Lateral Movement of Front Seat Passengers in Everyday Traffic

Katarina Bohman, Lotta Jakobsson, Pernilla Nurbo, Anna Olander, Agnes Andersson

Abstract With the objective to understand passengers' variation in lateral torso position relative seat centreline in real-world traffic situations, this study contributes with front seat passenger lateral sitting posture and comfort perception in two driving studies. In the first study, 26 participants travelled 40 minutes in a suburban area including turns with lateral accelerations of $1.3m/s^2$-$3m/s^2$. In the second study, 14 participants were exposed to low-force seat belt tensioning. The participants' lateral torso, head positions and shoulder-belt positions, prior to and during the turn, in addition to perceived comfort and safety, were collected.

Prior to the turn, the majority had an inboard displaced position. In the turns with highest accelerations, the maximum torso lateral position during the turn was significantly different from prior to the turn. The shorter participants showed a trend of greater lateral movement than the taller. No shoulder belt slip-off occurred. For more than 95%, their head remained within the head-restraint width. The belt-tensioning did not influence the lateral movement, however the belt-tensioning perception deviated between individuals.

The frequent occurrence of non-nominal sitting postures, unlike crash test dummy postures in standardised testing, motivates more studies of this kind, gaining further understanding of the representativity of standardised tests, as well as real-world occupant protection.

Keywords Driving study, front seat passenger, lateral movement, shoulder belt position, sitting posture.

I. INTRODUCTION

Occupant protection in cars have continuously increased over the last few decades, reducing fatalities [1] as well as injuries [2]. The seat belt is the primary restraint in a passenger car [3]. By keeping the occupant restrained to the car in case of a crash, access to a host of safety technologies is provided, such as advanced car body design and auto brake systems, in addition to restraint technologies, including airbags and advanced seat belt retractors. Especially in a frontal impact, it is essential to ensure the seat belt restrains the strong parts of the body; the pelvic bones and across the chest and over the shoulder [4-6]. In real-world crashes, occupant sitting postures at impact are influenced by the selected sitting posture and the posture as a result of the vehicle motion prior to a potential crash. Substantial data on sitting postures and behaviour in cars today are needed to enhance the interpretation of existing real-world data and to form the knowledge foundation towards future challenges of more unique crashes, in which human properties and sitting postures are becoming increasingly important [7].

Studies on occupants' seat belt fit and perception are essential in enhancement of seat belt design. Several studies on shoulder belt fit have been conducted in stationary vehicles, such as to understand how shoulder belt position may vary due to age and body mass index (BMI) [8-9]. Other studies focusing on seat belt fit and elderly in their own vehicles, showed that about 47% had poor belt fit, and one fifth would reposition the seat belt due to discomfort [10-11]. However, in cases with non-optimal belt fit there were low awareness, with few participants recognising the non-optimal belt fit [12-13]. A crowd sourced study through Instagram was performed 2019, investigating shoulder belt position of car occupants in their cars when stationary [14]. By sharing selfies, 394 people around the world contributed. Categorised into shoulder belt positions, almost four in 10 had their seat belt positioned on the edge of the shoulder or off the shoulder. Zhang et al. [25] made a

K. Bohman (+46 72 887 0567, katarina.bohman@volvocars.com) is Technical Expert Biomechanics, P. Nurbo is Technical Leader Ergonomics, and L. Jakobsson is Senior Technical Leader, Injury Prevention at Volvo Cars in Sweden. A. Olander and A. Andersson recently graduated Master Students in Industrial Design Engineering and L. Jakobsson is also Adjunct Professor in Vehicle Safety at Chalmers University of Technology, Sweden. The authors are associated with SAFER – Vehicle and Traffic Safety Center at Chalmers in Sweden.

survey with 560 participants. They identified 29 sitting postures for adult passengers and estimated the frequency of those. Upright selected posture was the most common (45%), followed by leaning inboards (8%) and leaning outboards towards the b-pillar (8%).

A few studies have monitored and quantified passenger belt fit while riding in the cars. Driving studies with children show that shoulder belt position varies over time during the ride, due to activities and discomfort [16-19], in addition to evasive vehicle movements [10-23]. Graci et al. [24] studied nine adults and six children in a vehicle subjected to a constant radius manoeuvre, designed to produce lateral acceleration, providing insight into bracing strategies and kinematics in this type of evasive event potentially preceding a crash. Investigating the lateral and forward movement of the head by exposing 87 adult front seat passengers to braking and lane-change, [25] found that BMI and stature affect the lateral head movement; while age, but not gender, affects the forward movement. Using the same method with three vehicles of different body styles, [26] found no major effect of vehicle differences on head excursion. A driving study [27], including 306 front seat passengers, found that upright centralised posture was selected in 85% of the time, while forward pitch was chosen 10%. Inboard or outboard tilt were each chosen 7% of the time. In an observational study by Bingley et al. [28], front seat occupants were observed from the outside of the car while out driving. Passenger head centreline to vehicle centreline was collected, in addition to use of seat belts, hand positions and activities.

With the goal to improve car passengers' protection by enhanced seat belt performance, there is a need to gather data on seat belt fit and perception for a diverse population of car passengers in common real-world traffic situations. Hence, the overall objective of this study was to understand how passenger sitting postures varies in suburban driving for front seat passengers. Specifically, the objective was to quantify the lateral torso, head and shoulder belt position in addition to subjective data of front seat passengers, while riding on straight roads and during turns exposing them to a lateral acceleration from mild to harsh turns. Additionally, investigating an intervention of low-force belt-tensioning on lateral movement and comfort perception is included.

II. METHODS

Two user studies were performed with adult participants travelling as front seat passengers, quantifying lateral position and movements in addition to perception in every-day turning traffic situations. User Study 1 focused participants' size differences on lateral movement and perceived comfort in six different turn situations. User Study 2 focused influence of low-force belt-tensioner on perceived comfort and lateral movement, in one turn.

In both studies, the participants were seated in the front passenger seat of a Volvo S90 (MY2018) with comfort seats. They were recruited from Volvo Cars, with no association to the study. The same driver drove the car in all the tests. A test leader was seated in the rear seat behind the participant controlling the recordings and conducting a semi-structured interview. The seat and the seat belt were marked using film analysis targets. The car was equipped with cameras (Dewesoft DS-CAM-GIGE-600) monitoring the participants in a frontal view and a lateral top view, in addition to a forward view to monitor the road ahead. The lateral vehicle acceleration was collected with a gyro (Dewesoft DS-IMU 2) placed in the centreline of the vehicle just behind the rear seat.

