Comparison of Sitting Postures and Shoulder Belt Fit of Rear Seat Car Passengers Over Time in Stationary and Driven Scenarios

M. Makris, K. Bohman, A-L. Osvalder

Abstract Adult car passengers adopt a wide range of sitting postures while travelling. This user study compared a stationary and a driven scenario of 45 minutes each, and a stationary scenario over time, to investigate the potential influence study scenarios and time have on sitting postures and shoulder belt fit of rear seat passengers. A machine learning algorithm tracked head, upper sternum, and shoulder belt positions from video data of 13 participants, captured using two 3D cameras. The results showed small differences in the average head and sternum positions and position ranges when comparing the two scenarios. The average belt position was similar in both scenarios, but the shoulder belt tended to move closer to the neck in the driven scenario for participants with specific body shapes. Average belt, head and sternum positions were similar during the first three minutes, as for the total 45 minutes of the stationary scenario, but the position ranges were wider over the total 45 minutes. To conclude, a simplified short stationary test may be used to estimate the average postures and belt fit of passengers, but longer dynamic tests are needed to capture variations in posture and belt fit of passengers with specific body shapes.

Keywords Belt fit, driving study, passenger car, shoulder belt fit, sitting posture, stationary study.

I. INTRODUCTION

Adult car passengers may adopt a wide range of sitting postures when travelling in cars. There are various reasons for this, including vehicle dynamics, comfort, and activities, but also because of individual differences such as size and body shape. Therefore, to incorporate more variation when designing safe and comfortable cars to accommodate a wide range of people, it is essential to understand how sitting postures and belt fit vary among occupants over time.

Seat belts are an important safety feature in vehicles, contributing to saving lives and reducing the risk of injury [1]. The seat belt should fit a wide variety of body sizes. Body shape, anthropometry, fat distribution, body mass index (BMI), and occupant posture can affect the positioning of the seat belt [2-5]. A user study showed [6] that test subjects with a higher BMI were more likely to have the shoulder belt higher up on the abdomen, routed closer to the neck, independent of age and gender. The belt fit is judged optimal when the shoulder belt is positioned on the mid-portion of the shoulder, and the lap belt is positioned below the anterior-superior iliac spine and in contact with the upper thigh [3].

Both stationary and driving studies are useful methods in research of sitting postures and belt fit. Driving studies are used for studying passenger behavior, posture and belt fit over time [7-8]. However, driving studies come with the challenge of collecting detailed, hands-on measurements of seated postures and belt fit. Such measures are more easily assessed in stationary studies. For example, sitting posture and belt fit have typically been studied in static, laboratory settings, including detailed measures of shoulder and lap belt positions relative body landmarks [2][6][9-10]. Nonetheless, stationary studies may lack the natural context that is associated with real-world vehicle usage.

In previous driving studies, postures and belt fit have been classified manually by observing video recordings of car passengers [7-8][11-12]. Such qualitative approach requires systematic procedures where sitting postures and belt positions are categorized by a group of trained analysts. Two of these studies divided sitting postures and belt positions into several categories of sagittal (fore-aft) torso and head postures, as well as lateral torso and head postures [11-12]. They also classified shoulder belt position into four categories: shoulder against neck, mid-shoulder, edge of shoulder, and off-shoulder. Each posture and belt position were categorized if maintained for at least one second.

M. Makris is a PhD student in Design and Human Factors at Chalmers University of Technology in Gothenburg, Sweden (melina.makris@chalmers.se). K. Bohman, PhD, is a Technical Expert Biomechanics at Volvo Cars, Sweden. A-L. Osvalder is a Professor in Human Machine Systems and Ergonomics at Chalmers University of Technology in Sweden.

Likewise, the belt fit of adult passengers sitting in the front [8] and rear seat [7] was investigated in driving studies. In these studies, a team manually coded sub-sets of frames from video recordings captured inside the car and quantified the shoulder belt position into one of five categories: mid-clavicle, on neck, lateral of clavicle, under arm, and cannot assess. Manual coding procedures are resource intensive compared to the usage of automated methods, such as Machine learning (ML) models. ML models can be used to support the estimation of postures and belt fit in both stationary and driving studies [13-14]. Utilizing such methods often requires the ML model to be customized to the specific car environment studied, as well as knowledge of its limitations, such as estimation errors.

Although both stationary and driving studies are applied in the research of sitting postures in cars, there is limited knowledge regarding the comparison of the results between these two types of studies, i.e., how the study setup affects the sitting postures and belt fit of passengers over time. Since driving studies are more complex and time consuming, and less convenient when conducting parameter studies, it is valuable to investigate whether the study setup can be simplified by performing a stationary study instead, while still being able to capture relevant sitting posture and belt fit data. Therefore, the objective of this user study was to compare a stationary and a driven scenario, as well as a stationary scenario over time, to investigate the potential influence that study scenarios and time have on the sitting postures and shoulder belt fit of rear seat passengers. By quantifying the passengers' positions when travelling in a driven car and in a stationary car over time, it could be possible to identify if a short stationary study could be as useful as a long driving study when exploring sitting posture and belt fit in cars.

II. METHODS

The experimental user study compared two scenarios (stationary and driven), where sitting postures and shoulder belt fit over time of rear seat car passengers were evaluated for 13 test subjects. The postures and shoulder belt fit of the test subjects were captured by video recordings. The study protocol received approval from the Swedish Ethical Review Authority {Dnr 2022-00157-01}.

Test Setup

The test vehicle was a Volvo V90 (model year 2021) equipped with leather upholstery seats. The participants were seated in the rear seat behind the front passenger seat, which was set to the lowest vertical setting (in the z-direction), and 50 mm rearward from the most forward position on the seat rail. The participants were recruited through advertisements on bulletin boards and through social media groups. The selection criteria were based on stature, age (18-70 years) and sex. The intention was to recruit a diverse group of participants with varying stature following normal distribution data and an even distribution of males and females. The recruitment resulted in 19 participants. Due to data loss, the analysis was based on data from 13 participants with a mean age of 43 years (SD, standard deviation,17 years), including eight females with a mean stature of 169 cm (SD 6 cm), and five males with a mean stature of 184 cm (SD 9 cm).

Test Procedure

The participants were instructed to sit in the rear seat on the right-hand side of the car. While seated, a target was attached on the jugular notch, which is a body landmark henceforth referred to as *upper sternum*. Two scenarios were tested for 45 minutes each; a stationary scenario conducted in an indoor garage, and a driven scenario where the car was driven on a pre-defined route in regular traffic. The route started with 10 minutes of city driving in approximately 50 km/h, followed by 25 minutes of highway driving in approximately 100 km/h, and ended with another 10 minutes of city driving. An overview of the route is showed in Appendix A. The route did not include any evasive manoeuvres or harsh braking. During both scenarios the participants listened to pre-selected podcasts or music through their headphones, using their mobile phone. They were instructed not to use their phone nor to talk with the test leader during the test, except if they wanted to terminate the test. They did not wear jackets or coats during the tests.

Data was collected by means of video recordings during the entire 45-minute scenarios to capture the participants' posture and belt fit. Their front and inboard side views were recorded in 3D by two cameras (Intel RealSense Depth Camera D415) attached inside the car. In total, the complete study took approximately 2.5 hours for each participant. All but one participant completed the test during a morning or an afternoon session in daylight, and one participant during an evening session. The start order of the test scenarios was randomized. Between the scenarios, the participants left the car for a 15-minute break. In each scenario, the participants responded twice to questionnaires for another research study for approximately 3-5 minutes per scenario, using pen and paper. All tests were performed by the same test leader with the aid of an assistant. The participants sat alone in the car during the stationary scenario, whereas the driven scenario included the test leader (the first author), who drove the car.

