Effects of Seating Position of Short Stature Drivers in Frontal Impacts

Axel Malczyk, Ingo Müller, Stefanie Eßers, Michael Hänsel

Abstract Accident research indicates that small drivers have a higher risk to sustain severe injuries in frontal crashes than mid-sized drivers. This study employed two methods; accident analysis and a survey of drivers' seating positions. Frontal impacts from three different German accident databases were analyzed for belted drivers protected by an airbag. Evaluation of in-depth data focused on severe injuries (MAIS 3+). No major differences in the injury risk and pattern were found between small drivers (up to 170 cm) and taller ones, however based on relatively small case numbers. Analysis of 609 additional frontal crashes compared AIS 2+ injuries in female and male drivers and indicated that females have benefited most from improvements of passive safety. A field study was conducted to determine seat adjustments and seating postures of drivers. The survey included only drivers in small and compact cars. Thirty drivers with a height up to 165 cm and 35 drivers between 175 and 183 cm participated. Short stature drivers sat significantly closer to the steering wheel and the lower instrument panel than those in the control group. Nevertheless, a large variance in seating posture was found even among the group of small drivers.

Keywords frontal crash, gender, injury risk, small driver

I. INTRODUCTION

With the enhanced passive safety of passenger cars over the years, questions arise whether these improvements benefit all groups of occupants similarly. Consequently, some accident research work has been dedicated to the effects of seating position, age and gender on the risk of injury to drivers. Particularly gender and height have been considered as possible factors influencing driver injury pattern and severity. It is generally acknowledged that these two variables, but also biomechanical properties, are correlated with each other.

Dischinger et al. [1] analyzed 1,520 car and truck drivers among U.S. trauma patients between 1987 and 1992 and linked them to police reports for additional crash information. Their focus was on injuries to the lower extremities in frontal crashes. A higher risk for lower extremity fractures was found for women than for men (20 % versus 13 %). When grouping the material by body height, regardless of gender, smaller drivers showed an increased risk of lower leg fractures. Significant differences pertained primarily to ankle and tarsal injuries and belt use was deemed ineffective to prevent them. Since no significant association with vehicle characteristics like size and weight existed it was suspected that the leg position as a function of the seat placement would influence the risk for these injuries.

Bose et al. [2] explored more than 45,000 injured belted drivers in 1998 – 2008 NASS-CDS data (U.S. National Accident Sampling System Crashworthiness Data System) with the objective to determine differences in risk for moderate to serious injury between men and women. Females constituted 43 % of the drivers, being on average 14 cm shorter and 16 kg lighter than males. For women, the odds to sustain MAIS 3+ (Maximum Abbreviated Injury Scale) and MAIS 2+ injuries were 47 % higher and 71 % higher, respectively, than for men when controlling for other factors like age, weight, vehicle body type and crash conditions. For AIS 2+ injuries to the chest and to the spine, the odds were 38 % and 67 % higher, respectively. No details were given regarding lower extremity injuries, especially under frontal impact conditions.

Austin [3] investigated the causation of AIS 2 and AIS 3 lower extremity injuries in frontal crashes and particularly the role of intrusion. The author analyzed NASS-CDS data from 1997 – 2009 on 7,284 belted drivers in vehicles of the model year period 1998 – 2010 after a frontal impact. Women represented 52 % of the drivers.

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Frontal crashes were categorized according to the amount of overlap with the longitudinal rails. Lower leg injuries were defined as including the foot, tibia and fibula and the knee, upper leg injuries as including the femur and the pelvis. Of all drivers in the material, 3.3 % received AIS 2+ injuries to the lower leg and 1.1 % to the upper leg. The multi-variate models developed to control for other factors indicated four to seven times higher odds for female drivers to sustain lower leg fractures and almost two times higher odds for upper leg injuries than for male drivers.