Test Execution User Study 1

User Study 1 involved 26 participants exposed to a 40 minutes car ride in a suburban area in Gothenburg, Sweden. The route included three different turns, taken both as a left turn and as a right turn. The six different turn situations exposed the participants to average lateral accelerations ranging from 1.3m/s^2 to 3m/s^2; highest in TurnC, followed by TurnB and TurnA. Left turns, exposing the participant to outboard movements, were generally higher. Average values for all test participants for each of the six turn situations are provided in Appendix, Figure A1.

The participants were selected to be taller/shorter or higher/lower BMI. Thirteen participants were taller (stature>175 cm) and 13 were shorter. All taller participants were men and all shorter participants were women. Twelve of the participants were grouped as higher BMI>25 and 14 as lower BMI<25. Demographics for each test subject is summarised in Appendix, Table AI.

The participants were informed that the study included a driving study on front seat passenger comfort during normal driving. Before starting the test, a black/yellow film analysis target was placed on their suprasternal notch (upper sternum). The seat was pre-set between mid- and most rearward position, and the shoulder belt height adjuster was set in its lowest position. They were asked to adjust the seat according to their own preferences. Adjustments could be made to the seat in height, fore-aft and seatback angle.

During the test, the participants took part in a conversation with the driver to simulate a normal car journey as much as possible. They were not involved in any other activity during the ride. Each of the six turn situations was taken twice, to increase likelihood of achieving targeted acceleration exposure. The repetitions being closest to the target acceleration values for the different turns were selected for analyses.

After 10 minutes ride, two smooth left turns were passed at 70 km/h (TurnA-outboard) followed by left turns through two roundabouts in 20 km/h (TurnB-outboard) and 28 km/h (TurnC-outboard), respectively. A short stop was made while a semi-structured interview was held. Thereafter the car was driven back through the two roundabouts in right turns (TurnB-inboard and TurnC-inboard), turned back and repeated all the four turn situations a second time (including a short stop at the same place), before the car was driven back towards the start position and taking the two right turns of TurnA (TurnA-inboard). A map view of the turns is shown in Appendix, Figure A2.

Test Execution User Study 2

User Study 2 exposed 15 participants to four repeated right turns on a test track circuit while varying activity and exposure of belt-tensioning. A test track was used to achieve high repeatability, and to safely achieve harsh right turns (exposing the participant to an inboard movement) in line with the highest lateral accelerations in User Study 1. An average lateral acceleration of 3.4 m/s^2 was achieved by approaching at 40km/h and driving 32km/h through the turn. Average lateral accelerations from the turns, separated in four scenarios, are provided in Appendix, Figure A3. The participants were recruited based on their stature, enrolling shorter participants (stature<175 cm) only. From User Study 1, the shorter participants were identified as those with largest lateral movement. All participants were women and average BMI was 23.6kg/m^2. Demographics for each test subject are summarised in Appendix, Table AII.

The participants were told that the test aimed to investigate front seat passenger comfort with focus on belt comfort during normal driving. They were instructed not to wear dark or chunky clothes and to keep long hair tied back, in addition to bring a mobile phone connected to their email. Before starting the test, a film analysis target was placed on their suprasternal notch. The seat was locked in one position, mid-height and in longitudinal distance in-between mid- and far most position, with a backrest angle of 20˚. The height adjuster of the seat belt was in its lowest position. The seat position and height adjuster position were chosen to give improved shoulder belt contact and wrapping of the shoulder for the subject group being investigated. The seat belt comprised an electrical reversible retractor possible to activate in two low-force tensioning levels; 40N (lower) and 70N (higher).

At the start of the test while the car still was stationary, the participants were exposed to the lower-level belt-tension profile, to eliminate the surprise effect that otherwise might have occurred during the test. They were informed that they would receive three emails, which they were to read and perform the task when the test leader in the back told them to. They were also informed that they were not tested on how well they performed the task. The purpose of the tasks was to distract the test person from looking at the road and avoid using the arm supports without telling the participant explicitly.

The total test lasted for about 30 minutes. Each of the participants were exposed to four different scenarios. The order of the scenarios was randomly selected (Appendix, Table AII). Scenario A was the reference scenario, with no assignment nor belt-tensioning. Scenario B included an email task only and no belt-tensioning. Scenarios C and D included belt-tensioning (lower and higher, respectively) together with the email task. The specific email tasks were; write an email about what you had for breakfast (Scenario B), reply and answer if you can attend a meeting (Scenario C), and create a new appointment in your calendar (Scenario D). Between each scenario lap, the car was stopped for semi-structured interviews, evaluating that specific scenario. When all four laps were conducted, the participants were asked what scenario was the most preferred.

Data Collection and Analyses

Objective measures were collected twice for each turn; prior to entering the turn; the so called pre-position defined as start of lateral acceleration ramp-up, and at the time of maximum lateral position of the torso (measured at sternum).

The frontal view camera was used to quantify the test subject's torso lateral position and to assign the head and shoulder belt position categories, by analysing the pictures from the two times, for each turn in both studies. The camera was mounted in a centralized position relative the seat, perpendicular to the occupant enabling measurements of the selected targets within 0.5cm certainty. The average values were rounded off to closes 5mm interval. The torso lateral position was measured from the centreline of the seat (A) and the film analysis target on their upper sternum (B), see Figure 1a. The torso lateral movement is a calculation of the torso lateral position at the time of maximum lateral position, relative the position at the pre-position time for each specific turn and participant. The head position was assigned to three categories; mid, edge position and off the head restraint (Figure 1b). Mid-position is defined as head centralized within the head restraint. Edge position, with at least half of the head within the head restraint. Off the head restraint position when half of the head's width is outside the head restraint. The shoulder belt position was assigned one of the four categories; close to the neck, mid-shoulder position, shoulder edge position and off the shoulder position (Figure 1c). Close to the neck is defined as belt touching the test person's neck. A support-line was drawn through the test persons armpit, and if the complete width of the belt passed the help line the belt position was defined as off-the shoulder, if the centreline of the belt was on the inside of the help line the belt positon was defined as mid-shoulder. If the centreline of the shoulder belt was on the outside of the help line, but not complete off the shoulder, the belt position was defined as shoulder edge.

The lateral top view camera was used to see the arm positions, due to the view restriction in height for the frontal view camera. The arm position was categorised into use of the centre console, use of the door armrest and a combination of use of the centre console and the door armrest or none. Each participant was assigned one category throughout the ride. No annotation was made for each turn individually.

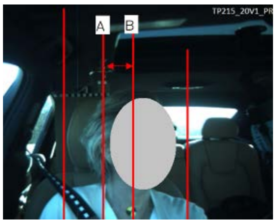

Fig. 1a. Torso lateral position measured from centreline (A) to upper sternum (B).