Method of Analysis

A machine learning (ML) based algorithm built on previous work [14], further refined to fit the specific car environment, was utilized to estimate the x (fore-aft), y (lateral), and z (vertical) positions of the upper sternum and to derive the center of the head and the distance from the upper sternum to the center line of the seat belt (Fig. 1), with five frames per second. In the lateral and vertical directions, the measurement error of the estimated key point positions was approximately 10 mm with respect to human annotated ground truths. Additionally, due to depth estimation accuracy of the cameras, the error in the longitudinal direction (fore-aft) was approximately 20 mm.

Descriptive statistics were used to present the averages and ranges of head, sternum, and shoulder belt positions in the two scenarios, and over time during the stationary scenario. The average head and upper sternum positions of participants were described in x, y, and z (Fig. 2), as well as individual differences of participants for their head and upper sternum positions, and for the vertical distance from the upper sternum to the shoulder belt. Also, the 5- to 95-percentile ranges of the head and sternum positions in x, y and z, as well as the same range for the distance from the upper sternum to the shoulder belt were described and compared. The average head and upper sternum positions of participants in x, y and z, and the vertical distance from the upper sternum to the shoulder belt during the first three minutes of the stationary scenario were compared to the average of the total 45 minutes in the stationary scenario. Also, the average 5- to 95-percentile range was described for all participants for the first three minutes of the stationary scenario compared to the total 45 minutes.

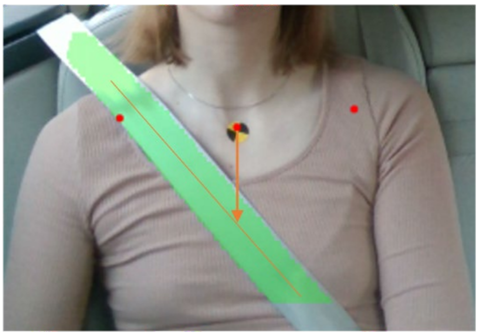

Fig. 1. Vertical distance between the shoulder belt and upper sternum.

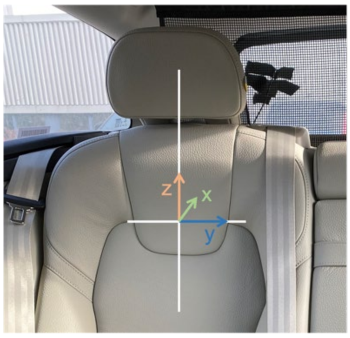

Fig. 2. Definition of the coordinate system.

In addition, heatmaps were generated, clustering frames of the 5-95 percentile range of head and upper sternum positions of all participants, i.e., the 90 % ranges of positions that all participants moved within. Lastly, a manual analysis of the video recordings was performed to increase the understanding of the data in terms of how the postures and belt fit of participants varied between the scenarios and over time in the stationary scenario. The manual analysis included observations of video data from each participant, to characterize the belt position. If the shoulder belt was centralized between the neck and the edge of the shoulder, it was characterized as 'mid-shoulder'. If the shoulder belt was in tangent to the upper sternum mark, it was characterized as 'close to the neck'. Lastly, if the shoulder belt was off the edge of the shoulder, it was characterized as 'off-shoulder'. The manual analysis also included observations of video data of the participants with the widest ranges of positions, with the aim to identify patterns of how behaviors vary between scenarios and over time in the stationary scenario. Table I shows an overview of the descriptive analyses.

Table I.
AN OVERVIEW OF THE DESCRIPTIVE ANALYSES OF THE HEAD AND UPPER STERNUM POSITIONS, AND VERTICAL DISTANCE BETWEEN THE UPPER STERNUM AND THE SHOULDER BELT.

	Stationary vs driven scenarios				First three minutes vs total 45 minutes stationary scenario		
Head and upper sternum in x,y and z	Average positions	Individual differences	5-95 percentile range of positions	Heatmaps of 5-95 percentile range of positions of all participants	Average positions	Individual differences	5-95 percentile range of positions
Distance from upper sternum to belt	Average distance	Individual differences	5-95 percentile range of distance		Average distance	Individual differences	5-95 percentile range of distance

The Wilcoxon signed-rank test was used to analyse if the two scenarios had significantly different (≤0.05) effects on the mean values of the merged x-, y- and z-positions (3D) for the head and upper sternum, as well as the shoulder belt position (the vertical distance from the upper sternum to shoulder belt), during the total 45 minutes for each participant. The Wilcoxon signed-rank test was also used to test if the stationary scenario in the first three minutes and over the total 45 minutes had significantly different effects on the mean values of the merged x-, y- and z-positions (3D) for the head and upper sternum, as well as the shoulder belt position during the total 45 minutes for each participant.

III. RESULTS

Comparison Between the Stationary and Driven Scenarios

No statistically significant differences were shown between the two scenarios, nor over time in the stationary scenario regarding head, upper sternum, and belt position. In general, the results showed small variations in the participants' head and upper sternum positions when comparing the two scenarios, while the belt fit showed some differences. Table II shows the average spread of the average positions of head and upper sternum in the stationary and driven scenarios, as well as differences between scenarios. The average positions and average position ranges of head, upper sternum and shoulder belt of individual participants in the stationary and driven scenario are presented in Appendix B. Moreover, heatmaps of the 5- to 95 percentile range of positions of the head and upper sternum of all participants in the stationary and driven scenarios respectively are presented in Appendix C.

TABLE II
THE TABLE SHOWS THE AVERAGE POSITIONS AND AVERAGE RANGES OF THE HEAD AND UPPER STERNUM FOR THE STATIONARY AND DRIVEN SCENARIO, AND DIFFERENCES BETWEEN THE SCENARIOS. A HIGHER VALUE IN THE X-POSITION INDICATES A MORE FORE POSITION, A HIGHER POSITIVE VALUE IN Y-POSITION INDICATES A POSITION MORE TOWARDS THE PARTICIPANTS' LEFT-HAND SIDE AND A HIGHER VALUE IN Z-POSITION INDICATES A SUPERIOR POSITION.

Body part	Average position stationary [mm]	Average position driven [mm]	**Δ average position (stationary-driven)[mm]**	Average range of positions stationary [mm]	Average range of positions driven [mm]	**Δ average range (stationary-driven)[mm]**
Head x	-122	-116	**-6**	93	80	**13**
Head y	-10	-1	**-9**	67	69	**-2**
Head z	218	225	**-7**	39	41	**-2**
Upper sternum x	-210	-207	**-3**	29	29	**0**
Upper sternum y	2	-6	**8**	26	29	**-3**
Upper sternum z	28	30	**-2**	22	22	**0**

Head and Upper Sternum Positions for Stationary and Driven Scenarios

The average positions of the head and upper sternum in the x-direction were more fore in the stationary scenario compared to the driven (head 6 mm, upper sternum 3 mm). Nine participants showed this pattern. The average position of the head in the y-direction was 9 mm closer to the door in the stationary scenario compared to the driven for eight participants, whereas the average position of the upper sternum was 8 mm closer to the door for seven participants. The average positions of the head and upper sternum in the z-direction were more inferior in the stationary scenario compared to the driven (head 7 mm, upper sternum 2 mm). Eleven participants showed this pattern for the head and ten for the upper sternum.

