Observation of Front Seat Passenger Posture and Motion in Driving Manoeuvres

Stefan Kirscht, Gerd Müller, Heiko Johannsen, William Goede, Stefanie Marker

Abstract Active safety measures such as emergency and autonomous braking offer the possibility to avoid or to mitigate accidents. Especially for the mitigation systems the change in posture and the motion of the occupants resulting from the pre-impact manoeuvres are important input parameters for passive safety measures. This is especially true when using human models because it is almost impossible to simulate the whole process from the intervention up to the impact due to computational efforts and numerical instabilities. In this study the change in posture and motion of front seat passengers in several manoeuvres (such as braking with different acceleration level and lane change with different amplitudes) are assessed using a fixed track with defined scenarios. The occupants are filmed from several perspectives and the movement is tracked. In addition to volunteers the tests are executed with dummies to compare the motion. The data show a large spread between individual subjects that is mainly independent from anthropometry. However, the adult dummies' movement is normally within the spread of the human subjects. Furthermore the stabilisation by the arm rest (if used) seems to have an important influence on the results. The applied methods were discussed and improvements were proposed.

Keywords Front seat passenger, kinematic behaviour, naturalistic observation field test, anthropometry, pre-crash relevant manoeuvre taxonomy

I. Introduction

Up to now, the kinematic behaviour of front-seat passengers in pre-crash scenarios has not been analysed with naturalistic passenger observation methods. Differences between the behaviour of front-seat passengers and drivers can be expected according to differences in seat position, seating, bracing and expectation/anticipation. Particularly for pre-crash relevant manoeuvres, it would be helpful to know and understand the kinematic behaviour of front-seat passengers. This will help for the assessment of passive safety features for mitigated accidents. The change in posture and the motion of the occupants resulting from the pre-impact manoeuvres are important input parameters for passive safety measures. Especially the proper use of human body models requires sufficient input parameters because it is almost impossible to simulate the pre-crash phase from the intervention up to the impact due to computational efforts and numerical instabilities

Given that front-seat passengers represent an inhomogeneous group of people in this context, a quantitative field test of 30 volunteers and 3 dummies was arranged, aiming to record the front-seat passenger kinematics to derive a taxonomy for pre-crash relevant manoeuvres. Furthermore, the data should serve for a comparison of dummy kinematics and human kinematics. Upstream, the field test should be used to test the measurement setup and its adequacy for such investigations.

Due to improvements in computing capacity and image data processing, methods of naturalistic driving observation (NDO) can be applied in more and more research areas, including accident research. A first major study was the VTTI 100 car study (2000-2005), where 100 vehicles were observed in the greater Washington D.C. area. A data set of approx. 200,000 miles of driving data, or 43,000 hours of video material, was generated and analysed according to the accident behaviour [1]. It revealed that 78% of the accidents and 65% of the near accidents followed driver inattention. The most frequently occurring source of inattention was the mobile

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phone/PDA, followed by interaction with other passengers [2].

In Europe, PROLOGUE (PROmoting real life Observations for Gaining Understanding of road user behaviour in Europe, 2009-2011) was a pioneering project to define requirements for a consistent technical and methodological standard of NDO [3]. UDRIVE (eUropean naturalistic Driving and Riding for Infrastructure and Vehicle safety and Environment) is implementing these requirements (2012-2016) with the goal of establishing a public domain database hosting 470 vehicle years. Main research areas are accident risk due to inattention and distraction, vulnerable road user behaviour and ecologic driving [4]. Another NDO project, UR:BAN, focuses on the development of driver assistance systems and traffic management tools in urban areas. Here, not only drivers but also pedestrians and bicyclists are considered to improve safety by methods of cognitive assistance [5]. Currently, the behaviour of the front-seat passenger is not directly considered in naturalistic driving studies.

Approximately 50% of drivers react with evasive manoeuvres, e.g., braking and/or steering in the pre-crash phase [10] citing [11]. According to the analysis of 860 Japanese frontal impact accidents between 1993 and 2004 most of the evasive manoeuvres are isolated braking manoeuvres (16.0% in single vehicle frontal impact to 54.6% in front-to-rear impact accidents) or combination of braking and steering (7.5% in front-to-front to 19.2% in other frontal accidents). Isolated steering manoeuvres were observed in 0.6% (other frontal accidents) to 16.0% in single vehicle frontal impact accidents. No reaction before impact was observed in 26.8% (front-to-rear) to 58.3% in single vehicle frontal impact accidents.

Hault-Dubrulle et al. [9] investigated driver behaviour in the event of an unavoidable crash situation in a driving simulator. All subjects decelerated the vehicle when the situation occurred with a brake pedal force that was 11.8 to 85.9% of their controlled full power brake pedal activation. In addition some of the subjects tried to evade. That shows the range of reaction (in case of reactions) of drivers in pre-crash events.

II. METHODS

Setup

In this study driving tests with a total number of 30 volunteers (24 males and 6 females) were performed. As asked beforehand all subjects wore close-fitting clothing (checked by sight) on which several markers were affixed to track the passenger's motion later on. Before the driving test each subject had to fill a form, confirming their medical health and well-being and specifying their body height and weight. In addition the sitting height was measured.

The test vehicle was a BMW 535i Touring (F11). The position of the passenger seat was defined in advance and remained unchanged for nearly all subjects. In two driving test the seat position were altered unintended. Both subjects of these tests (both male; 62 y.o, 178cm, 110kg and 26 y.o., 185cm, 62kg) were excluded in the analysis to keep comparability between the results. The body weight of the remaining 28 subjects ranged from 43 to 108 kg and their body heights varied from 156 to 190 cm (see Fig. 1 and Fig. 2).

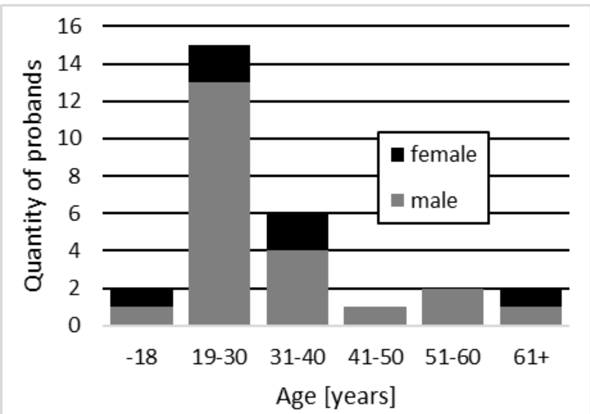


Fig. 1: Volunteer's share of age-groups

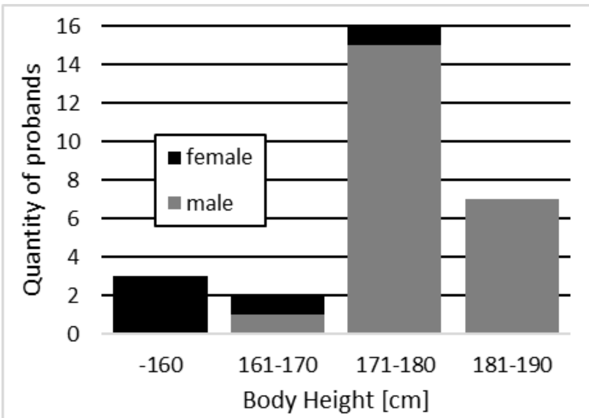


Fig 2: Volunteer's share of body heights

Driving manoeuvres

For the driving tests several dynamic driving manoeuvres on a plain concrete surface were conducted. Tests with longitudinal and/or lateral acceleration were chosen.

