificial autonomous driving situation. Both user studies conducted with OSCCAR were able to attain a dataset of preferred seat rotations and verified sitting postures and activities. Within the OSCCAR project, these results, together with expected future crash scenarios, serve as input to a three-dimensional matrix. The individual human variation completes the corresponding matrix as a third axis. In the further course of the project, the matrix conduces initially as a starting point for the generation and identification of relevant test cases in order to highlight not merely future challenges, but rather chances of occupant protection. A methodological selection process, considering the context of specified operational design domains, can be applied subsequently. Within the selection-process, the results of the second and third user study do not only serve as input to the occupant use case dimension of the matrix, but also support the decision making in the identification process of the most relevant use cases. For a selection of test cases, including information on occupant use case frequency combined with an estimation of the severity in case of a crash event, novel protection principles will be deduced and potential solutions through the further course of the project investigated. The investigation and assessment of novel protection principles will take place on virtual and physical level.

The three user studies presented define an early step in the product development process. Being equipped with specific customer insights, products can be developed close to user requirements. The detailed insights of these user studies confirm the initially stressed importance of user involvement in the development process [1] [2], especially when disruptive technologies as autonomous vehicles are concerned.

6 Acknowledgements

The work described was carried out at the Institute for Automotive Engineering (ika) of RWTH Aachen University within two independent research projects. Part of this research is accomplished within the project “UNICAR*agil*” (FKZ EM2ADIS002). We acknowledge the financial support for the project by the Federal Ministry of Education and Research of Germany (BMBF).

The second part was accomplished within the EU H2020 project "OSCCAR - Future Occupant Safety for Crashes in Cars" has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 768947.

The authors wish to thank Nicolas Herzberger for his support in preparing the user study in UNICAR*agil* and Julia Pelzer for her contribution and support in preparing, testing, and analyzing the user studies in OSCCAR. Furthermore, we thank Muriel Schnelle, Mareke Heykena, Maren Klatt, Paul Levasseur, and Jana Gähl for their support in this research.

7 References

[1] HANNA, Rick, KUHNERT, Felix, n.d.
How to be No.1 Facing future challenges in the automotive industry.
In www.pwc.com

[2] HERSTATT, Cornelius, SANDER, Jan G., 2004.
Produktentwicklung mit virtuellen Communities - Kundenwünsche erfahren und Innovationen realisieren. 1. Auflage.
Wiesbaden: Betriebswissenschaftlicher Verlag Dr. Th. Gabler.
ISBN: 978-3-409-12476-8

[3] ECE R 137, 2016.
Uniform provisions concerning the approval of passenger cars in the event of a frontal collision with focus on the restraint system
Regulation No. 137, United Nations, June 9, 2016

[4] SAE, 2014.
On-Road Automated Vehicle Standards Committee.
In: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems, Information Report.

[5] WOOPEN, Timo; et al., 2018.
UNICAR*agil* - Disruptive Modular Architectures for Agile, Automated Vehicle Concepts.
In: 27th Aachen Colloquium Automobile and Engine Technology, Aachen, 2018.
Wiesbaden: Springer Vieweg, pages 663 - 694.
DOI: https://doi.org/10.1007/978-3-658-25939-6_65

[6] RANA, Iman, 2014.
Measuring Public Transport Satisfaction from User Surveys.
In: International Journal of Business and Management. 9(6), pages 106-114.
DOI: 10.5539/ijbm.v9n6p106

[7] BÖRJESSON, Maria, RUBENSSON, Isak, 2019.
Satisfaction with crowding and other attributes in public transport.
Transport Policy. 79, pages 213-222.
DOI: https://doi.org/10.1016/j.tranpol.2019.05.010

[8] KÖHLER, Anna-Lena, Holz, Alexandra, DEPNER, Nico, SCHWALM, Maximilian, 2018.
Identifying Customer Insights for Autonomous Urban Shuttles – A Methodological Approach.
In: Proceeding of the 27th Aachen Colloquium Automobile and Engine Technology, Aachen, 2018.

[9] REED, Matthew P., 2000.
Survey of Auto Seat Design Recommendations for Improved Comfort.
In: Michigan Transportation Institute.

[10] SHEN, Wenqi, and PARSONS, Kenneth C., 1997.
Validity and reliability of rating scales for seated pressure discomfort.
In: International Journal of Industrial Ergonomics. 20(6), 441–461.
DOI: 10.1016/SO169-8141(96)00068-6

[11] JAKOBSSON, Lotta, FORNELLS; Alba, KÖHLER, Anna-Lena, MAYER, Christian, 2019, under review
D2.1 Report: Test Case Matrix and selecting Demonstrator Test Cases
In http://osccarproject.eu/media/deliverables/

[12] OSVALDER, Anna-Lisa, HANSSON, Ida, STOCKMAN, Isabelle, CARLSSON, Anna, BOHMAN, Katarina, and JAKOBSSON, Lotta, 2013
Older Children’s Sitting Postures, Behaviour and Comfort Experience during Ride – A Comparison between an Integrated Booster Cushion and a High-Back Booster.
In: International Research Conference on the Biomechanics of Impact (IRCOBI) Gothenburg, Sweden, September 11-13, 2013.

[13] JAKOBSSON, Lotta, BOHMAN, Katarina, STOCKMAN, Isabelle, ANDERSSON, Marianne, and OSVALDER, Anna-Lisa, 2011.
Older Children's Sitting Postures when Riding in the Rear Seat.
In: International Research Conference on the Biomechanics of Impact (IRCOBI) Krakow, Poland, 2011.

[14] BRANTON, P, and GRAYSON, G., 1967.
An evaluation of train seats by observation of sitting behaviour.
In: Ergonomics, 10(1), 35-51.
DOI: 10.1080/00140136708930838

[15] VAN NIEKERK, Sjan-Mari, LOUW, Quinette, VAUGHAN, Christopher, GRIMMER-SOMERS, Karen, and SCHREVE, Kristiaan, 2008.
Photographic measurement of upper-body sitting posture of high school students: a reliability and validity study.
In: BMC musculoskeletal disorders, 9(1), 113.