On average, the participants' heads moved in a wider range of positions in the x-direction in the stationary scenario compared to the driven (13 mm wider range), whereas heads moved in smaller ranges of positions in the y- and z-directions in the stationary scenario (2 mm smaller range in both y- and z-directions). On average, the upper sternum of participants moved in a slightly smaller range of positions in the y-direction in the stationary scenario compared to the driven (3 mm smaller range), whereas there was no difference in the average range of upper sternum positions in the x- or z-directions.

Shoulder Belt Fit for Stationary and Driven Scenarios

The shoulder belt stayed on the shoulder for all participants during both scenarios. The average distance from the upper sternum to the shoulder belt was slightly larger in the stationary scenario compared to the driven (81mm compared to 75mm), indicating that the belt was slightly further away from the neck during the stationary scenario (Table III). Eight participants showed this pattern, and they wore the shoulder belt in average 13 mm closer to the upper sternum during the driven scenario compared to the stationary. The distance from the upper sternum to the shoulder belt varied over a smaller range in the stationary scenario compared to the driven scenario (46 mm compared to 52 mm). For seven participants, the shoulder belt was found closer to the neck rather than on the middle of the shoulder throughout both scenarios. For one of these seven participants this was only observed during the driven scenario, and for another participant only during the stationary scenario. The remaining five wore the seatbelt close to the neck, in tangent to the target throughout both scenarios.

TABLE III

COMPARISON OF BELT POSITIONS BASED ON THE VERTICAL DISTANCE MEASUREMENTS BETWEEN THE UPPER STERNUM AND THE SHOULDER BELT, BETWEEN SCENARIOS. THE TABLE SHOWS THE AVERAGE DISTANCES AND AVERAGE DISTANCE RANGES FOR THE STATIONARY AND DRIVEN SCENARIO, AND DIFFERENCES BETWEEN THE SCENARIOS. A LARGER DISTANCE CORRESPONDS TO THE SEAT BELT BEING FURTHER AWAY FROM THE NECK.

	Average distance **stationary** [mm]	Average distance **driven** [mm]	**Δ average distance (stationary-driven) [mm]**	Average range of distance stationary [mm]	Average range of distance driven [mm]	**Δ average distance range (stationary-driven) [mm]**
Distance between upper sternum and shoulder belt	81	75	**6**	46	52	**-6**

Comparison Over Time

In general, the variation in the head and upper sternum average position over time was minor, while the belt fit showed some variations among participants. Table IV shows the spread of the average positions of the head and upper sternum in during the total 45 minutes of the stationary scenario, as well as for the first three minutes, and the differences between the scenarios. The average positions and average position ranges of head, upper sternum and shoulder belt of individual participants over time in the stationary scenario, are presented in Appendix B.

TABLE IV
COMPARISON OF THE HEAD AND UPPER STERNUM POSITIONS OVER TIME IN THE STATIONARY SCENARIO. THE TABLE SHOWS THE AVERAGE POSITIONS AND AVERAGE RANGES FOR THE TOTAL 45 MINUTES OF STATIONARY SCENARIO AND THE 3 FIRST MINUTES, AND DIFFERENCES OVER TIME. A HIGHER VALUE IN THE X-POSITION INDICATES A MORE FORE POSITION, A HIGHER POSITIVE VALUE IN Y-POSITION INDICATES A POSITION MORE TOWARDS THE PARTICIPANTS' LEFT-HAND SIDE AND A HIGHER VALUE IN Z-POSITION INDICATES A SUPERIOR POSITION.

Body part	Average position total 45 min [mm]	Average position first 3 min [mm]	**Δ average position (total 45 min – first 3 min) [mm]**	Average range of positions total 45 min [mm]	Average range of positions first 3 min [mm]	**Δ average range (total 45 min – first 3 min) [mm]**
Head x	-122	-114	**-8**	93	56	**37**
Head y	-10	-10	**0**	67	32	**35**
Head z	218	221	**-3**	39	25	**14**
Upper sternum x	-210	-206	**-4**	29	15	**14**
Upper sternum y	2	2	**0**	26	7	**19**
Upper sternum z	28	31	**-3**	22	11	**11**

Head and Upper Sternum Over Time

The average positions of the head and upper sternum in the x-direction were further forward from the seat in the total 45-minute stationary scenario compared to the first three minutes (8 mm more forward, and 4 mm more forward respectively). Nine of the participants showed this pattern for the head position, and eight for the upper sternum position. There were no differences in average positions of the head and upper sternum in the y-direction when comparing the total 45-minute duration with the first three minutes of the stationary scenario. The average positions of head and upper sternum in the z-direction were more inferior in the total 45-minute scenario compared to the first three minutes (3 mm more inferior for both). Nine of the participants showed this pattern for the head position, and eleven for the upper sternum position.

For 90% of the time in the stationary scenario, the participants' heads moved through a smaller range of positions during the three first minutes compared to the total 45 minutes in all directions (on average x=37mm, y=35mm and z=14 mm smaller ranges respectively). Likewise, the participants' upper sternum moved through a slightly smaller range of positions in all directions during the three first minutes compared to the total 45 minutes (in average x=14mm, y=19mm and z=11 mm smaller ranges respectively).

Shoulder Belt Fit Over Time

The average distance from the upper sternum to the shoulder belt was slightly larger during the first three minutes compared to the total 45 minutes of the stationary scenario (87 mm compared to 81mm). Twelve participants had a larger vertical distance between the upper sternum and the shoulder belt during the first three minutes compared to the complete stationary scenario (on average 7 mm larger), meaning that the belt was further away from the neck initially. The range of the vertical distance between the participant's upper sternum and the shoulder belt was smaller during the first three minutes of the stationary scenario compared to the range during the total 45 minutes (26 mm larger range) (Table V).

TABLE V
COMPARISON OF THE BELT POSITIONS BASED ON THE VERTICAL DISTANCE MEASUREMENTS BETWEEN THE UPPER STERNUM AND THE SHOULDER BELT, OVER TIME IN THE STATIONARY SCENARIO. THE TABLE SHOWS THE AVERAGE DISTANCES AND AVERAGE DISTANCE RANGES FOR THE TOTAL 45 MINUTES OF STATIONARY SCENARIO AND THE 3 FIRST MINUTES, AND DIFFERENCES OVER TIME. A LARGER DISTANCE CORRESPONDS TO THE SEAT BELT BEING FURTHER AWAY FROM THE NECK.

	Average distance total 45 min [mm]	Average distance **first 3 min** [mm]	**Δ average distance [total 45 min – first 3 min] [mm]**	Average range of distance total 45 min [mm]	Average range of distance first 3 min [mm]	**Δ average distance range [total 45 min – first 3 min] [mm]**
Distance between upper sternum and shoulder belt	81	87	**-6**	46	20	**26**

IV. DISCUSSION

The objective of this user study was to compare a stationary and a driven scenario, as well as a stationary scenario over time, to investigate the potential influence that study scenarios and time have on the postures and shoulder belt fit of rear seat passengers. The results showed no statistically significant differences in the sitting postures (3D positions of the head and upper sternum), or belt fit (the vertical distance from the upper sternum to shoulder belt) of participants when comparing stationary and driven scenarios, nor over time in the stationary scenario.