The tests were chosen to simulate typical pre-crash scenarios such as partial- or full-braking before an impact, but tests with a high lateral acceleration instead of skid movements were also conducted. For the lateral acceleration three tests were conducted: a double lane change and a slalom test with acceleration in both directions and an evasive manoeuver with a sudden lateral acceleration in one direction. For the braking scenarios two situations are possible. Braking is either initiated by the driver or by an automatic braking system. In both cases partial- or full-braking is possible, depending on the system or on the driver's behaviour. It has been observed that drivers in emergency situations often do not brake sufficiently. To address this problem, brake assist was developed. Also the first autonomous braking systems were designed in a way that they braked only with a part of the full possible brake force, so the partial-braking tests simulated the behaviour of these systems as well.

All test speeds were driven according to the car's speedometer, which is usually a bit slower than the actual speed. All manoeuvres, except for one of two full braking, were announced to the volunteers.

In order to ensure that the driven manoeuvers were similar their routing was marked on the ground. As a result the passenger was in general able to anticipate the following manoeuver depending on his experience and attention. In order not to have an additional spread resulting from the different anticipation of the manoeuvers it was decided to inform all participants.

The following manoeuvres were chosen:

Double lane change

The double lane change manoeuvre was conducted according to its description in the ISO 3888-2. However, the entry and exit lanes were wider than described in this standard and the test velocity was set at 40 km/h. The test was conducted in both directions; the average lateral acceleration was measured at 0.5 to 0.6 g (see Fig 3 and Fig. 4).

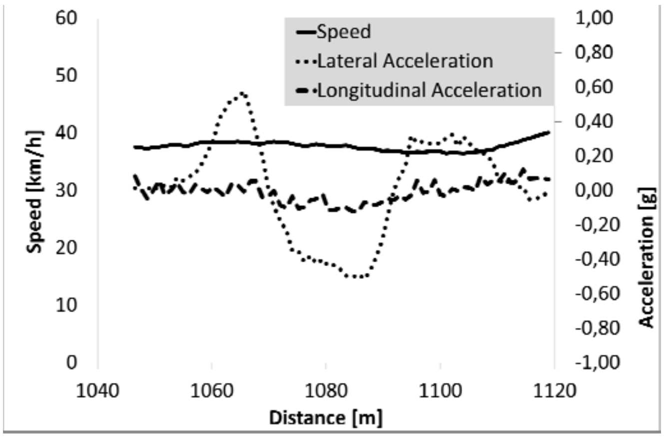


Fig. 3: Double lane change left

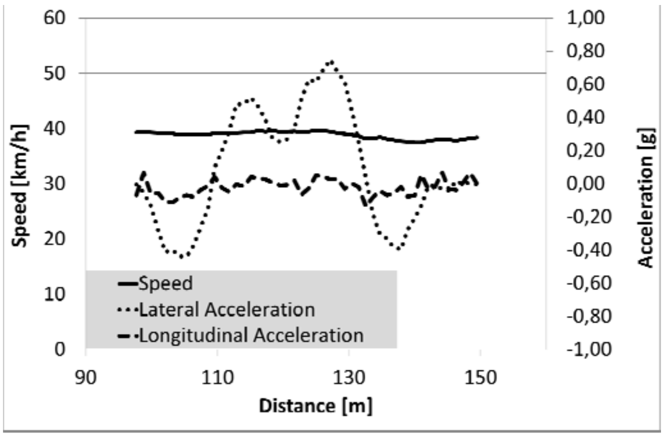


Fig. 4: Double lane change right

Slalom

The slalom test was conducted at a speed of 30 km/h. All in all four pylons were rounded (see Fig. 5).

Full braking

This test was conducted twice during the whole test drive. The first braking was announced, the second one was unannounced to surprise the passenger. The starting speed in both cases was 50 km/h; a maximum deceleration of 1 g could be reached, which led to a breaking distance of about 12 meters (see Fig.6).

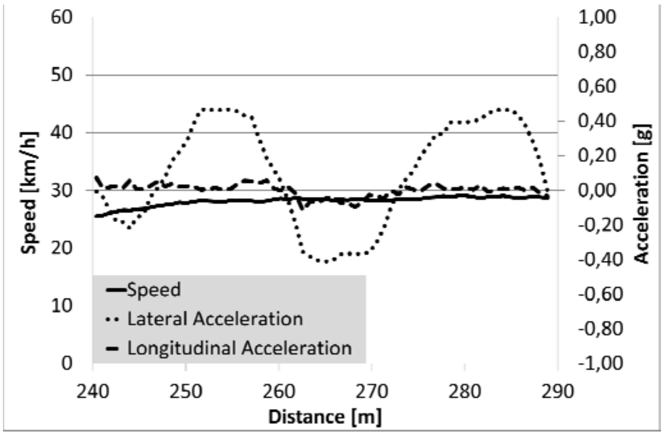


Fig. 5: Slalom

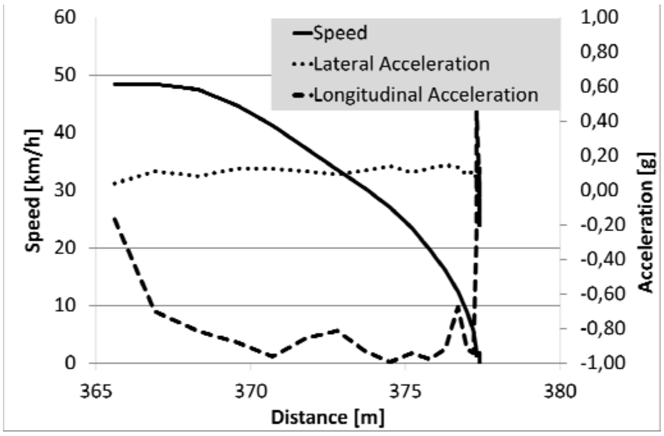


Fig 6: Full braking

Partial braking

The partial braking was conducted three times: braking without steering manoeuvre and braking with evasive manoeuvre to the right and to the left side. The starting speed was 50 km/h; the average deceleration was 0.6 g (see Fig. 7-9).