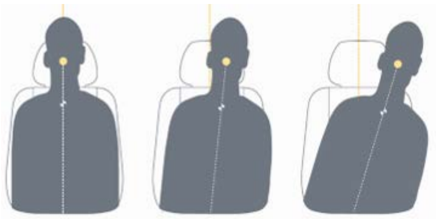

Fig. 1b. Head position categories; left: mid-position, mid: edge position, right: off the head restraint.

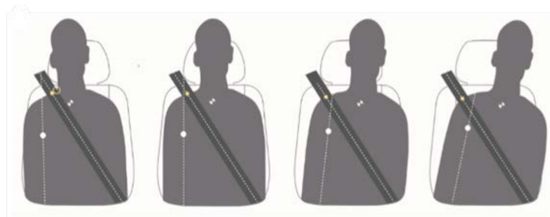

Fig. 1c. Shoulder belt categories; left: close to the neck, mid-left: mid-shoulder position, mid-right: edge position and right: off the shoulder position.

Subjective data was collected through semi-structured interviews, including questions on perceived comfort and safety. The interview consisted of four questions where the participants were asked to mark with an *X* on a 10cm long line to specify how they perceived the overall ride, seat and belt comfort as well as the perceived safety on a scale from *very poor* to *very good*. The semi structured interview generated both qualitative quotes and quantitative judgements about each of the questions. Semi-structured interviews are an established method to explore and understand test persons' comfort experience [29-30].

Descriptive analyses included box-plots and graphs with frequencies. Non-parametric tests were implemented, and significant interaction were investigated using Mann-Whitney test with the level of significance set to $p<0.05$. In User Study 1, tests were conducted to identify differences between taller and shorter participants, and participants with higher and lower BMI, in the different turns, in addition to the significance of lateral movement depending on turn situation. In User Study 2, tests were conducted to identify differences between the 4 different scenarios.

III. RESULTS

User Study 1

Torso lateral position and movement

Figure 2a shows the torso lateral position, inboard as well as outboard, prior to the turn (pre-position). There is a large spread, especially for the shorter group and the BMI>25 group. For all participants, the average torso lateral position, was 15mm inboard relative the centreline of the seat. Shorter and taller participants were on average 25mm and 15mm inboards. Participants with BMI<25 were on average seated 25mm inboards from the seat centreline, while those with BMI>25 were on average 10mm inboards.

Average values for torso lateral position at time of maximum lateral position, is presented in Figure 2b, for each of the turns separately. The maximum torso lateral position was significantly different from the pre-position, for both inboard and outboard in TurnB and TurnC (p=0.037, p=0.006, p=0.000, p=0.000). As can be seen in Figure 2b, highest torso lateral positions were seen for TurnC, with an average torso lateral position of 45mm in the outboard turn. For all three turns, there was a trend of outboard movement (turning left) was higher than the inboard movement (turning right), and there was a significant difference for TurnC (p=0.035). This trend corresponds to the differences in lateral acceleration values (Appendix, Figure A2), hence reflecting the exposure of severity.

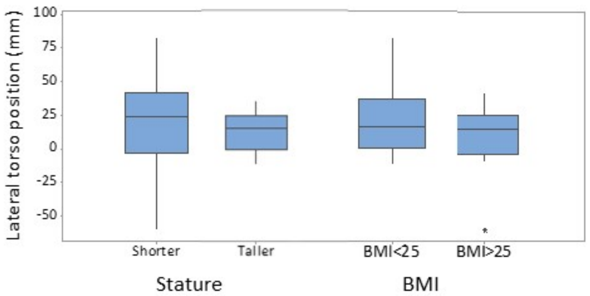

Fig. 2a. Boxplots on torso lateral position, pre-position; shorter vs. taller participants, BMI>25 vs BMI>25. Positive values inboards and negative values outboards.

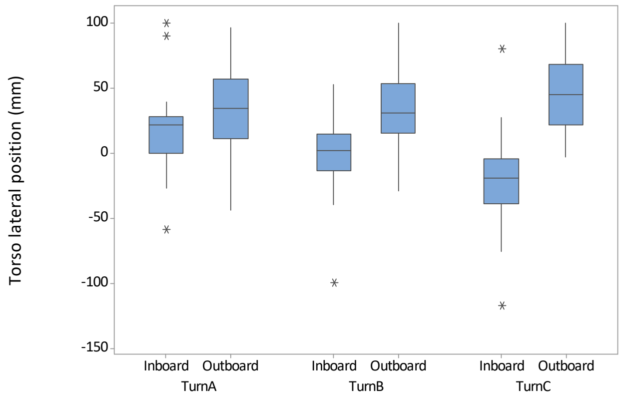

Fig. 2b. Boxplots on torso lateral position, at time of maximum lateral position, separated by each turn (A, B, C, inboard and outboard).

Figure 3 presents the relative torso lateral movement during each of the turn situations. There was a significant increase in lateral movement in TurnC compared to TurnA and TurnB, for both inboard and outboard turns (p=0.022, p=0.003). Also, there was a significant increase in lateral movement for TurnB compared to TurnA. (p=0.002, p=0.002) The average lateral movement in TurnC was 45mm in outboard turns and 35mm in inboard turns. In Appendix, Figure A4, individual lateral movement as function of lateral acceleration of each turn are plotted.

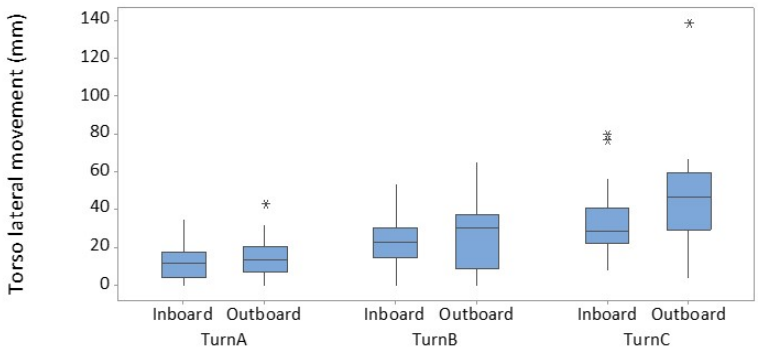

Fig. 3. Boxplots of relative torso lateral movement; maximum lateral position in relation to position prior to the turn (pre-position), separated by each turn situation.

When separating participants in the groups of stature and BMI, there was a trend of shorter participants having larger torso movement than the taller for all turns except outboard TurnC, however, the difference was not statistically significant except for outboard TurnB, Table I. There was no statistically significant difference between the BMI groups in any of the turn situations.

TABLE I.
AVERAGE LATERAL TORSO MOVEMENT (MM) PER TURN FOR THE STATURE AND BMI GROUPS. P-VALUES IN BRACKETS.