In both the stationary and driven scenarios, as well as over time in the stationary scenario, the average lateral positions of the head and upper sternum remained centred around the origin of the y-axis. The average longitudinal and vertical head and sternum positions were similar in both scenarios, as well as over time in the stationary scenario. Moreover, the participants' average ranges of head and sternum positions were also similar between the scenarios. However, when comparing the stationary scenario over time, the ranges of these positions were slightly greater for the total scenario duration compared to the first three minutes. Regarding the belt fit**,** the average range of the shoulder belt positions was slightly larger in the driven scenario, as well as during the total stationary scenario compared to the first three minutes. These observed differences between scenarios and over time in the stationary scenario may be a result of few participants showing different postures or belt fit due to influence by study scenario, time, or anthropometrics. Moreover, these small differences in average positions and ranges should be interpreted with caution, since the ML model used for estimating the positions has a measurement error of 20 mm in the x-direction and 10 mm in the y- and z-directions.

When examining the participants with the largest ranges of positions in the z-direction, the video data showed tendencies towards a more slumped posture of the upper torso, with the shoulders not fully in contact with the seatback or leaning laterally to either side of the car in both scenarios (Participant 9, Fig. 7a). However, there was no clear slouching of the pelvis observed in either of the scenarios or over time which could have been expected from a vertical movement of the sternum. Likewise, the participants with the largest ranges of longitudinal positions in x-directions demonstrated variations in their postures. These variations ranged from a leaned-back posture with the shoulders resting against the seatback, to more forward positions, including slumped postures that resulted in reduced shoulder contact with the seat back (Participant 9, Fig.7a-7c). Some participants adopted these slumped postures while gazing out of the window during the drive.

The participants with larger ranges of lateral positions of the head or upper sternum, tended to lean towards the door and used the arm rest (Participants 1 and 5, Fig. 8a-8b). This static, passive posture was observed in the stationary scenario and could be a result of the absence of car movement, which may have enabled the participants to lean towards the door and armrest for support without discomfort caused by vibrations. Moreover, the passiveness could also be a result of the environment outside the car i.e., in the indoor garage, which probably did not provide surroundings that were interesting enough for participants to observe through the windows. Another participant with large ranges of lateral positions used the ceiling handle (Participant 8, Fig. 8c). In contrast to the previous cases, this behaviour was only observed during the driven scenario, and may be a result of the vehicle dynamics provided during the ride. The vehicle dynamics might have led to a more active sitting posture , where the participant held onto the handle to acquire more physical support while leaning towards the centre seat to observe the traffic through the front window. The desire to observe the traffic may be associated with wanting to be aware of the surroundings and may increase the perceived control when someone else, in this case the test leader, is driving.

Fig. 7a. Participant 9 in a more slumped posture during the stationary scenario, viewed from the side.

Fig. 7b. Participant 9 with shoulders in contact with the seat back during the stationary scenario, viewed from the side.

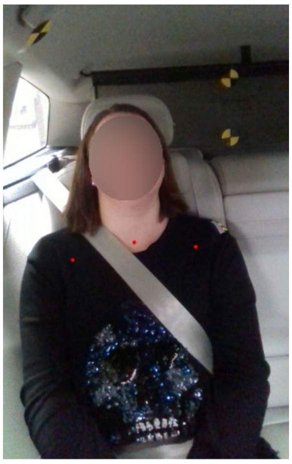

Fig. 7c. Participant 9 with shoulders in contact with the seat back during the stationary scenario.

Fig. 7d. Participant 9 with the belt positioned close to the neck and armpit during the driven scenario.

Fig. 7. Examples of participants with the shoulder belt positioned close to the neck and with the shoulders in contact with the seat back, compared to a more slumped posture with reduced shoulder contact.

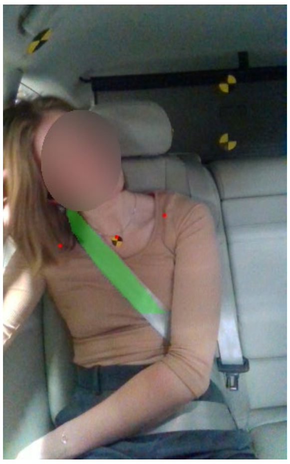

Fig. 8a. Participant 1 leans towards the door and uses the arm rest during the stationary scenario.

Fig. 8b. Participant 5 leans towards the door and uses the arm rest during the stationary scenario.

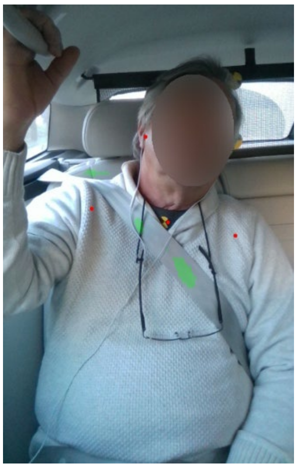

Fig. 8c. Participant 8 holds the ceiling handle during the driven scenario.

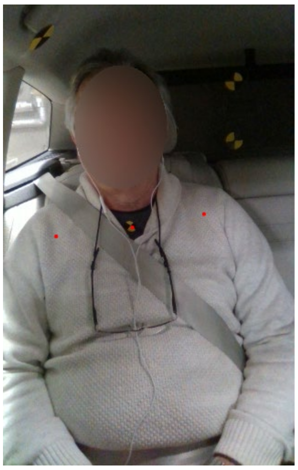

Fig. 8d. Participant 8 has the belt close to the neck during the stationary scenario.

Fig. 8. Examples of participants leaning towards the armrest and door (8a-b) and of one participant leaning towards the center seat during the drive (8c), compared to a more centralized posture in the stationary scenario (8d).

The presence of the test leader driving the vehicle may have influenced the behaviours of some passengers. Although participants in this study did not communicate with the test leader during the drive, participants often feel pressure to perform in user studies, especially when being video recorded or observed [14]. Hence, a few passengers' perceptions of the test leader's driving style or presence may influence their behaviour, for instance by wanting to observe the traffic, and by feeling observed respectively. However, the test leader was not assigned to observe the participants during either of the scenarios. Instead, participants were observed through video recordings in both scenarios, and the influence of the observations may thus be similar in both scenarios. In addition, this study did not focus on any type of performance, only passive sitting. Yet, this shows that although all participants were driven on the same pre-defined route, there were external factors in the driven scenario which potentially might have influenced the sitting postures of individual participants. However, there were no significant differences of postures or belt fit between scenarios, and it may therefore be interpreted that, in general, these potential influences were minor.

There was no statically significant difference in the average distance between sternum and the shoulder belt between the scenarios. Moreover, no major difference in the average distance range was observed. However, the belt fit showed some variations when comparing the belt fit of individual participants between the scenarios. Specifically, eight participants had a larger average distance from the sternum to the shoulder belt in the stationary scenario compared to the driven scenario, indicating that the belt was somewhat closer to the neck during the driven scenario. These differences between scenarios were particularly observed among a few participants with certain body shapes, such as larger chest, pronounced abdominal fat, shorter sitting height, and higher BMI.

One of the eight participants who wore the shoulder belt closer to the neck during drive had pronounced abdominal fat and a large breast shape, which may have affected the shoulder belt fit during the drive. The video data of the driven scenario showed how the participant's belt moved across the chest, ending up close to the armpit and neck (Participant 10 Figure 9a). After two minutes of the ride, the participant started to hold the shoulder belt away from the neck and below the left chest for approximately 10 minutes (Participant 10, Figure 9b). The participant also adjusted the shoulder belt several times during drive, and each time the participant released the belt, it started moving across the chest towards the neck. In the stationary scenario, the belt had a similar initial position as during the drive but did not move towards the armpit to the same extent throughout the scenario. This suggests that movements and vibrations from the car, combined with the shape of the abdominal fat and chest, may have contributed to the shoulder belt movements across the chest during the driven scenario.