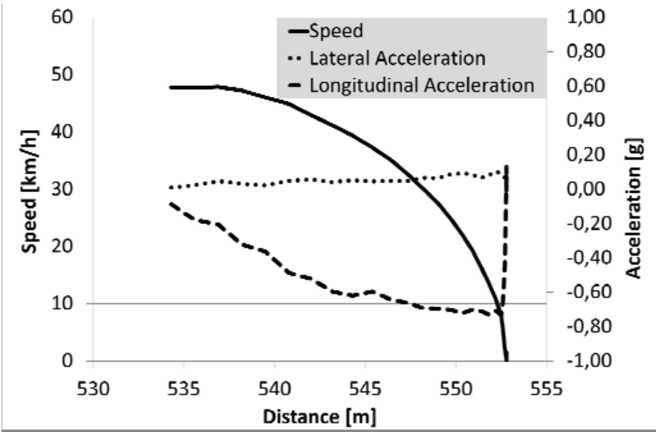


Fig. 7: Partial braking without evasion

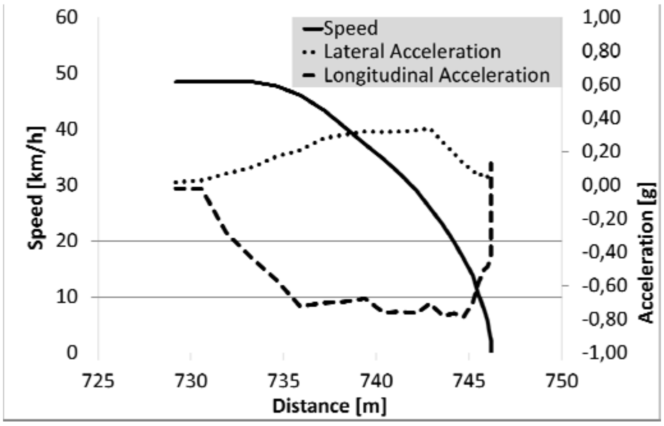


Fig. 8: Partial braking with evasion to the left

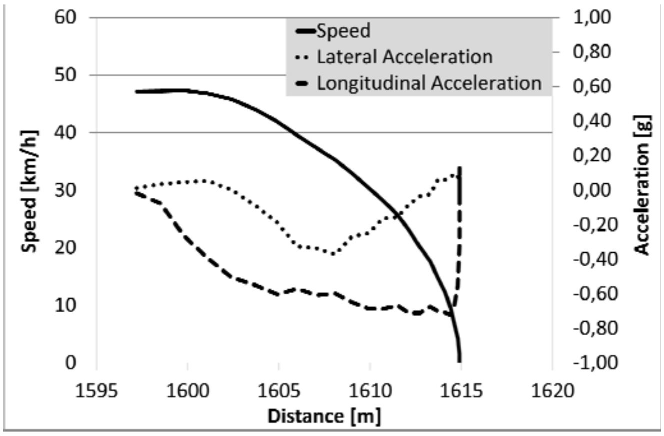


Fig. 9: Partial braking with evasion to the right

Evasive manoeuvre

The evasive manoeuvre was done to the left and to the right side in the test drive. At a speed of 50 km/h the lane was changed as fast as possible and the lateral movement was one vehicle width. The lateral acceleration was between 0.7 and 0.8 g (see Fig 10 and 11).

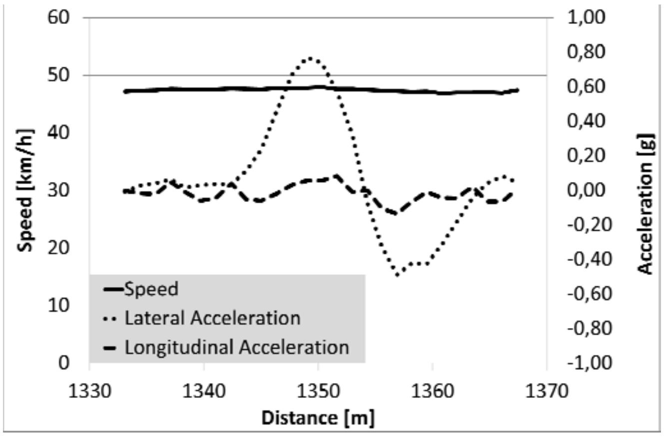


Fig. 10: Evasive manoeuvre left

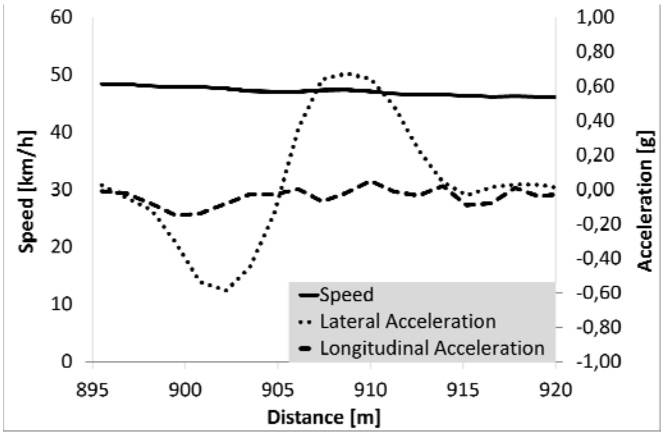


Fig. 11: Evasive manoeuvre right

Measurement and data processing

The measuring system is based on the Racelogic Video VBOX. It serves as GPS receiver, data logger and video/audio recorder, thus allowing for a synchronised data set so that no extra data matching procedure has to be executed. The sampling rate is 10 Hz. Since the whole system comes from one manufacturer, no further configuration is necessary, except for the acceleration sensor. Regarding Doppler Effect, the GPS carrier signal can be used to enhance the preciseness of the measurements. Otherwise, poor transmission reduces the preciseness.

The acceleration sensor MM5.10 (BOSCH) records linear accelerations in three spatial directions and rotational velocity around two axes. The CAN bus connection operates with a transmission velocity of 500 Kbaud at a range of ±163 °/s with a resolution of 0,1 °/s for the rotational velocity, and a range of ±4,2 g with a resolution of 0,01 g for the linear accelerations, respectively. All measurements are valid for a temperature interval of -20°C – 85°C [8]. The sensor was mounted on the transmission tunnel between the front seats. Power supply came from the cigarette lighter.

Four pole cameras operated as part of the Racelogic equipment. Three cameras were directed on the subjects: the first camera was placed on the window next to the driver to record forward directed movement. The second camera was attached at the top edge of the windshield and aimed vertically down on the knee and legs of the subject. The third camera was attached on the lower edge of the windshield and faced the subjects directly. The last camera was also fixed on the windshield but aimed in the driving direction of the car to record its course during the driving manoeuvres. Microphones were not used in this study.

VBOX combines the video output of all four cameras in a four-sector screen with a resolution of 720x576 pixel and a refresh rate of 25/s [7]. Additionally, a text file is compiled. It contains the recorded driving performance data and the time stamp which was used to synchronize the data with the video/audio recordings.

The motion of each passenger in each manoeuver was measured by video analysis with the software TrackIt (IAT Ingenieurgesellschaft für Automobiltechnik mbH), which allows visual tracking of several markers placed on defined body parts of the subjects. This point tracking process was partially done in an automated process, which is based on the colour comparison of each pixel of a user-defined search pattern in different pictures/frames. Theoretically any pattern can be found by this method. Due to changes of brightness and shadows caused by the vehicle movement, the automated tracking process lost the defined marker and manual tracking was necessary. Because the software is not compatible with the file format of videos obtained by the VBOX, the video files had to be converted. Quality losses apparently did not occur but were not investigated.