In Europe, Welsh et al. [4] analyzed data of the CCIS (Co-operative Crash Injury Study) in the UK regarding the relationship between stature and injury outcome in frontal crashes of passenger cars. It was hypothesized that smaller drivers adopt a more forward seating position resulting in closer proximity to the steering wheel and instrument panel fascia. Accidents between 1992 and 2001 yielded 1,470 drivers with known height. Females accounted for 35 %. Eight size categories were defined and compared regarding occurrence of AIS 2+ injuries in different body regions. Smaller drivers showed a significantly higher risk for moderate to severe injuries to the head and the lower extremities including the pelvis, but not to the chest and the abdomen and for MAIS. Above-average rates of head and lower extremity injuries were also found in some groups of taller drivers. Approximately one third of the vehicles were equipped with a driver airbag, generally reducing the probability of AIS 2+ head injury. The study also included a survey of seating positions of 100 small drivers in their own car and in a reference car. It was concluded that small drivers have to sit closer to the steering wheel and instrument panel in order to reach the control pedals. This may increase the risk of hard contact with these structures. It was further suspected that small drivers also drive smaller cars which are more susceptible to toepan intrusion in collisions, thus adding to the problem of leg injuries.

Although existing research work provides some concepts of the injury situation for small drivers in frontal crashes the results are not totally consistent. It can be assumed that differences in vehicle population between North America and Europe contribute to diverse pictures of the underlying mechanisms. Similarly, it can be expected that passive safety improvements driven by consumer tests in Europe have changed the conditions for short stature occupants, too.

Our study is intended to examine the injury outcome of short stature drivers in severe frontal impacts of passenger cars in Germany, especially those with up-to-date standards of passive safety and investigate the drivers' seating position and posture in modern vehicles.

II. METHODS

The topic was approached with two methods: An analysis of German accident data from different sources and a survey of seating positions and postures of drivers in their own cars.

Analysis of Accident Data

Three sources of accident data were exploited: GIDAS data (German In-Depth Accident Study) from 1999 to 2010, data from a 2008 prospective study of the German Insurers Accident Research on road users with multiple severe injuries and UDB data (Unfalldatenbank der Versicherer) of the German Insurers Accident Research from 2001 to 2008.

GIDAS collects data on accidents with bodily damage in the regions of Hanover and Dresden according to a sampling plan to ensure representativeness for the whole of Germany. Information is gathered prospectively from on-site investigations. The sample of GIDAS data was controlled for vehicle impact direction, occupant position and seat belt use. More than 7,500 cases of belted drivers in passenger cars involved in a frontal crash (between 11 o' clock and 1 o' clock impact direction) as the major impact were available for initial evaluation.

The study on multiple severe injuries was conducted in a southern region of Germany with a population of 1.32 million, being largely representative for severe accidents on a national level [5]. All road users with an Injury Severity Score ISS ≥ 16 treated in a trauma center were collected prospectively and their crash circumstances determined in collaboration with medical facilities, the police and fire departments between November 2007 and December 2008. Motor vehicle occupants accounted for approximately half of the more than 150 road users who had sustained trauma of this severity.

The UDB database contains data obtained retrospectively from claim files of German motor liability insurers. Since this type of insurance covers only third party claims, single-vehicle accidents are underrepresented. Only cases involving bodily damage and claim costs of at least 15,000 Euros are analyzed, thus including a rather large portion of severe crashes. The sampling procedure and stratification of data ensures that it is representative for injury crashes handled by liability insurers. Since the database includes a relatively small number of cases with known occupant size, it was primarily used to determine gender effects on driver injury risk while controlling for airbag protection. The case selection was restricted to vehicles with a frontal impact (derived from the location of the major damage) with belted drivers (confirmed by technical investigation or self-reported) and with the driver airbag having deployed. Accident data on 609 passenger cars and their drivers was available for evaluation.

Field Study on Driver Seating Position and Posture

Accident data is usually very limited with regards to detailed information about the driver's seating posture. However, this parameter may be important for the injury mechanisms of small drivers. Even if it may prove impossible to document the actual posture adopted by an occupant at the time of the crash, it can be assumed that drivers of disparate height differ also with respect to their seating positions during normal operation of a vehicle. Therefore, a field study was conducted to determine the seating situation of short stature users of modern cars under realistic conditions and to help explain the results from accident analysis.

The general concept of the field study intended to compare an experimental group consisting of short stature drivers and a control group of drivers of average body height. Potential study participants were contacted through various channels. With a brief telephone interview, interested persons were screened whether they matched the study design. The height ranges defining the experimental and the control group were based on existing survey results of the German population. The German Institute for Standardization DIN (Deutsches Institut für Normung) in its standard 33402-2 [6] states that 5 % of men aged 18 to 65 years are shorter than 165 cm and that 50 % of women aged 18 to 65 years are shorter than 163 cm. SizeGERMANY [7], a project to collect representative anthropometric data of the German population for the textile and automotive industry, determined 165 cm as the average height of women between 14 and 70 years of age. Table I gives an overview of the body heights in the German population in comparison with the current anthropomorphic test devices (ATD) used for frontal crash testing.