Fig. 9a. Participant 10 with the belt positioned close to the neck and armpit.

Fig. 9b. Participant 10 holds the shoulder belt during the driven scenario.

Fig. 9c. Participant 3 with the belt positioned close to the neck and armpit during the driven scenario.

Fig. 9d. Participant 7 with the belt positioned close to the neck and armpit during the driven scenario.

Fig. 9. Examples of participants with the shoulder belt positioned close to the neck and armpit.

In general, no unexpected events occurred that could have caused evasive steering manoeuvres or harsh braking during the driven scenarios, that in turn could have influenced the participants' posture to a greater extent. Furthermore, such occasional events would still have had limited influence on the average posture and average posture range over 45 minutes. However, a similar pattern of the shoulder belt moving across the chest and towards the neck during the drive was observed for three additional participants (Participant 3, 7, Fig. 9c-9d, and Participant 9, Fig. 7d). The BMIs of all the four participants with this pattern ranged from 24 to 32. These examples support the findings from a previous stationary study on belt fit that demonstrated that participants with increased BMIs tended to wear the shoulder belt closer to the neck [6-7].

The six participants who wore the shoulder belt close to the neck in the stationary scenario were all females with an average stature of 169 cm. Five of them had the shoulder belt close to the neck in both scenarios, whereas one wore the belt close to the neck mainly in the stationary scenario. During the drive, the shoulder belt was close to the neck for this one participant, but not in tangent to the upper sternum target to the same extent as in the stationary scenario. The participant also moved the upper sternum and head through a larger range of positions in the stationary scenario compared to the driven scenario, which in turn might have caused the shoulder belt to move more during the stationary scenario.

The participant who held the ceiling handle while observing the traffic outside through the front window was the only male participant who wore the shoulder belt close to the neck, in tangent to the upper sternum (Participant 8, Figure 8c). During the drive, this participant held the ceiling handle in the right hand, which resulted in a more superior position of the right shoulder, leading to the belt wrapping around the shoulder. The belt wrap, in combination with the abdominal fat and body shape seems to have contributed to the belt being guided towards the neck. During the stationary scenario, the shoulder belt was close to the neck, but not in tangent to the upper sternum target to the same extent as during the drive, as the participant did not hold the ceiling handle (Participant 8, Figure 8d). All this indicates that the belt fit of individual participants may be influenced by the stationary and driven scenarios. Moreover, the differences between scenarios may be more pronounced for passengers with certain body shapes, such as a larger chest, pronounced abdominal fat, shorter sitting height, and higher BMI.

When comparing postures over time, the primary difference lies in the average range of positions of both head and upper sternum. In the 45-minute scenarios, this average range was consistently greater in all directions compared to the first three minutes. Examining the shoulder belt fit over time, the results reveal a 20 mm increase in the average range of the vertical distance between the upper sternum and shoulder belt during the 45 minutes stationary scenario, as opposed to the first three minutes. These differences in average ranges suggest that a few participants alter their sitting postures and exhibit more upper body movement over the 45 minutes, which may likely be due to perceived discomfort. These adjustments may aim to ease strain in different body parts. However, there was no statistically significant difference in positions or belt fit over time. This indicates that, in general, even after 45 minutes, which is a representative time for typical car journeys, the participants remained comfortably seated in the test car without apparent signs of discomfort. Moreover, it suggests that the upper body posture and belt fit when sitting for a short duration versus a longer period in the same car are comparable.

When further comparing the shoulder belt fit for the first three minutes of the stationary scenario with the complete driven scenario for all participants, the average range of the vertical belt distance increased by 32 mm. This may indicate that a short stationary study may not yield the same results for belt fit as a long driving study. Hence, the possibility of spread in seat belt positions needs to be considered when drawing conclusions on whether to perform a study with a short or long duration, and whether to perform a stationary or driving study.

Throughout each scenario, the participants did not only listen to podcasts or music through their headphones, but they also responded to questionnaires for another research study using pen and paper. They completed the questionnaires twice during each scenario, corresponding to approximately 3-5 minutes of the 45 minutes. While responding, the participants tended to bend their head more forward to look down at their thighs, where they placed the paper questionnaire. This activity was not excluded from the video analysis, as its impact on the complete results for the total 45 minutes was minimal.

Moreover, to avoid the influence of test order and sitting over time, the stationary and driven scenarios were balanced among participants and there was a 15-minute break between scenarios. On the one hand, a 15-minutes break between the 45-minutes scenarios may not be entirely sufficient to completely exclude the influence of test order. However, a longer break would have extended the test procedure, which already took 2.5 h per participant. Hence, the 15-minutes break was considered adequate, as a longer procedure would likely result in fewer participants.

Further studies are needed to better understand if the findings from this study are valid for other types of cars with different interior designs, as this user study was limited to one vehicle with a spacious rear seat. When it comes to applying the research to other seat positions, the results are considered applicable to passengers in the front seat as well. However, the sitting postures of drivers are more limited due to the driving task which requires being able to reach the steering wheel, pedals, and gear box, and therefore it may be expected that the results do not apply for drivers. Additionally, when generalizing the results of this study, the study sample size should be taken into consideration. The participants in this study had varying stature which aligned well with the normal distribution and comprised both men and women with diverse body shapes. However, a larger sample size is required to conduct more in-depth studies of the behavior of participants with specific body shapes. In this study, analyses were performed on video data and 3D positions from 13 participants, which is a sufficient number of participants for non-parametric statistical analysis.

This study focused on the analyses of head and upper sternum positions, as well as on shoulder belt position over time and between scenarios since these position parameters were supported by quantitative continuous data from the ML model [13]. However, to obtain a comprehensive understanding of the participants' postures, other body measures could also have been analyzed. For example, measurements of pelvis orientation and position are of great interest but require more intrusive means of measurements than video data can offer. Overall, the measures of the upper sternum and head capture the movements if the passenger is pitched excessively away from the seatback or is tilted excessively laterally. Furthermore, the measures of the distance between the upper sternum and the shoulder belt provide insight into the positioning of the shoulder belt.

By studying the sitting postures and belt fit of rear seat passengers in both stationary and driven scenarios, as well as observing changes over time in a stationary scenario over time, this study offers valuable insights that can support decisions on which types of study methods to apply when conducting in future research.

V. CONCLUSIONS

This study aimed to compare the effects of a stationary and a driving study scenario on the sitting posture and belt fit of rear seat passengers over time. Overall, no statistically significant differences were observed in the passengers' postures or shoulder belt positions between the stationary and driven scenarios. Additionally, no significant difference was detected over time in the stationary scenario.

The variations in the participants' head and upper sternum positions were small across the different scenarios. Furthermore, the average positions were not specifically influenced by the duration of the stationary scenario. However, the average 90% ranges for both the head and upper sternum positions were smaller during the first three minutes compared to the full 45 minutes of the stationary scenario. This suggests that there is less variation in sitting posture captured during the first three minutes.