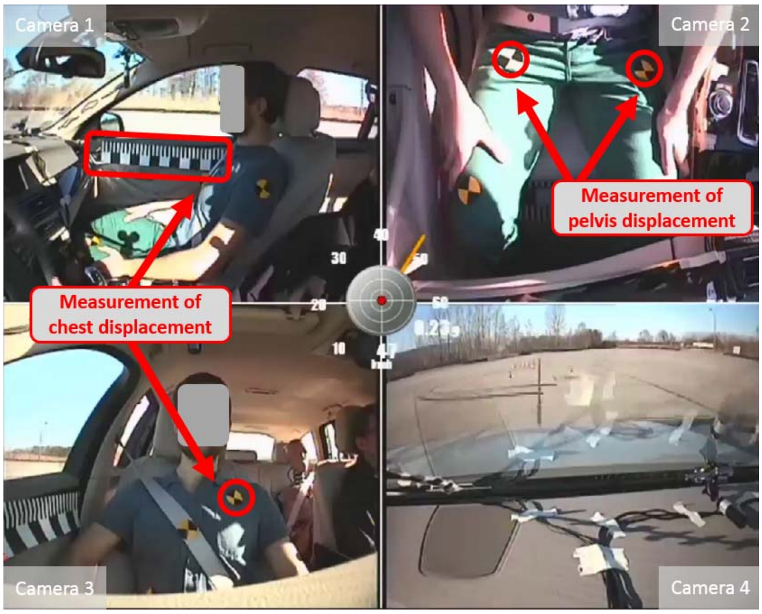


Fig. 12: Example of video output file and selected markers for measurement

The motion of the following markers was analysed (see Fig 12): For measurement of the lateral movement of the passenger's trunk, markers were placed on the left chest, next to the shoulder joint and under the clavicle, so that an interaction with the belt could be avoided. Two markers were placed on each thigh of the passenger, one on the upper thigh and one above the knee. The forward displacement of the passenger's chest was measured along the measuring scale affixed to the vehicle structure next to the passenger. The displacements were scaled for each camera angle separately with known reference measures. The effects of parallax were not corrected.

III. Results

The results for the passenger's tracked motion are divided according to the type of driving manoeuvre. In the lateral dynamic manoeuvres (evasion, double lane change, slalom) the maximal lateral displacement of the passenger's chest marker and one pelvis marker are presented below. Similarly longitudinal displacements of the chest and one pelvis marker are shown for the partial- and full braking manoeuvre (see Fig. 13 and 14)

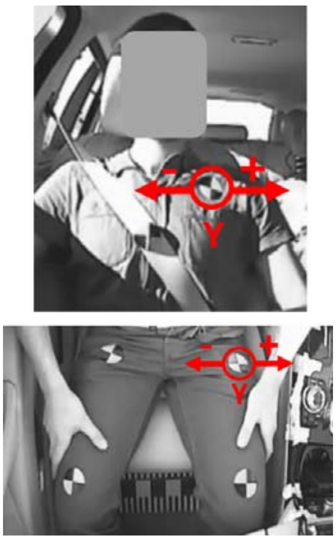


Fig. 13: Markers used for the measurement of lateral displacement [Y direction]

Fig. 14: Markers used for the measurement of longitudinal displacement [X direction]

At the beginning of each manoeuvre the position of each marker was set as zero position for the remainder of the manoeuvre, so that all displacements are measured in reference to this subject-specific zero position.

The maximal lateral displacement of the passenger's chest and pelvis markers in both directions are presented in Figs. 15 to 19 for each subject in both evasion manoeuvres, in both double lane changes and in the slalom manoeuvre. Five subjects were excluded because their pelvis markers were concealed by their own arms during most of the time so no valid measurement of their pelvis marker motion could be done.

(Note: The shown numbers (#) in the following figures correspond to their test drive numbers and not to the total number of subjects. Several test drives were conducted for camera positioning and measurement tests.)

In the **evasive manoeuvre to the left** all subjects showed an average maximal lateral chest marker displacement of -88 mm in the direction of the passenger's door and of 72 mm in positive measurement direction. In contrast the pelvis marker showed a higher average maximal displacement in the direction of the driver (74 mm) than to the door (-59 mm).

Lateral chest marker movements in the **evasive manoeuvre to the right** also had on average a higher amplitude in the direction of the door (-106 mm, 85 mm), whereas the maximal lateral pelvis marker displacements were -64 mm and 68 mm. The dummy pelvises tended to move more pronounced towards the inboard direction than observed with the volunteers. However, the maximum dummy amplitude was in the range of the average volunteer amplitude. For the chest displacement the dummy appeared to overestimate average the human displacement (with maximal overestimation in the 5th percentile HIII dummy) followed by Euro SID and 50th percentile HIII dummy. However, the dummies were in both manoeuvers below the maximum volunteer displacement.

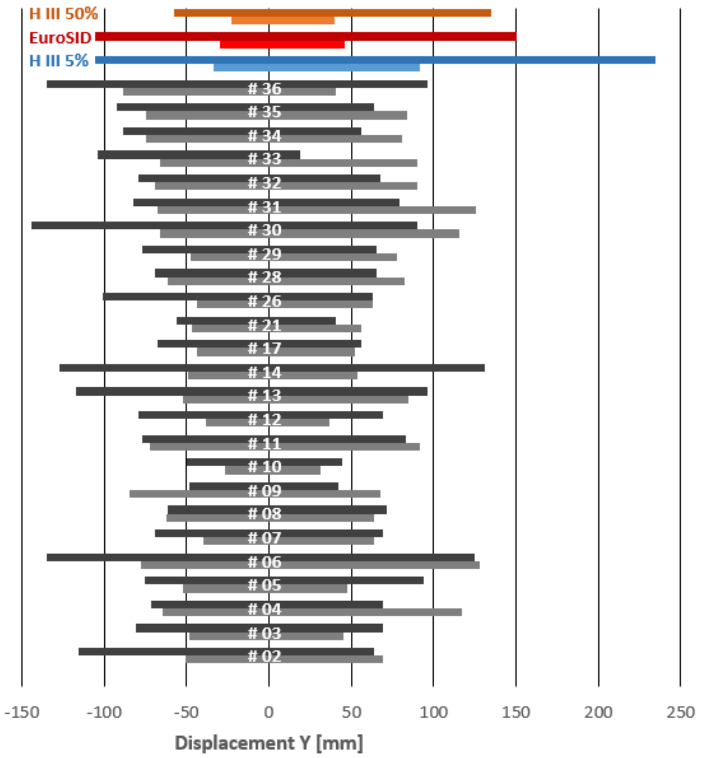


Fig. 15: Maximal lateral displacement of chest and pelvis during evasion to the left (negative values correspond to the right in driving direction while positive values correspond to left in driving direction)