TABLE I
HEIGHT OF FEMALES AND MALES IN GERMANY, DUMMY HEIGHT

		DIN 33402-2 (2005)	SizeGermany (2009)	Hybrid III dummy theor. erect height
Female	5th percentile			150 cm
	50th percentile	163 cm	165 cm	
	95th percentile	172 cm		
Male	5th percentile	165 cm		
	50th percentile	175 cm	179 cm	175 cm

For the experimental group in the course of this study, 165 cm was chosen as the upper boundary, representing the 50 % limit for females and the 5 % limit for males. The height range of the control group was defined to lie between 175 cm and 183 cm, marking the approximate range of men of average size. In effect, the threshold between short stature and taller drivers was set arbitrarily at 170 cm. The margin of 5 cm to the upper boundary (165 cm) of the experimental and to the lower boundary (175 cm) of the control group was expected to provide a clearer separation between the results for the two groups.

The results of the preceding accident analysis had shown that subcompact and compact cars constituted a large part of the vehicle population involved in injury crashes in general and with female drivers in particular. Therefore, the field study aimed not only at controlling for age, body weight and annual mileage driven by the participants, but also the car models they used. The selection of cars was limited to several generations of one subcompact and one compact model of a German manufacturer, sold between 1997 and 2012. In 2011, both models together had a share of 21 % of new registrations and represented the best-selling car in their segments in Germany [8]. Two of their model siblings offered by a Czech and Spanish manufacturer were also included as they are based on the same platforms and present very similar interior architecture and adjustment features. Models from other manufacturers showed substantial variation in the shape, size and positions of interior components which would have jeopardized the goal of determining differences in individual drivers' seating positions. With these constraints, 30 drivers could be recruited for the experimental group and 35 for the control group. The control group contained 22 men and the experimental group included only one male.

The measurements were taken on the premises of the organization in charge of the field study in Berlin, Germany, and participants were asked to arrive in their own vehicle. Measurements of the driver in the vehicle environment were conducted according to a standard program. The documentation included the position of the steering wheel, the seat and the seat belt height. An overview of all measured variables is provided in Chapter "Results", Fig. 9 and Fig. 10.

Geometrical key variables of the driver's seating position were measured in his or her vehicle relative to interior components. While the individual seating posture and adjustments adopted by the driver were not altered, the left foot was placed on the left footrest for all measurements. The possibilities to determine certain dimensions, like the position of the right leg, were limited to avoid interference with the participant's privacy. The position of key components of the interior, like steering wheel or seat, was documented with the driver outside of the vehicle.

In addition, the participant was photographed on a separate stool to obtain general anthropometric data like proportionate lengths of his or her trunk, arms and legs. After that, the participant completed a questionnaire about the use pattern of the car and his or her perception of the ergonomics and safety of the vehicle. Only then, he or she was informed about the background of the study.

III. RESULTS

Analysis of Accident Data

The three databases were analyzed separately since they employed different methods of case collection. Depending on the available detail information and sample size the focal points of analysis differed.

Analysis of GIDAS Data

Comparison with data on body height [7] and age of licensed drivers [9] showed that the German adult population is quite well represented regarding anthropometry and demography by occupants in GIDAS cases. The distribution of vehicle segments in GIDAS resembles that of the German passenger car fleet [10].