	Average movement (mm); stature groups			Average movement (mm); stature groups		
	Shorter	Taller	P value	BMI<25	BMI>25	P value
TurnA, inboard	15	10	0,234	15	10	0,63
TurnA, outboard	15	10	0,065	10	10	0,72
TurnB, inboard	30	20	0,064	25	20	0,765
TurnB, outboard	35	20	0,003	25	25	0,566
TurnC, inboard	35	30	0,662	30	35	0,918
TurnC, outboard	45	45	0,504	50	40	0,101

Photos from one shorter and one taller participant are shown in Figure 4, exemplifying that although the pre-position is rather similar, the shorter participant moved relatively more laterally during the turn.

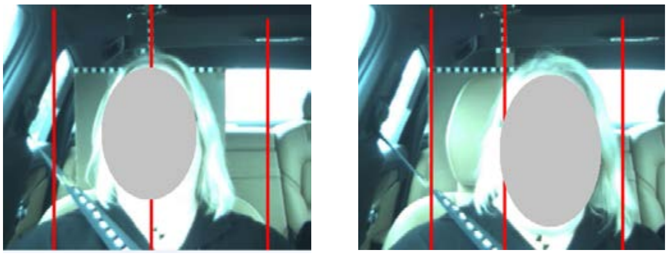

Fig. 4a. Example of sitting posture prior to turn (left) and at maximum lateral position (right); shorter participant in TurnC, inboard.

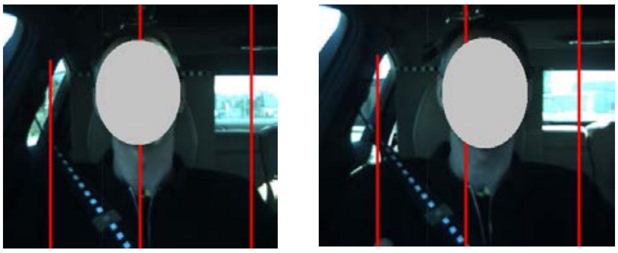

Fig. 4b. Example of sitting posture prior to turn (left) and at maximum lateral position (right); taller participant in TurnC, inboard.

Head lateral position and movement

Prior to the turn, the majority of the participants (ranging from 64% to 81%) had a mid-position of their head relative the head restraint, Figure 5a. It was more common among the shorter participants (35% versus 18%) compared to taller participants to have the head at the edge of the head restraint, while 1% were off the head restraint in each stature group. A similar trend was seen for the BMI groups; with a relatively higher prevalence for the group of BMI<25, including the 3% that initially were seated with the head position off the head restraint.

During the turn, the proportion of head position off the head restraint increased to 11% among the shorter participants and to 10% for the group of BMI<25, see Figure 5b and photos in Figures 6a and 6b. Within the taller group and the group of BMI>25, it did not change to the same extent compared to the pre-position.

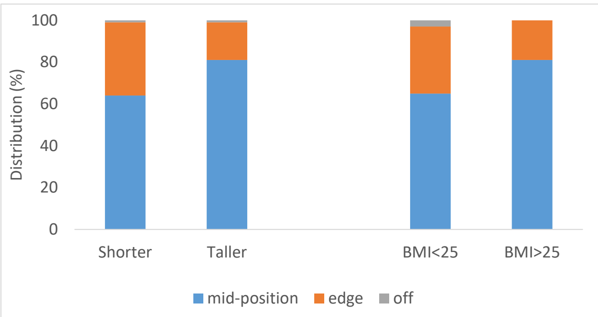

Fig. 5a. Head position before the turn, pre-position, categorised into the stature and weight groups.

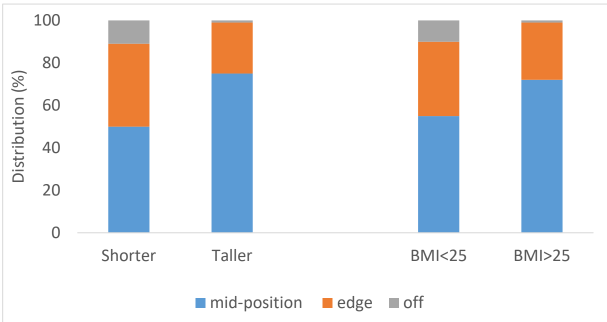

Fig. 5b. Head position at time of maximum lateral movement, categorised into stature and weight groups.

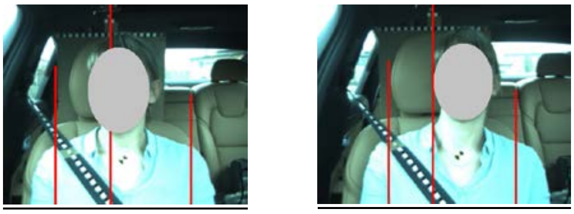

Fig. 6a. Example of head position edge, prior to turn (left) and at maximum lateral position with head off the head restraint (right); shorter participant in Turn C, inboard turn.

Fig. 6b. Example of head position edge, prior to turn (left) and at maximum lateral position with head on edge of the head restraint (right); taller participant in Turn C, outboard turn.

Shoulder belt position

At time of pre-position, the majority of the participants (ranging from 68-88%) had a mid-shoulder position of the shoulder belt, Figure 7a. No one had shoulder belt off the shoulder, while shoulder belt on edge of the shoulder were seen in 10% of the cases. This was more common among the shorter (19%) and among those with BMI>25 (21%). Eleven percent of the participants had shoulder belt contact with the neck. A notable difference with respect to BMI groups was seen; 21% in the group of BMI>25 as compared to 4% within the BMI<25 group.

The shoulder belt stayed on the shoulder for all participants in all turns, see Figure 7b. In the majority of the cases, the shoulder belt stayed in the mid-shoulder position (69-90% outboard and 75-88% inboard turns). During the outboard turn, 17% of the shorter group and 21% of the group of BMI<25, respectively, had the shoulder belt close to the neck at the time of maximum lateral movement.

In total, there were five cases with the shoulder belt moving from mid-shoulder position to shoulder edge position, and the majority were shorter (4/5) and all of them had BMI<25.

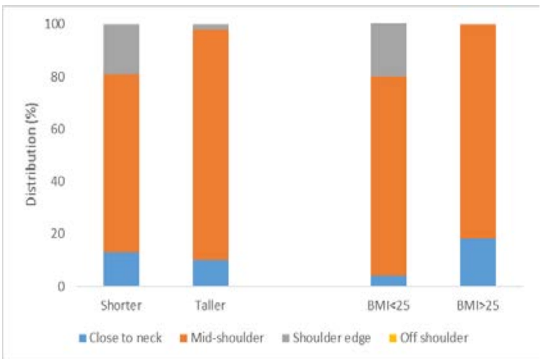

Fig. 7a. Shoulder belt position before the turn, pre-position, categorised into the stature and BMI groups.