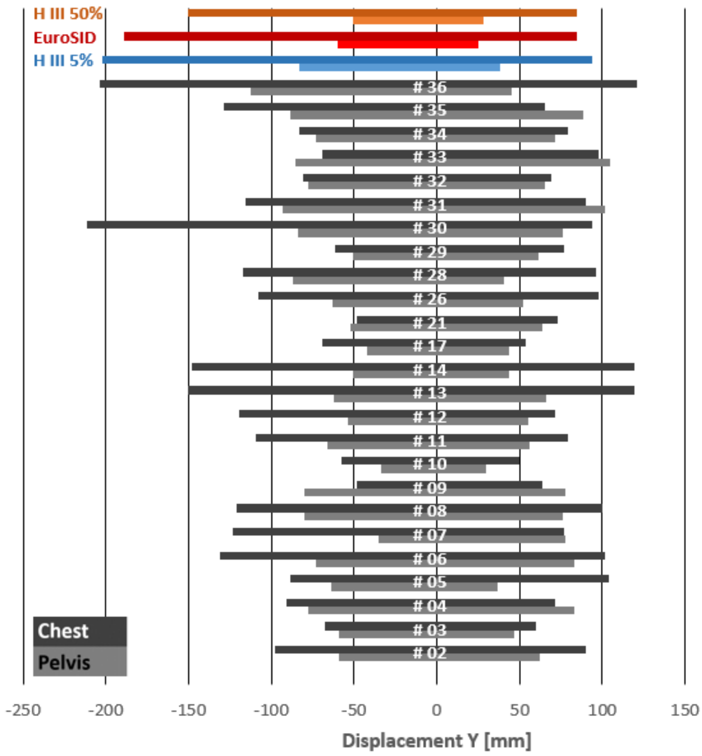


Fig. 16: Maximal lateral displacement of chest and pelvis during evasion to the right (negative values correspond to the right in driving direction while positive values correspond to the left in driving direction)

In the **double lane change to the left** manoeuvre the lateral chest marker movement showed on average a similar maximum in both directions (-69 mm, 74 mm). The average maximal displacement of the pelvis marker was more distinctive in the direction of the driver (-42 mm, 59 mm).

For both directions lateral chest marker movements also showed a similar average maximum (-88 mm, 80 mm) in the **double lane change to the right** manoeuvre. Lateral pelvis marker movement had a higher amplitude in the negative direction (-68 mm, 56 mm).

For both manoeuvres the lateral movement of the dummies' chest and pelvis was in the range of the volunteer's amplitude. Again, the 5th percentile HIII showed the widest displacement range of all three dummies.

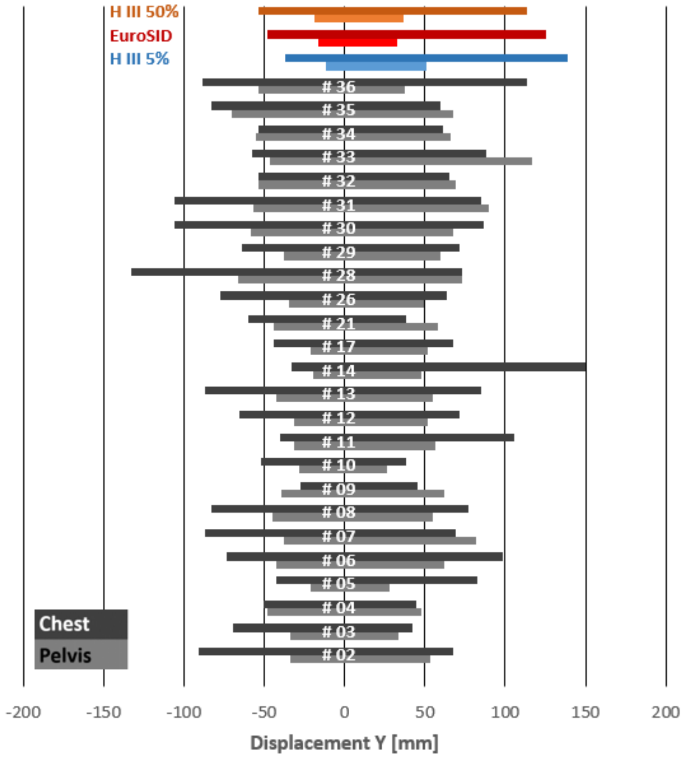


Fig. 17: Maximal lateral displacement of chest and pelvis during double lane change to the left (negative values correspond to the right in driving direction while positive values correspond to the left in driving direction)

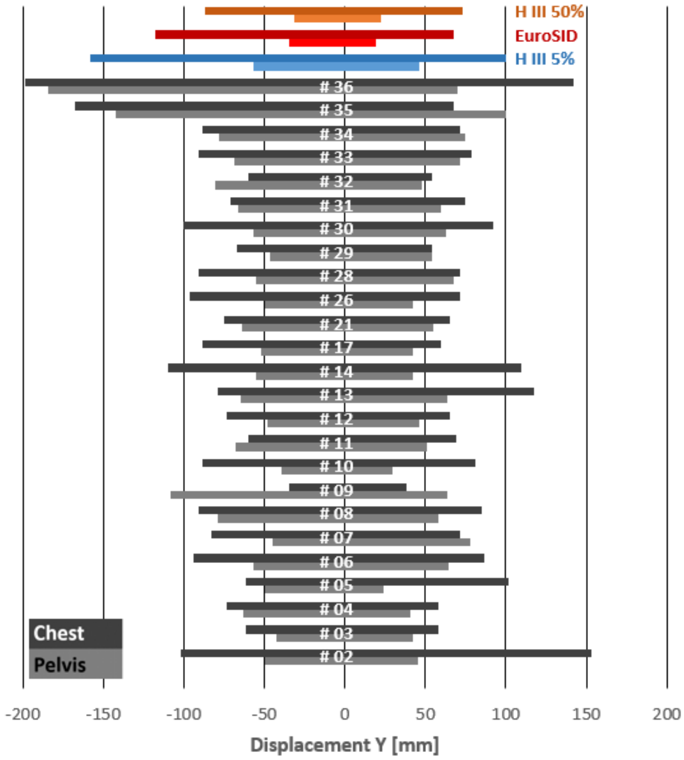


Fig. 18: Maximal lateral displacement of chest and pelvis during double lane change to the right (negative values correspond to the right in driving direction while positive values correspond to the left in driving direction)

In the **slalom manoeuvre** lateral chest marker displacement as well as lateral pelvis marker movement showed on average a higher amplitude in the door direction (chest: -80 mm compared to 58 mm; pelvis: -60 mm compared to 33 mm). All dummies showed a pronounced movement towards the door. The maximal displacement of the 5th percentile HIII dummy in this direction exceeded that of all volunteers.

In the **partial braking** manoeuvre the maximal forward displacement of the passengers' chest ranged from 58 mm to 137 mm and averaged 95 mm. Pelvis marker displacements varied between 6 mm and 33 mm and had an average of 15 mm (Fig. 20).

The average maximal forward displacement of the chest in the **announced full braking** manoeuvre was 134 mm and individual values ranged from 73 to 220 mm. In the **unannounced full braking** manoeuvre the same displacement varied between 76 and 182 mm with a slightly lower average of 125 mm. The amplitude of the maximal forward displacement of the pelvis marker averaged 21 mm and 23 mm in both manoeuvres, respectively (Fig. 21).

In all braking manoeuvres (without evasion) the maximal forward displacements of all dummies were under or at least at the lower limit of the volunteers.