Analysis of GIDAS data focused on the effects of driver height on serious to severe injuries (MAIS 3+) in frontal impacts. Altogether, the material contained 174 cases of belted passenger car drivers with MAIS 3+ involved in all types of collisions, except multi-collisions and roll-overs. Of these, 113 had been in a frontal crash. To address the effect of body height on injury outcome the cumulative frequency of these drivers was contrasted to those without injuries in GIDAS. A slightly higher share of drivers between 165 and 170 cm was noticeable in the MAIS 3+ group (Fig. 1). However, severely injured drivers showed a more pronounced shift towards younger age and especially towards smaller vehicles. Seventy percent of all drivers with MAIS 3+ were found in subcompact and compact cars (Fig. 2). Also, differences in vehicle use depending on driver gender could be observed. About one third each of the uninjured females drove minis or small cars (35 %) and compact cars (30 %). Among uninjured male drivers, 30 % used compact cars, but only 16 % preferred small cars or minis. The percentage of smaller car categories was much higher among the 113 drivers with MAIS 3+ injuries. More than 70 % of the severely injured women had been either in minis or small cars (47 %) or in compact cars (26 %). A similar proportion of men with MAIS 3+ were found in the smaller car categories; 26 % in minis or small cars and 41 % in compact cars.

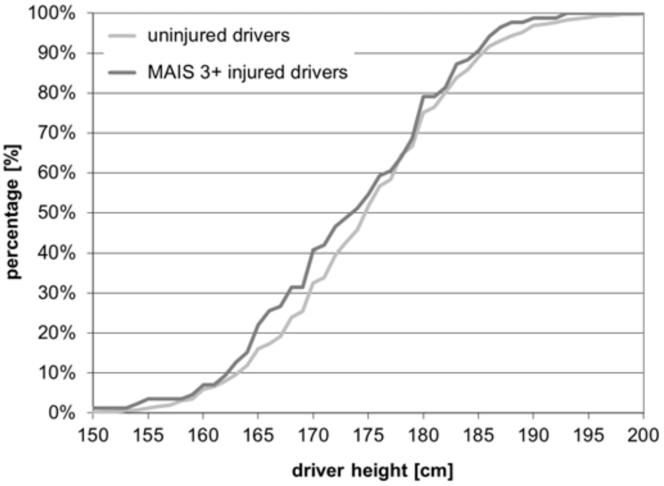

Fig. 1. Cumulative frequency of driver height; uninjured drivers and MAIS 3+ drivers; frontal crash.

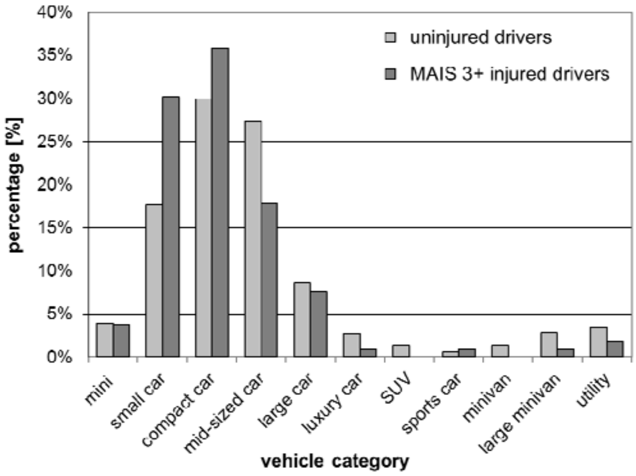

Fig. 2. Distribution of vehicle segments; uninjured drivers and MAIS 3+ drivers; frontal crash.

Due to this predominance of compact and subcompact cars, further analysis of GIDAS data concentrated on these segments. In order to reflect contemporary passive safety, the samples were restricted to vehicles equipped with driver airbags in impacts with a delta v between 26 and 70 kph. In this range of velocity change, one can expect the airbag to deploy, but it excludes cases with total collapse of the occupant compartment. With these additional constraints, 19 drivers with known height remained. The group of small drivers consisted of seven people measuring up to 170 cm (range: 154 – 170 cm, mean: 164.1 cm). Except for one male, all drivers were females. The mean age in this group was 51.0 years. Twelve drivers measured over 170 cm in height (range: 172 – 186 cm, mean: 178.1 cm), forming the group of taller drivers. The group consisted of ten men and two women and displayed a mean age of 45.9 years. Fig. 3 gives the distribution of all documented injuries (excluding AIS 1) sustained by the two groups according to their AIS level. The chart shows a higher percentage of severe injuries in smaller drivers whereas both groups displayed similar numbers of injuries per driver (4.7 per small driver and 4.3 per tall driver, on average). Fig. 4 depicts which body regions were primarily affected by injury severities of AIS 2+. Altogether, AIS 2+ severity levels are found most frequently in the lower extremities and the thorax while they appear to be rather uncommon in the head region. The black vertical marks in the chart indicate the theoretical distribution of small drivers and taller drivers that could be expected if it were solely based on their proportion (ratio 7 : 12) among the 19 drivers. The diagram suggests, though on the basis of small case numbers, that short stature drivers may be proportionately overrepresented regarding AIS 2+ injuries in the spine and the lower extremities, but underrepresented in the thorax.