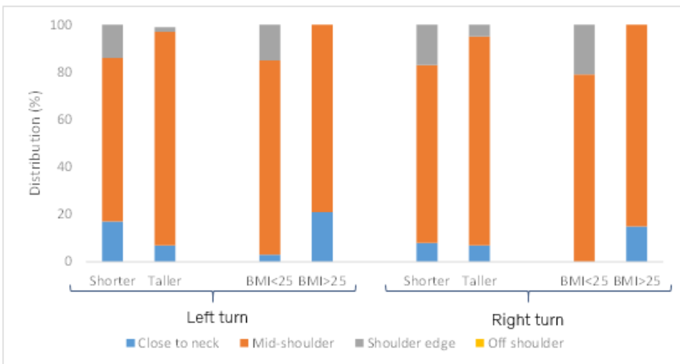

Fig. 7b. Shoulder belt position at time of maximum lateral movement, categorised into stature and BMI groups per outboard and inboard turn, respectively.

Arm support

The majority of the shorter participants did not use any dedicated vehicle arm support while all taller participants used the centre console, either alone or in combination with the door armrest, Table II. It was more common among participants with BMI>25 to use a combination of arm supports, as compared to participants with BMI<25.

TABLE II.
DISTRIBUTION (%) OF PARTICIPANTS' USE OF ARM SUPPORT ON CENTRE CONSOLE OR A COMBINATION OF CENTRE CONSOLE AND DOOR ARMREST; CATEGORISED INTO STATURE AND BMI GROUPS.
EACH PARTICIPANT WAS ASSIGNED ONE CATEGORY THROUGHOUT THE RIDE.

	No support (%)	Centre console (%)	Door armrest (%)	Centre console and door armrest (%)
Shorter	62	15	0	23
Taller	0	38	0	62
BMI<25	38	46	0	23
BMI>25	23	8	0	62

Subjective data

Figure 8 summarises the comfort and perceived safety scoring. Overall ride comfort, belt comfort, seat comfort and the perceived safety was scored high overall, and no major differences were seen between the subgroups. Exemptions were two participants, both shorter and with BMI>25, scoring low belt comfort. Overall, the participants expressed no concerns about safety, and they commented that nothing was out of an ordinary calm traffic situation. The majority mentioned that they did not even think about the seat belt, except the two participants who complained about shoulder belt chafing towards the neck.

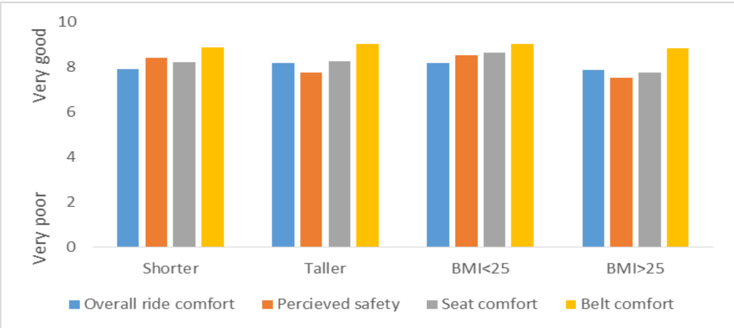

Fig. 8. The average scoring of overall ride comfort, perceived safety, seat comfort and belt comfort, categorised into stature and BMI groups.

User Study 2

Torso lateral movement and shoulder belt position

The torso lateral movements for all participants are shown in Figure 9 for each of the four scenarios, respectively. The average torso lateral movement ranged 40 - 50mm, with no large difference in the two scenarios including belt-tensioning (Scenarios C and D) compared to those without (Scenarios A and B). The influence of activities (Scenarios B, C and D) on lateral torso position, did not differ from the reference scenario without activity (p>0.05).

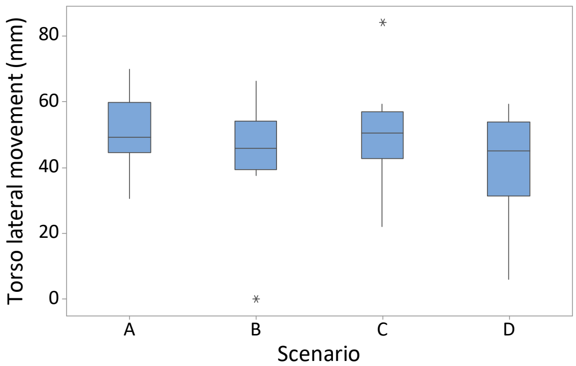

Fig. 9. Boxplots of the torso lateral movements in the four different scenarios.

The shoulder belt did not slip off the shoulder in any of the cases. In all four scenarios, the shoulder belt was mainly on mid-shoulder position (ranged from 64-83%) prior to the turn, Figure 10a. At the time of maximum lateral movement, the mid-shoulder position ranged from 50-58%, increasing the proportion of passengers with edge shoulder position. In the scenarios including belt-tensioning (C and D), the shoulder edge position was in the same range as in those without belt-tensioning (scenarios A and B), Figure 10b.

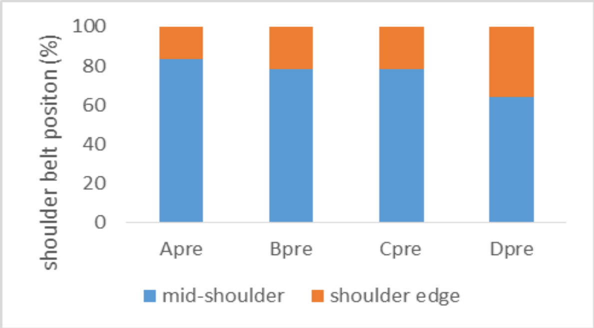

Fig. 10a. Shoulder belt position before the turn, pre-position, for the four scenarios.

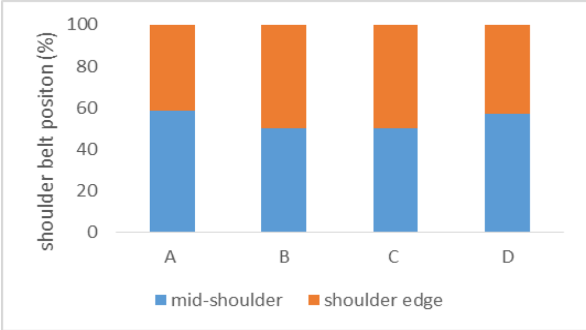

Fig. 10b. Shoulder belt position at time of maximum lateral movement, for the four scenarios.

Subjective data

Comparing the scenarios, 43% of the participants preferred Scenario C, followed by Scenario D (36%) and Scenario A (21%). No one preferred Scenario B. The majority scored close to very good regarding the perception of the turn in the four different scenarios, while there were some participants scoring very low on the perception of the turn (Figure 11a). A similar scoring pattern was found for the shoulder belt comfort (Figure 11b).