The average shoulder belt position showed small differences between the scenarios and over time. However, for a few passengers with certain body shapes, such as a larger chest, pronounced abdominal fat or short sitting height, the shoulder belt moved closer to the neck in the driven scenario compared to the stationary scenario. Additionally, the average range of the shoulder belt position increased over time in the stationary scenario.

To conclude, these findings imply the potential of conducting more simplified user studies when investigating sitting postures and belt fit in cars, in terms of performing stationary studies with shorter durations, without the need for full driving studies. However, longer driving studies are probably needed to capture variations in posture and belt fit of passengers with certain body shapes.

VI. ACKNOWLEDGEMENT

The authors would like to thank the participants for their valuable time and participation. This work has been carried out at SAFER- Vehicle and Traffic Safety Centre at Chalmers, Sweden and is financed by FFI (Strategic Vehicle research and Innovation) by VINNOVA, the Swedish Transport Administration the Swedish Energy Agency and the industrial partners within FFI. The project partners are Volvo Cars, Autoliv Research and Chalmers University of Technology. The authors would also like to thank Professor Anders Colmsjö, Stockholm University for help with the statistical analyses.

VII. REFERENCES

[1] Kahane C. Fatality Reduction by seat belts for front-seat occupants of cars and light trucks, Technical Report. DOT HS 809 199. NHTSA. 2000, December. Available at. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/809199 [Accessed 2023-04-01].

[2] Reed MP, Ebert SM, Rupp J, Effects of Obesity on Seat Belt Fit, Traffic Injury Prevention, 2012, 13:4, 364-372

[3] Reed MP, Ebert SM, Hallman J. Effects of Driver Characteristics on Seat Belt Fit Stapp Car Crash Journal, 2013, Vol. 57.

[4] Coxon, K., Keay, L., Fong, C., Clarke, E., & Brown, J. The use of seat belt cushion accessories among drivers aged 75 years and older. Proceedings of the 2014 Australasian Road Safety Research, Policing & Education Conference, 2014, Melbourne.

[5] Fong CK, Keay L, Coxon K, Clarke E, Brown J. Seat belt use and fit among drivers aged 75 years and older in their own vehicles. *Traffic Injury Prevention*, 2016, 17(2):p.142-50.

[6] Bohman K, Osvalder A-L, Ankartoft R, Alfredsson S. (2019) A comparison of seat belt fit and comfort experience between older adults and younger front seat passengers in cars. *Traffic Injury Prevention*, 20:sup2:p.7-12.

[7] Reed, M. P., Ebert, S. M., Jones, M. L. H. & Hallman, J. J. A naturalistic study of passenger seating position, posture, and restraint use in second-row seats. Traffic Injury Prevention, 2022, 1-6.

[8] Reed MP, Ebert SM, Jones ML. (2020) Naturalistic passenger behaviour: posture and activities, Technical Report UMTRI-2020-2. University of Michigan Transportation Research Institute.

[9] Osvalder A-L, Bohman K, Lindman M, Ankartoft R, Alfredsson S. Seat belt fit and comfort for older adult front seat passengers in cars. *IRCOBI Conference*, IRC-19-12, 2019, Florence, Italy.

[10] Baker, G. H., Mansfield, J.A., Hunter, R. L. & Bolte, J. H. Evaluation of static belt fit and belt torso contact for children on belt-positioning booster seats. Traffic Injury Prevention, 2021, Vol. 22, S87-S92.

[11] Osvalder, A.-L., Hansson, I., Stockman, I., Carlsson, A., Bohman, K. & Jakobsson, L. Older children's sitting postures, behaviour and comfort experience during ride – A comparison between an Integrated Booster Cushion and a high-back booster. Proceedings 2013 IRCOBI Conference, 2013, Gothenburg, Sweden.

[12] Jakobsson, L., Bohman, K., Stockman, I., Andersson, M. & Osvalder, A.-L. Older children's sitting postures when riding in the rear seat. Ircobi Conference, 2011, 14-16.

[13]Hartleitner, F., Koppisetty, A., Bohman, K. Automated Quantification of Occupant Posture and Shoulder Belt Fit Using Safety Specific Key Points. *IEEE Open Journal of Intelligent Transportation Systems*, 2022, 3: 89-103.

[14] Nielsen, J. Usability Engineering, p. 182, *Morgan Kaufmann Publishers,* San Francisco, Calif. *1993*.

VIII. APPENDIX

Appendix A: The route in the driven scenario

Fig. A1. An overview of the route in the driven scenario. The route started with 10 minutes of city driving in approximately 50 km/h, followed by 25 minutes of highway driving in approximately 100 km/h (including a turning point), and ended with another 10 minutes of city driving. The dashed frame illustrates the city driving, whereas the lined frame shows a more detailed view of the turning point in the middle of the drive.

Appendix B: The head, upper sternum and shoulder belt positions during the stationary and driven scenarios, and over time in the stationary scenario

TABLE B1
HEAD POSITIONS IN STATIONARY AND DRIVEN SCENARIOS.

	Head x				Head y				Head z			
	Average		90% range		Average		90% range		Average		90% range	
	Stationary	Driven	Stationary	Driven	Stationary	Driven	Stationary	Driven	Stationary	Driven	Stationary	Driven
P1	-106	-99	86	26	-34	7	135	75	198	215	67	42
P2	-180	-161	66	27	-1	-17	34	59	222	221	33	34
P3	-112	-114	95	26	7	-2	31	39	283	289	37	46
P4	-135	-116	117	25	-16	17	59	56	186	188	36	33
P5	-156	-162	128	38	-10	-17	111	105	254	273	51	48
P6	-107	-78	100	17	-25	33	63	45	194	195	43	32
P7	-82	-76	64	22	-5	-7	39	38	202	210	27	36
P8	-107	-106	134	36	-17	-41	57	106	253	258	32	39
P9	-128	-110	109	47	-28	7	171	87	177	165	42	70
P10	-106	-139	66	34	3	-8	24	67	189	211	33	43
P11	-104	-108	60	20	11	-4	55	39	244	253	31	26
P12	-170	-157	123	37	-6	-7	63	135	258	269	39	44
P13	-91	-86	56	18	-10	22	28	46	169	178	37	46
Average	**-122**	**-116**	**93**	**80**	**-10**	**-1**	**67**	**69**	**218**	**225**	**39**	**41**

TABLE B2
UPPER STERNUM POSITIONS IN STATIONARY AND DRIVEN SCENARIOS.

	Upper Sternum x				Upper Sternum y				Upper Sternum z			
	Average		90% range		Average		90% range		Average		90% range	
	Stationary	Driven	Stationary	Driven	Stationary	Driven	Stationary	Driven	Stationary	Driven	Stationary	Driven
P1	-159	-157	22	26	-10	-3	57	38	-1	6	41	39
P2	-248	-239	36	27	-2	-17	17	27	32	39	10	23
P3	-198	-202	30	26	17	-12	19	17	56	66	21	27
P4	-225	-225	20	25	-2	0	18	34	-6	-3	17	18
P5	-245	-251	34	38	1	-10	40	35	58	60	26	29
P6	-201	-183	34	17	-11	16	18	9	3	7	18	7
P7	-192	-186	15	22	11	-18	18	20	33	27	16	17
P8	-217	-212	30	36	-5	-26	10	44	66	72	27	23
P9	-221	-231	61	47	-10	3	67	35	10	-2	37	23
P10	-204	-211	21	34	18	-17	11	42	24	21	11	26
P11	-193	-187	17	20	11	-5	27	19	40	41	14	11
P12	-231	-220	36	37	1	2	17	34	52	59	27	21
P13	-192	-183	17	18	5	2	18	20	-5	-2	16	20
Average	**-210**	**-207**	**29**	**29**	**2**	**-6**	**26**	**29**	**28**	**30**	**22**	**22**

TABLE B3
THE DISTANCES FROM THE UPPER STERNUM TO THE SHOULDER BELT IN STATIONARY AND DRIVEN SCENARIOS.