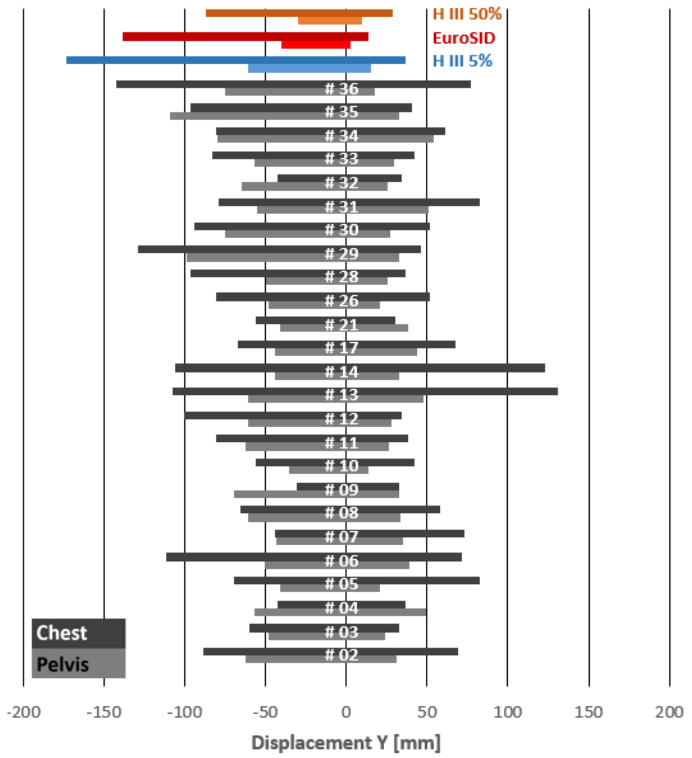


Fig. 19: Maximal lateral displacement of chest and pelvis during slalom manoeuvre (negative values correspond to the right in driving direction while positive values correspond to the left in driving direction)

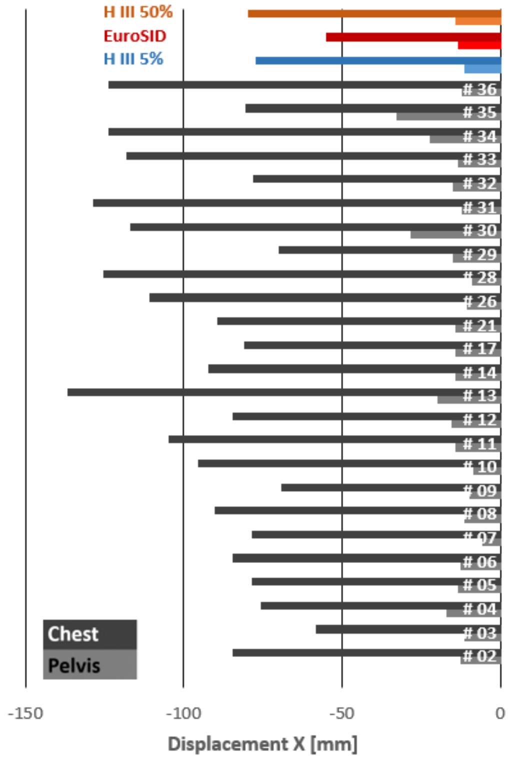
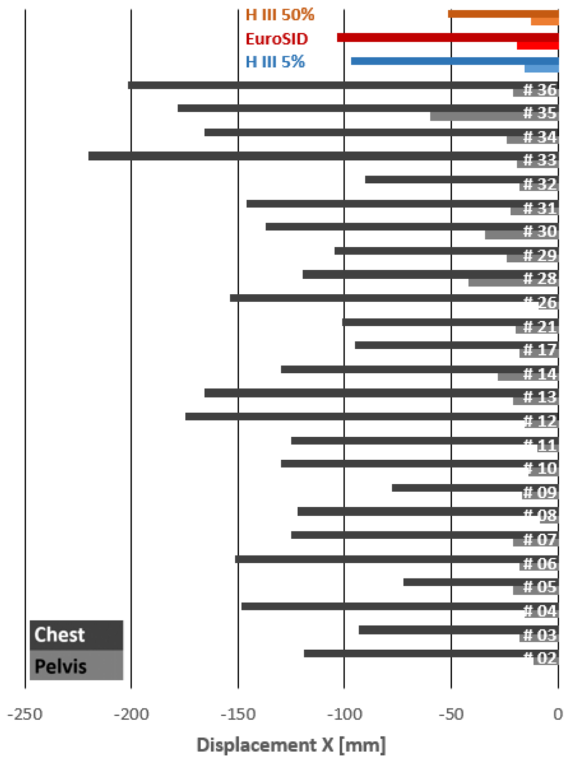


Fig. 20: Maximal forward displacement of chest and pelvis during partial braking (negative values correspond to a movement towards the front)



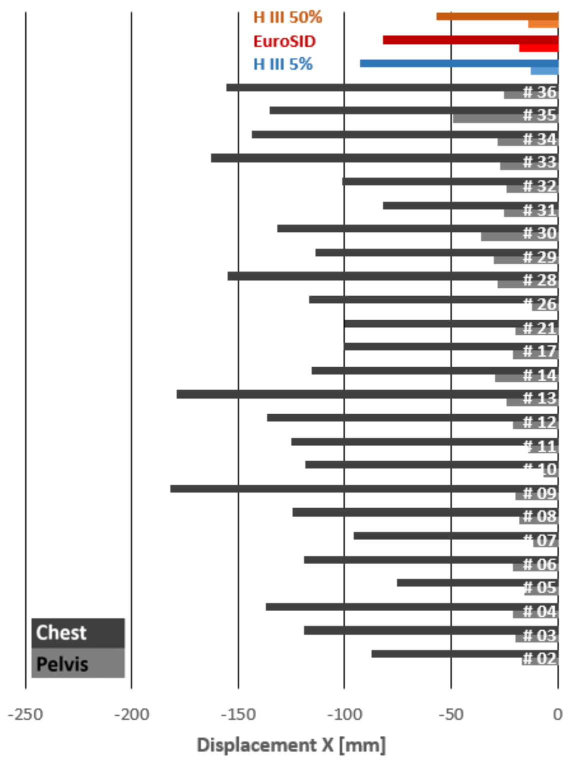


Fig. 21: Maximal forward displacement of chest and pelvis during announced full braking (left) and unannounced full braking (right) (negative values correspond to a movement towards the front)

The average maximal forward displacement showed a similar amplitude for the chest (85 mm) and the pelvis marker (17 mm) in both **partial braking with evasion (left/right)** manoeuvres (Figs 22 and 24). The lateral movement of the chest marker differed widely within the whole study group and showed no specific pattern. Fig. 23 and 25 show the plots of chest marker movement in lateral and vertical direction in both manoeuvres. Average maximal displacements for the chest marker were 41 mm in the manoeuvre to the left and 55 mm in the evasion to the right. Since there is no comparable baseline in volunteer movement, the movement of the dummies was omitted from presentation.