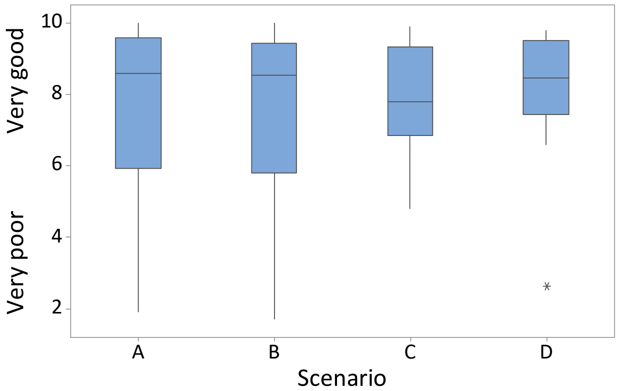

Fig. 11a. The perception of the turn.

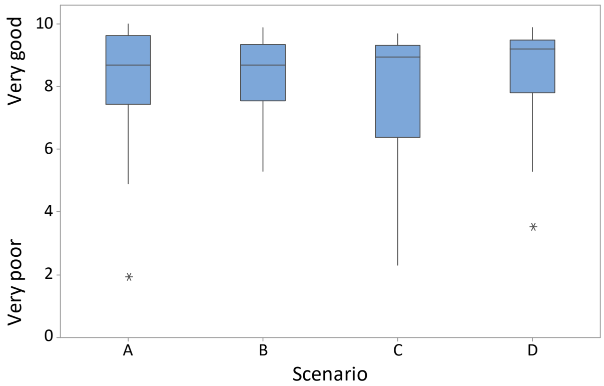

Fig. 11b. The perception of the shoulder belt comfort

IV. DISCUSSION

This study shows that the posture of most participants during suburban driving deviate from the standardised sitting posture of the crash test dummy. To what extent this will influence the interaction with the safety system, is to be further explored, and will vary depending on the type of restraint and situation of exposure.

Prior to the turn, the majority of the participants in User Study 1 had a tendency towards an inboard position, this was seen both for the shorter and taller participants. The inboard position is likely to have contributed to the shoulder belt position further out on the shoulder, hence influencing the relative high frequency of the shoulder edge position. Especially among the shorter participants, generally having narrower shoulders, this inboard sitting position poses potential higher consequences with respect to shoulder belt interaction during a crash as compared to taller participants. Some of the participants used the inboard armrest on the centre console, which likely could make them attain a more inboard position. In addition, an inboard position could likely be influenced by interaction with the driver. Further studies investigating influencing factors is encouraged.

Prior to the turn, four participants in User Study 1 were categorised as shoulder belt close to the neck. Two of them were in the group of BMI>25 and their body shape routed the shoulder belt upward the belly resulting in this position (see example in Figure 12a). This shoulder belt routing and position has been identified in other studies as a result of high BMI [12]. The other two participants had a laterally outboard torso position, contributing to the shoulder belt position closer to the neck (example shown in Figure 12b).

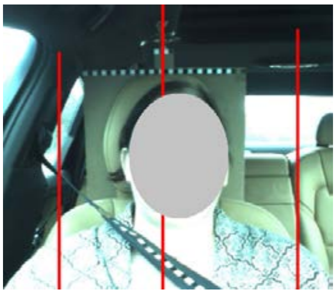

Fig. 12a. Example of shoulder belt position close to the neck, due to influence of body shape contributing to lower shoulder belt part being routed higher on torso.

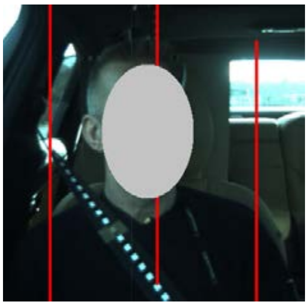

Fig. 12b. Example of shoulder belt position close to the neck, due to outboard torso lateral position.

During the turns, the torso lateral movement was highest in TurnC followed by TurnB and lowest in TurnA. This follows the pattern of lateral acceleration between the turns. Generally, the outboard turns resulted in higher lateral movements as compared to the inboard turns, for each of the three Turns. This was likely also related to the differences in lateral acceleration for the two different directions in the same turn, although approaching the turn at the same velocity, irrespective of right or left hand turn. See Appendix Figures A1 and A4.

The shorter participants showed a trend of greater torso lateral movement compared to the taller participants, both in position relative to the centreline as well as relative position in relation to their starting point, although not statistically significant. A similar trend was seen between participants with BMI<25 compared to participants with BMI>25. A higher degree of the taller participants, as well as the group of BMI>25 used the designated arm supports. Although not possible to analyse for each turn, this general trend of higher degree of arm support use and lower lateral movement, might be connected. For a smaller occupant, the designated vehicle armrests are more difficult to reach, unless the lateral sitting posture is changed, moving away from the centreline of the seat and therefore likely less attractive to use. Several participants with BMI>25 used the armrest at both the door and centre console, likely giving them good support for lateral acceleration from both inboard and outboard turns. In a driving study on drivers [31], it was found that men were more likely than women to use both left and right armrest. It was seen that women had approximately the same percentage of armrest use across vehicles, but men's usage differed widely, suggesting that armrest design may influence whether people of different statures can use the armrests comfortably.

None of the participants experienced shoulder belt position off the shoulder in any of the turns. However, during inboard turns some mid-shoulder positions changed into shoulder edge positions, which may influence the restraint efficiency in case of a crash. The shoulder belt position at time of maximum lateral position was influenced by both the initial sternum position as well as the lateral movement during the turn, meaning both parameters need to be addressed in order to improve shoulder belt position.

In the majority of turns, the head kept a lateral position within the head restraint width. The head restraint's main purpose is to support the head in a rear end impact, helping to reduce relative motion between the head and the torso protecting the cervical spine. Keeping the head within the width of the head restraint is essential for occupant protection.

The subjective experience reported in User Study 1 showed high average scoring and low spreads between individuals, for overall comfort, belt comfort, seat comfort and perceived safety, with exception of two participants with low scoring of belt comfort due to shoulder belt chafing to neck. The otherwise high scoring could be expected, since the vehicle used is a premium vehicle with high standards offering good comfort for a wide range of users. Furthermore, participants mentioned they felt safe being in this specific brand. Only a few participants stated TurnC as high and unpleasant. Also, the route was a normal ride without any unexpected extra-ordinary events.