	Average		90% range	
	Stationary	Driven	Stationary	Driven
P1	84	94	60	59
P2	47	10	52	41
P3	141	139	27	32
P4	82	52	176	159
P5	76	76	34	33
P6	66	76	40	21
P7	41	37	33	35
P8	70	63	19	40
P9	62	47	50	89
P10	68	74	27	81
P11	92	87	33	23
P12	107	111	22	30
P13	119	113	23	28
Average	**81**	**75**	**46**	**52**

TABLE B4
HEAD POSITIONS THE TOTAL 45 MINUTES AND THE FIRST 3 MINUTES OF THE STATIONARY SCENARIO.

	Head x				Head y				Head z			
	Average		90% range		Average		90% range		Average		90% range	
	45 min	3 min	45 min	3 min	45 min	3 min	45 min	3 min	45 min	3 min	45 min	3 min
P1	-106	-84	86	88	-34	-19	135	45	198	223	67	40
P2	-180	-179	66	43	-1	-13	34	32	222	227	33	22
P3	-112	-78	95	6	7	4	31	18	283	291	37	12
P4	-135	-125	117	68	-16	-12	59	44	186	190	36	22
P5	-156	-109	128	99	-10	-5	111	27	254	245	51	22
P6	-107	-92	100	58	-25	-30	63	39	194	195	43	31
P7	-82	-77	64	5	-5	-6	39	8	202	204	27	11
P8	-107	-122	134	26	-17	-21	57	15	253	261	32	23
P9	-128	-108	109	66	-28	-17	171	36	177	171	42	20
P10	-106	-145	66	21	3	-7	24	32	189	203	33	30
P11	-104	-105	60	75	11	8	55	53	244	246	31	25
P12	-170	-173	123	136	-6	-8	63	52	258	254	39	30
P13	-91	-90	56	35	-10	-9	28	15	169	166	37	33
Average	**-122**	**-114**	**93**	**56**	**-10**	**-10**	**67**	**32**	**218**	**221**	**39**	**25**

TABLE B5
UPPER STERNUM POSITIONS THE TOTAL 45 MINUTES AND THE FIRST 3 MINUTES OF THE STATIONARY SCENARIO.

	Upper Sternum x				Upper Sternum y				Upper Sternum z			
	Average		90% range		Average		90% range		Average		90% range	
	45 min	3 min	45 min	3 min	45 min	3 min	45 min	3 min	45 min	3 min	45 min	3 min
P1	-159	-152	22	14	-10	-7	57	11	-1	7	41	20
P2	-248	-240	36	13	-2	-7	17	1	32	32	10	10
P3	-198	-187	30	11	17	14	19	1	56	66	21	8
P4	-225	-225	20	8	-2	0	18	10	-6	-10	17	9
P5	-245	-237	34	20	1	4	40	1	58	64	26	10
P6	-201	-198	34	15	-11	-14	18	1	3	9	18	8
P7	-192	-188	15	10	11	14	18	9	33	37	16	10
P8	-217	-218	30	7	-5	-6	10	1	66	63	27	10
P9	-221	-209	61	25	-10	1	67	10	10	10	37	11
P10	-204	-202	21	10	18	16	11	9	24	25	11	7
P11	-193	-197	17	23	11	6	27	27	40	45	14	19
P12	-231	-234	36	29	1	0	17	9	52	53	27	20
P13	-192	-193	17	7	5	4	18	9	-5	1	16	3
Average	**-210**	**-206**	**29**	**15**	**2**	**2**	**26**	**7**	**28**	**31**	**22**	**11**

TABLE B6
THE DISTANCES FROM THE UPPER STERNUM TO THE SHOULDER BELT THE TOTAL 45 MINUTES AND THE FIRST 3 MINUTES OF THE STATIONARY SCENARIO.
Belt to upper sternum vertical distance

	Average		90% range	
	45 min	3 min	45 min	3 min
P1	84	90	60	24
P2	47	80	52	23
P3	141	143	27	11
P4	82	70	176	36
P5	76	79	34	11
P6	66	68	40	13
P7	41	57	33	21
P8	70	72	19	6
P9	62	73	50	33
P10	68	76	27	19
P11	92	95	33	32
P12	107	111	22	22
P13	119	119	23	14
Average	**81**	**87**	**46**	**20**

Appendix C: The head and upper sternum positions during the stationary and driven scenarios

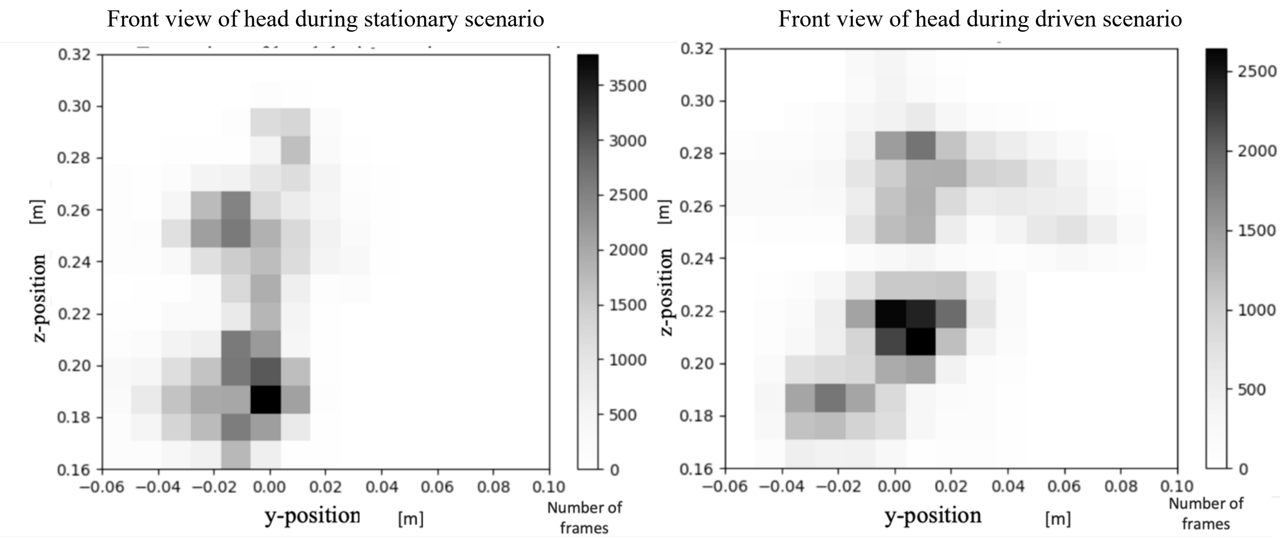

Fig. C1. Front views of the 5- to 95 percentile range of the head positions of all participants during the stationary (left) and driven (right) scenarios. The origin of the y-axis aligns with the vertical centerline of the seatback. The z-positions vary in a wider range due to the varying stature of the participants. Frames towards the left of the graph indicate that the head position is closer to the vehicle door, whereas frames towards the right indicate that the position of the head is closer to center seat.