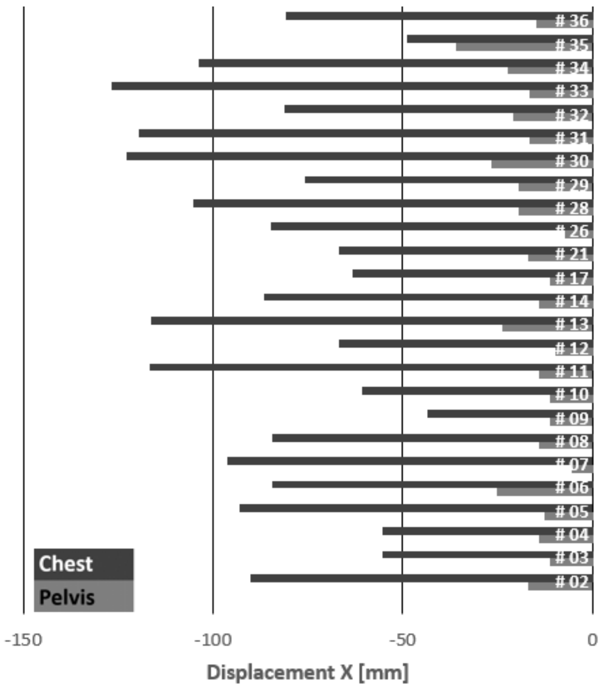


Fig. 22 Maximal forward displacement of chest and pelvis markers during partial braking with evasion to the left (negative values correspond to a movement towards the front)

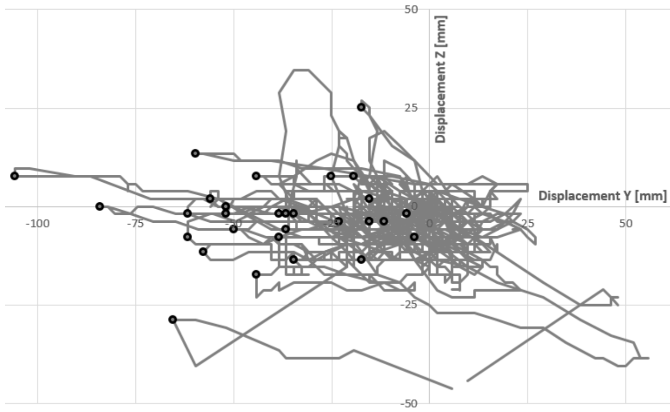


Fig. 23: Plot of lateral and vertical chest movement during partial braking with evasion to the left

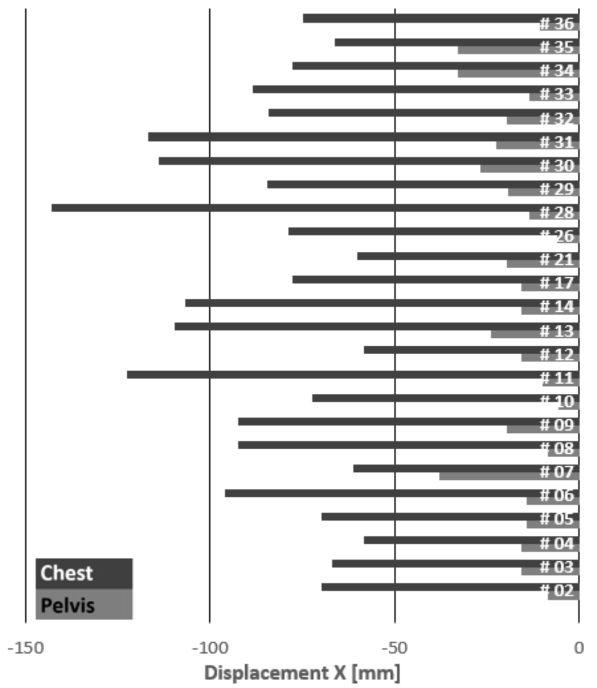


Fig. 24: Maximal forward displacement of chest and pelvis markers during partial braking with evasion to the right (negative values correspond to a movement towards the front)

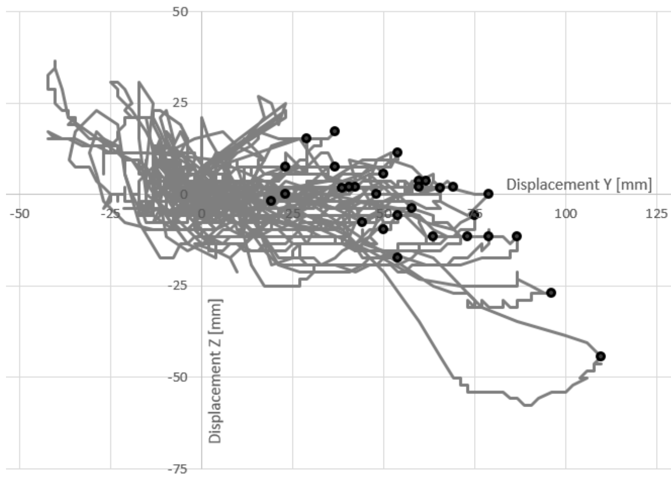


Fig. 25: Plot of lateral and vertical chest movement during partial braking with evasion to the right

The test data were compared with the anthropometric data of the subjects to find possible correlations. Therefore, the chest displacements in the evasive, slalom, partial and full braking manoeuvres (without evasion) were investigated. As presented in Figs. 25 to 28 there was no significant correlation between the maximal lateral chest displacements and the sitting height or the body weight of the subjects in the slalom and evasion manoeuvres. The same is true for the body mass index. However, in the slalom a greater maximal amplitude of the chest in the direction of the door (passenger's right) is visible.

To investigate the impact of the announcement of the manoeuvres, maximal forward displacements of the chest during both full braking manoeuvres were compared (Figs. 29 and 30). As already described above, both results look similar in principle. The announced manoeuvre showed a greater scatter. Therefore the average is slightly higher, because the forward displacement has a minimum.

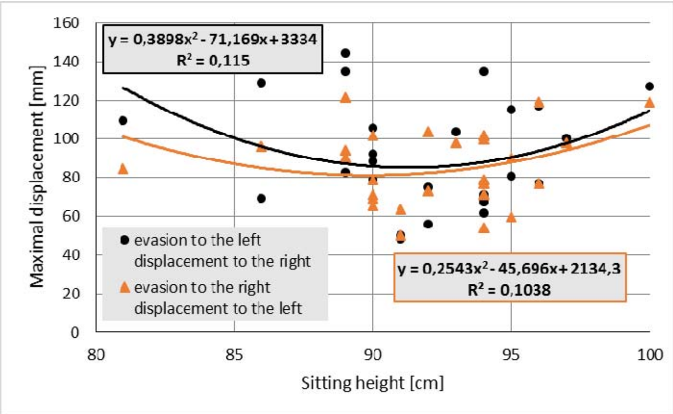


Fig. 25: Maximal lateral displacement of chest markers during evasion as function of subject's sitting height

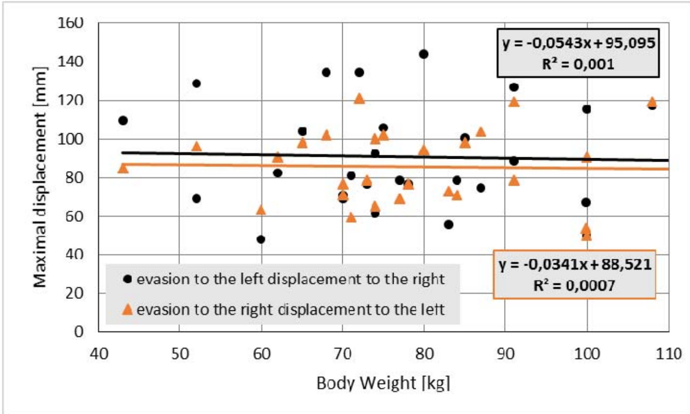


Fig. 26: Maximal lateral displacement of chest markers during evasion as function of subject's body weight