In User Study 1, the retractor did not lock in the turns due to the low levels of acceleration, meaning the seat belt did not provide any extra support. The strategy of helping to support the passenger through the seat belt during the turn was evaluated in User Study 2. However, the belt-tensioner intervention in that study showed no effect on the objective measurements, such as belt position or torso or head lateral movement. The belt-tensioning levels were chosen at the lower range, 40N respective 70N, and maybe these were too low to actually achieve any influence on the lateral movement. More studies are needed to evaluate this. Nevertheless, it was obvious that belt-tension levels must be balanced with the comfort experience. In the present study there was an overall high comfort scoring but the belt-tensioning perception deviated between individuals. Some experienced improved comfort while others did not appreciate it. Some felt taken care of by the vehicle, while some were more scared. By understanding the individual experiences; opportunities for personalisation is apparent, helping improve overall seat belt comfort and thereby safety.

The methods used in this study complement prior studies in the area studying car passenger sitting postures and seat belt positions. Prior studies have either been performed in a static setting [7-14] or during evasive manoeuvres [24-26] on test tracks, while this study is the first of its kind focusing on everyday traffic situations. The same car was used throughout the study, which is a strength when comparing influence by the individual variations such as stature and BMI. However, the choice of one specific car influences the results, the objective as well as the subjective. Another general limitation is that all participants were recruited from Volvo Cars. Although not involved in the study or the safety area in general, it cannot be neglected that it might have influenced the subjective scoring, such as perceived safety. However, it is not likely it has contributed to the objective results.

Although User Study 1 took the participants on a 40 min drive on a pre-defined route similar to everyday traffic situations, including roundabouts and smooth curves, it is different from naturalistic driving studies that would include a wider range of turns and even more exposure to everyday traffic situations. However, by exposing the test participants to the same pre-defined route, a systematic analysis of both turns and participant characteristics could be performed. The three turn characteristics (speed when entering and type of curve) were selected based on a compilation of vehicle lateral acceleration data, to be representative of rather harsh, but frequent, situations on rural road as well as crossings. For repeatability reasons, these lateral accelerations were recreated using the roundabouts and curves in User Study 1, and the test track in User Study 2.

The selection of participants was made targeting to gain an insight into differences with respect to both stature and shape; thereby the categorisation into the groups of stature and BMI, respectively, for User Study 1. Based on the results in the User Study 1, the characteristics with the highest lateral movements was targeted in User Study 2. Hence, shorter participants, preferably with low BMI were included in User Study 2. All of them were shorter than 175cm, the majority of them were below BMI 25. Another difference between the two sub-studies was the seat position. While targeting as normal seat position as possible in User Study 1, it was decided to use a pre-set seat position in User Study 2. The rationale for that was to get as much shoulder belt wrapping as possible for the selected population, when studying the influence of the belt-tensioning. Furthermore, in User Study 1, all the shorter participants were women and all the taller participants were males. The trend in differences in lateral torso position between shorter and taller, may also be affected by sex. Differences in muscle size as well as joint flexibility may influence the kinematics. Previous studies on volunteers in evasive manoeuvres [24][32][33], have mainly included male volunteers. Obviously, future studies should include a wider range of occupant sizes, in addition to variations in seat position and influence of sex.

The car was instrumented with cameras mainly focusing on the upper torso, shoulder and head position. The side-top view camera was targeting information on arm positions, however the limitations on both camera views limited the possibilities to get appropriate quality to assess the arm positions at every turn. Instead the use of armrest as reported in the study is based on an overview usage. Therefore, these numbers should be used with caution as they mainly reflect an observation on differences between the participant groups, and by that an indication of influencing factors of the lateral movement.

Due to limited view of the torso, it was not possible to analyse whether the upper torso lateral movement was related to upper torso tilt or the pelvis sliding on the seat. Previous study of lateral movement of volunteers in evasive lateral manoeuvres [24][32][33], also quantified lateral movement relative to the seat centreline, but no analyse was included whether the lateral movement was due to torso tilt or pelvis sliding in on the seat. This is valuable information for guiding protection principles targeting lateral movement and poor shoulder belt positions on the shoulder. Future studies are encouraged to include such analysis.

Today, passenger cars are mainly designed to protect upright sitting occupants, who are centralised on their seat. At least, this is the way the crash test dummies are designed to be used and are used in standardised testing. Insights into real world sitting postures and seat belt positions in common traffic situations, as presented in this study, will contribute to the knowledge foundation towards future challenges. This is important both with respect to interpretation of the real-world data today, i.e., what ranges of postures that are reflected by the data in the databases, as well as to understand future priorities in protection needs.

V. CONCLUSIONS

Shoulder belt fit on mid-shoulder position is essential for optimal protection and is important to maintain during the whole trip. This study provides data on the influence of passenger size and supporting strategies on lateral position and shoulder belt position. In the four most evasive turns, TurnB and TurnC outboard as well as inboard, maximum torso lateral position during the turn was significantly different from the position prior to the turn. The extent of average torso lateral movement ranged from 25 to 45 mm. There was a trend of shorter participants having greater lateral movements and more critical shoulder belt positions, than taller participants. The belt remained on the shoulder for all participants for all turns. However for some, mainly participants in the shorter or the BMI<25 groups, the seat belt reached shoulder edge position. The majority kept their head within the head restraint width.

The belt-tensioner intervention in this study did not affect lateral movement. Nevertheless, the perceived comfort was shown an important aspect to take into account, indicating opportunities for personalisation of restraints, which can help improve overall seat belt comfort and thereby safety.

The frequent occurrence of non-nominal sitting postures both prior the turns as well as during the turns, unlike crash test dummy postures in standardised testing, motivate more studies of this kind, gaining further understanding of the representativity of standardised tests as well as real-world occupant protection.

VI. ACKNOWLEDGEMENT

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VIII. APPENDIX

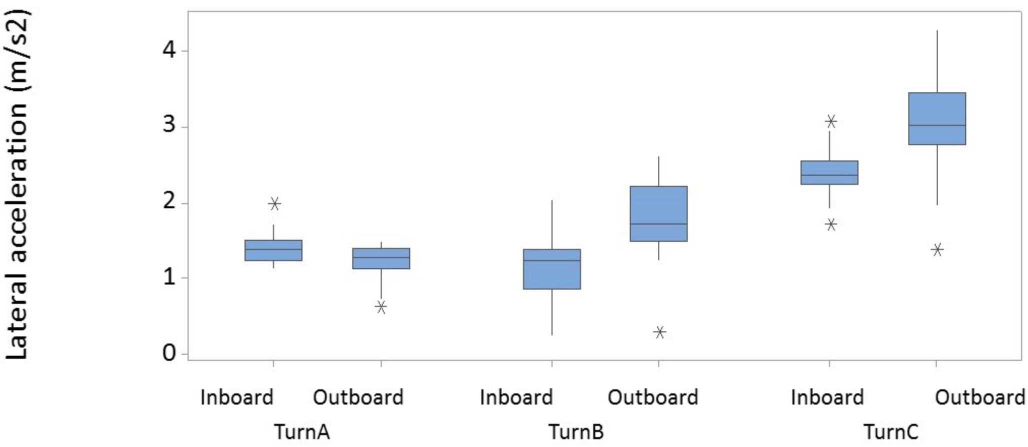

Fig. A1. User Study 1: Boxplot of lateral acceleration, at the time of maximum torso displacement.