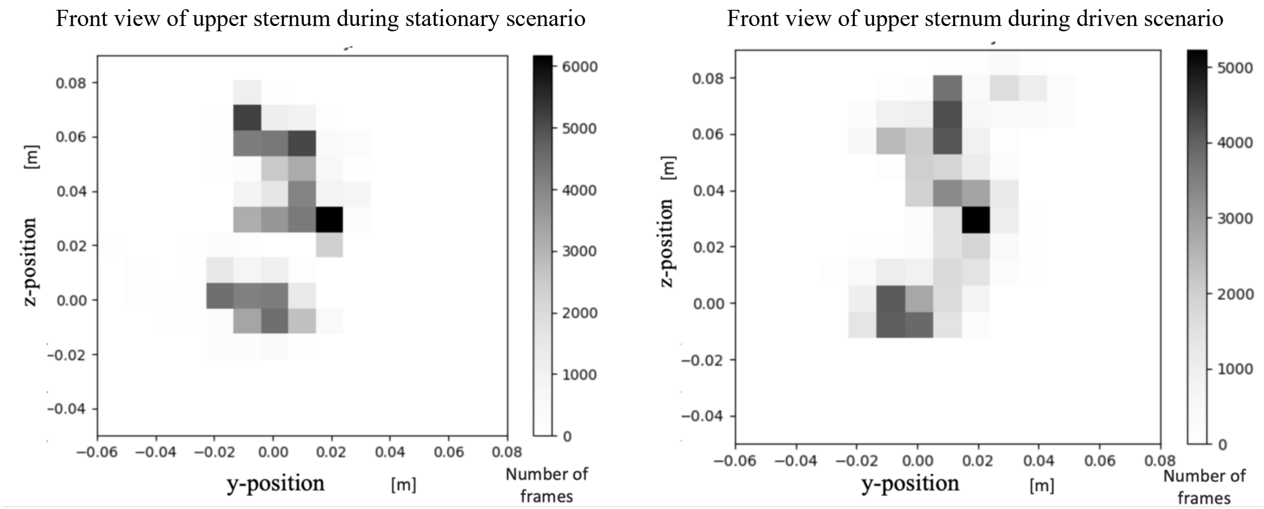

Fig. C2. Front views of the 5- to 95 percentile range of the upper sternum positions of all participants during the stationary (left) and driven (right) scenarios. The origin of the y-axis aligns with the vertical centerline of the seatback. The z-positions vary in a wider range due to the varying stature of the participants. Frames towards the left of the graph indicate that the upper sternum position is closer to the vehicle door, whereas frames towards the right indicate that the position of the upper sternum is closer to center seat.

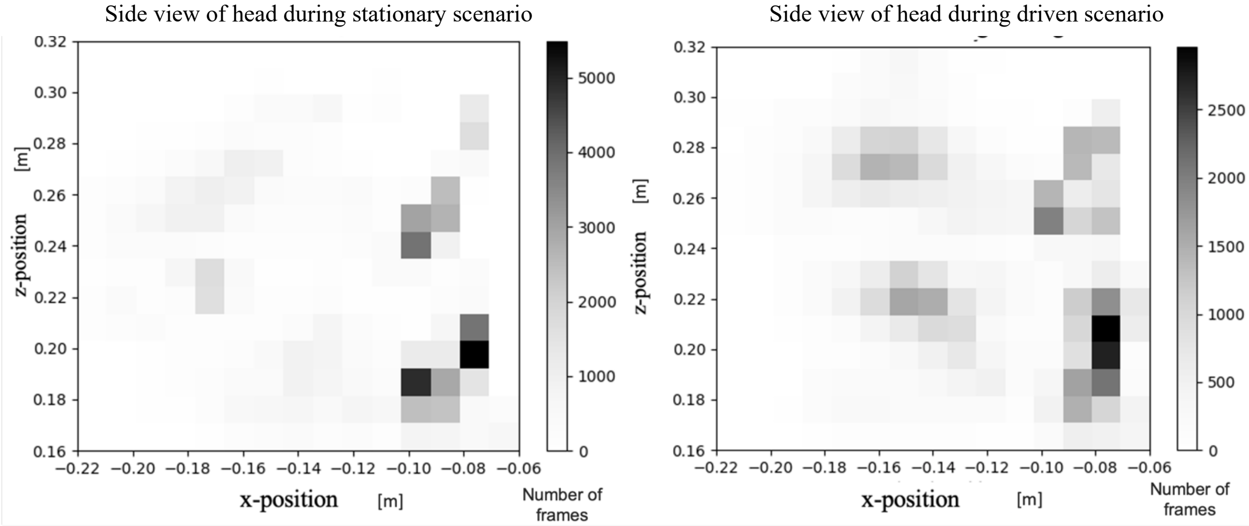

Fig. C3. Side views views of the 5- to 95 percentile range of the head positions of all participants during the stationary (left) and driven (right) scenarios. The z-positions vary in a wider range due to the varying stature of the participants. Frames towards the left of the graph indicate a more forward position of the head, whereas frames towards the right indicate that the position of the head is closer to the seatback and head restraint.

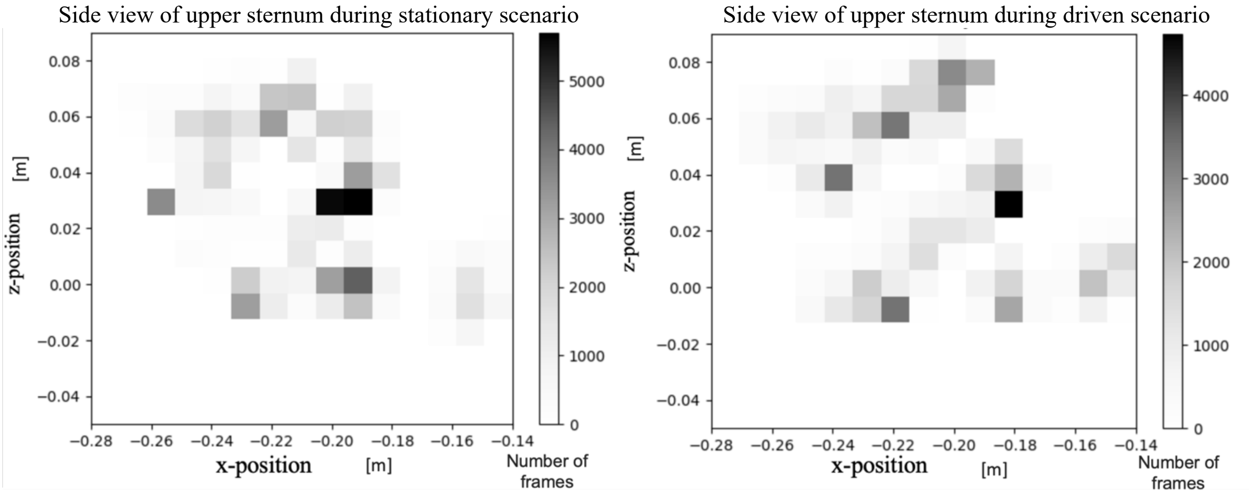

Fig. C4. Side views of the 5- to 95 percentile range of the upper sternum positions of all participants during the stationary (left) and driven (right) scenarios. The z-positions vary in a wider range due to the varying stature of the participants. Frames towards the left of the graph indicate a more forward position of the upper sternum, whereas frames towards the right indicate that the position of the upper sternum is closer to the seatback.