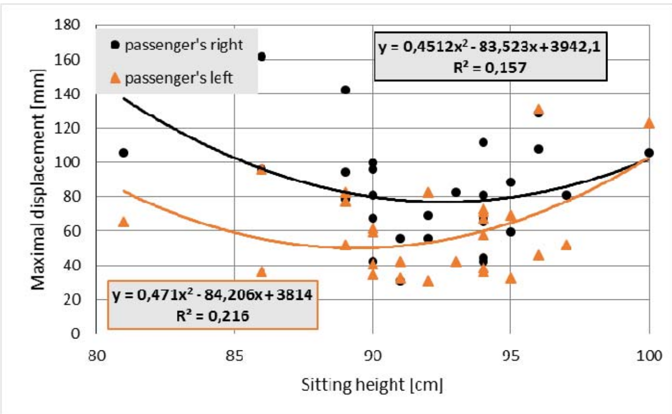


Fig. 27: Maximal lateral displacement of chest markers during evasion as function of subject's sitting height

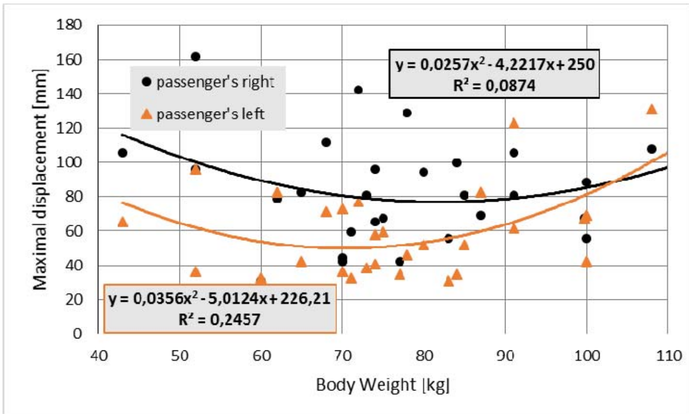


Fig. 28: Maximal lateral displacement of chest markers during evasion as function of subject's body weight

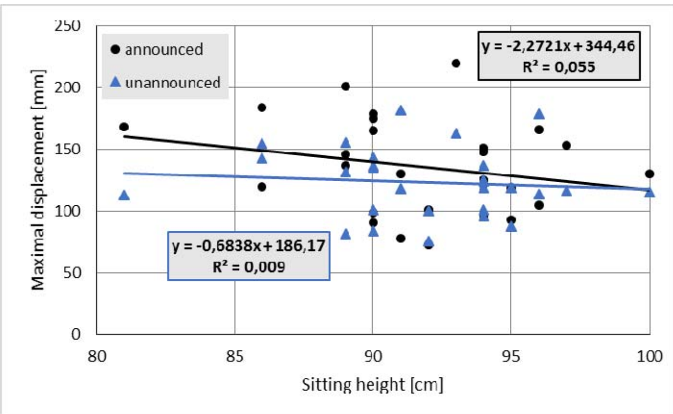


Fig. 29: Maximal forward displacement of chest markers during full braking as function of subject's sitting height

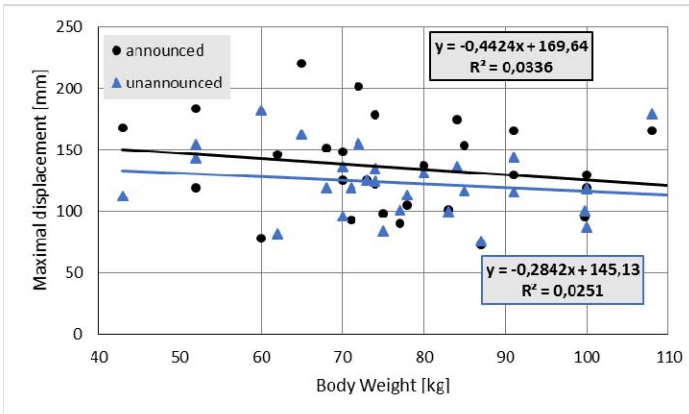


Fig. 30: Maximal forward displacement of chest markers during full braking as function of subject's body weight

The maximal, average and minimal displacements of the volunteers' chest and abdomen are summarised in the following table:

TABLE I
MAXIMAL, AVERAGE AND MINIMAL DISPLACEMENT FOR DIFFERENT DRIVING MANOEUVRES

Manoeuvre	Direction	Displacement [mm] Chest Max	Chest Aver	Chest Min	Pelvis Max	Pelvis Ave	Pelvis Min
Evasion Left	Passenger's right, door	144	88	48	88	59	27
	Passenger's left, inboard	131	72	19	128	74	31
Evasion Right	Passenger's right, door	212	106	48	112	68	34
	Passenger's left, inboard	121	85	50	105	64	30
Double Lane Change Left	Passenger's right, door	133	69	27	70	42	20
	Passenger's left, inboard	150	74	38	117	59	27
Double Lane Change Right	Passenger's right, door	198	88	35	184	68	39
	Passenger's left, inboard	154	80	38	100	56	24
Slalom	Passenger's right, door	142	80	31	109	60	35
	Passenger's left, inboard	131	58	31	54	33	14
Full Braking, announced	Forward	220	134	73	60	21	8
Full Braking, unannounced	Forward	182	125	76	49	23	7
Partial Braking	Forward	137	95	58	33	15	6

IV. DISCUSSION

Observation of pre-crash kinematics currently is mainly focussing on drivers. However, it is obvious that the occupant kinematics is different for driver and passenger due to preparation to the pre-crash manoeuvre initiated by the driver himself and by the interaction with pedals and steering wheel. By addressing the front seat passenger an important step forward is made.

The test data of this study showed considerable scatter between the volunteers that is mainly independent from anthropometry. In general the dummies behaved approximately similar to the volunteers, but they underestimated forward movement and overestimated lateral movement.

All manoeuvres were driven in one complete test drive for human subjects and dummies alike. But unlike the volunteers the dummies did not return to a proper initial seating position. Therefore, the measurement of the displacement from the position at the beginning of each manoeuvre has to be questioned for the dummies. To avoid this effect each driving manoeuvre should be driven separately.

The analysis of the movie data shows that movement of the pelvis is difficult to track in lateral dynamic manoeuvres with the method chosen for this study. The pelvis rotation, which results in a visible displacement of the marker, may corrupt the results. Tracking of both pelvis points may give more satisfactory results. In addition usage of another marker position/device may be appropriate (e.g., fixed at the lap belt).

During the analysis the effect of parallax was not corrected assuming it is negligible in a first approach.

The volunteers were asked to behave normally as they would in other rides as a front seat passenger. Analysis of the data showed that some subjects stabilised themselves using the armrest. It is likely that including such effects in the analysis may give further insight into the topic.

An important limitation of the study is the composition of the volunteer sample. While most injured front seat passengers are female [12], the analysed sample mainly included young males.

V. CONCLUSIONS

The analysed data show a large spread in findings between the subjects, as originally expected. No significant correlation between the volunteers' movements and their anthropometric data was identified. When compared to humans the dummies were mostly within the spread of humans.

The applied methods of measurement and data processing were discussed and improvements were proposed. The data should be tested for its appropriateness in passenger simulation. For future use of the data it is recommended to use maximum, average and minimum displacements.

VI. ACKNOWLEDGEMENT

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