Fig. A2. A map view of the four turn events in User Study 1, indicating the turns, in addition to the interview place (STOP) and place for turning back (Return). The two smooth turns (TurnA) were passed at 70 km/h followed by two roundabouts in 20 km/h and 28 km/h, TurnB and TurnC, respectively, exiting by the third exit. After the second roundabout, the car was stopped (STOP), and a semi-structured interview was held. Thereafter the car was driven back through the two roundabouts in right turns exiting first exit and turned back (Return) passing through the two roundabouts repeating the left turns through the third exit. A short stop was made at the same place (STOP), before the car was driven back; repeating the two right turns in the roundabouts and taken the right turns of TurnA.

TABLE AI.
CHARACTERISTICS OF THE PARTICIPANTS IN *USER STUDY 1*

Participant No.	Sex	Stature group	BMI group	Stature (m)	BMI (kg/m^2)
1	male	taller	BMI<25	1.77	20.56
2	female	shorter	BMI<25	1.72	22.1
3	male	taller	BMI<25	1.90	20.6
4	male	taller	BMI>25	1.97	30.1
5	female	shorter	BMI>25	1.68	32.8
6	female	shorter	BMI>25	1.66	28.1
7	female	shorter	BMI>25	1.68	28.3
8	male	taller	BMI<25	1.74	25.7
9	male	taller	BMI>25	1.83	29.9
10	female	shorter	BMI<25	1.54	24.5
11	male	taller	BMI>25	1.93	29.8
12	male	taller	BMI<25	1.84	23.8
13	male	taller	BMI>25	1.94	31.1
14	female	shorter	BMI<25	1.70	22.0
15	male	taller	BMI<25	1.98	21.32
16	female	shorter	BMI<25	1.70	25.4
17	female	shorter	BMI<25	1.60	20.4
18	female	shorter	BMI<25	1.65	25.3
19	male	taller	BMI<25	1.88	23.1
20	female	shorter	BMI<25	1.82	21.4
21	female	shorter	BMI>25	1.69	33.0
22	male	taller	BMI>25	1.93	27.6
23	male	taller	BMI<25	1.83	30.0
24	female	shorter	BMI>25	1.57	38.1
25	male	taller	BMI>25	1.91	28.2
26	female	shorter	BMI>25	1.64	29.1

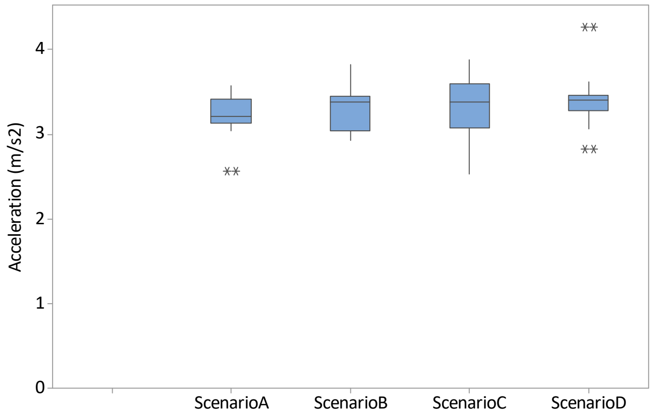

Fig. A3. User Study 2: Boxplot of lateral acceleration, at the time of maximum torso displacement.

TABLE AII
CHARACTERISTICS OF THE PARTICIPANTS IN *USER STUDY 2*

Participant No.	Sex	Stature (m)	BMI (kg/m^2)	Scenario order of sequence			
1	female	1.61	21.9	A	C	B	D
2	female	1.63	22.89	C	B	D	A
3	male	1.74	22.6	C	D	A	B
4	female	1.64	20.9	D	B	C	A
5	female	1.46	23.4	C	A	B	D
6	female	1.61	24.5	A	C	D	B
7	female	1.64	28.2	D	A	C	B
8	female	1.73	23.7	C	A	D	B
9	female	1.65	22.9	A	D	B	C
10	female	1.55	26.0	B	C	A	D
11	female	1.75	21.45	D	C	A	B
12	female	1.7	26.8	A	D	C	B
13	female	1.58	17.6	B	D	A	C
14	female	1.72	25.5	B	A	C	D
15	female	1.67	25.2	D	B	A	C

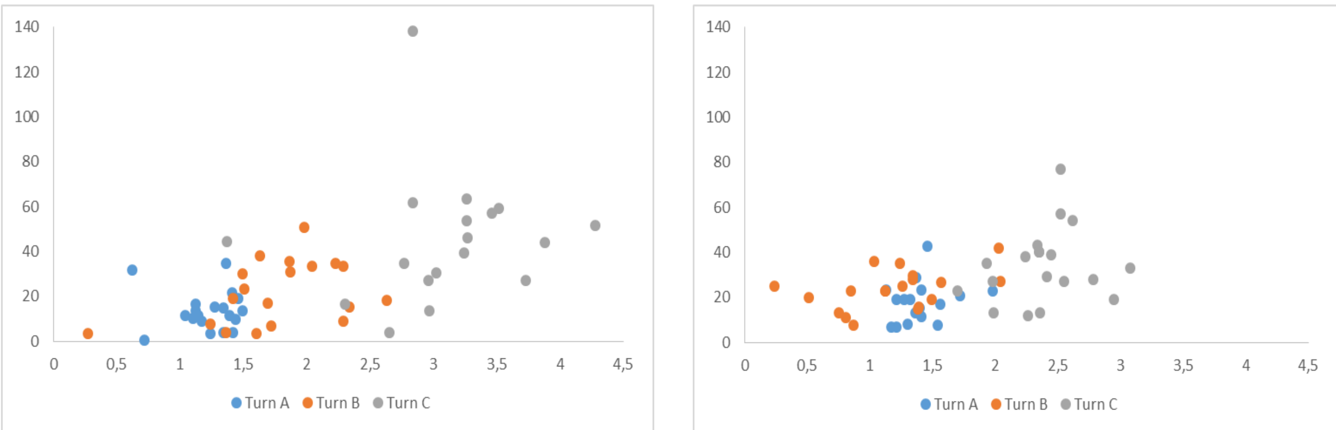

Fig. A4. Lateral movement as function of lateral acceleration, for each participant in TurnA, TurnB and TurnC. The left graph shows left turns (inboard motion) and right graph shows right turns (outboard movement).