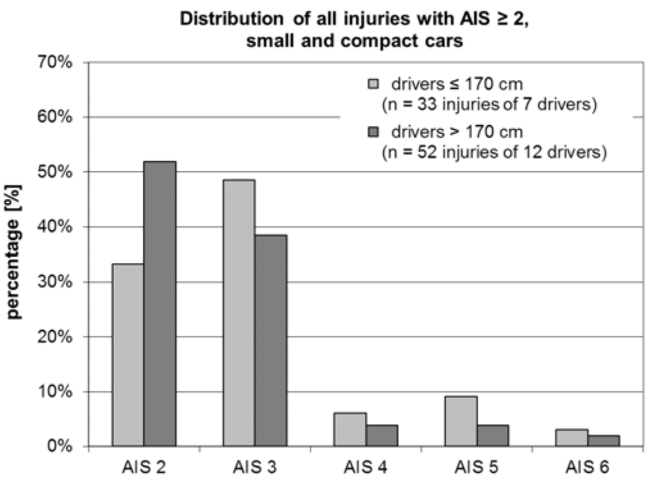

Fig. 3. Distribution of all injuries with AIS ≥ 2; drivers with MAIS 3+ in frontal crashes of subcompact and compact cars.

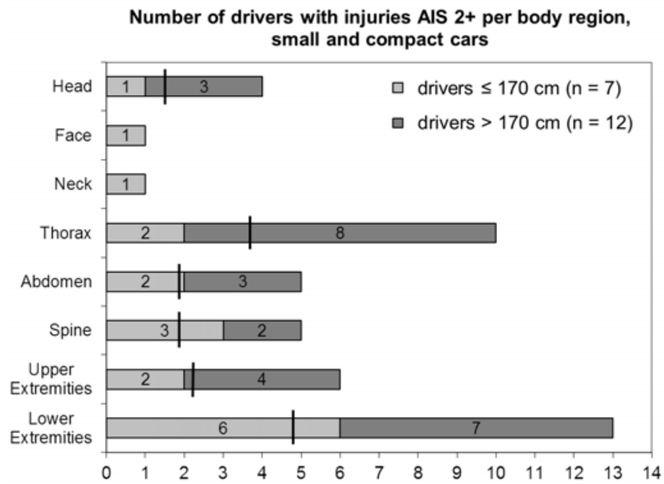

Fig. 4. Number of AIS 2+ injury levels per body region; drivers with MAIS 3+ in frontal crashes of subcompact and compact cars.

Analysis of Data on Multiple Severe Injuries

The database of road users with multiple severe injuries provided 14 cases after employing the same criteria as the previous GIDAS analysis (frontal crash, belted driver, MAIS 3+, driver airbag deployment). The case selection, however, was not limited to subcompact and compact cars, but included all types of passenger cars. Eight drivers, all of them females, were up to 170 cm tall (range: 162 – 168 cm, mean: 162.6 cm), thus representing the small driver group. The mean age in this group was 48.5 years. The six members of the tall driver group with a height over 170 cm were all males (range: 175 – 185 cm, mean: 180.0 cm). Averaging 29.8 years, they were not only considerably younger than the small drivers, but also younger than the taller drivers in the GIDAS data. When all documented injuries (excluding AIS 1) in the two groups are considered (Fig. 5), the case material from the study on multiple severe injuries delivers almost the opposite picture of the GIDAS analysis (see Fig. 3). Here, small drivers with MAIS 3+ displayed a smaller percentage of serious to severe injuries than the taller ones. It has to be noted that the limited number of cases makes analysis sensitive to relatively small variation in the accident material. For example, the injuries of two short stature drivers accounted for half of the AIS 2 spine injuries and AIS 2 lower leg injuries, respectively, in the small driver group. The average numbers of injuries per driver (4.1 per small driver and 5.0 per tall driver) in the case material were similar to the GIDAS data.

When the drivers are evaluated by the occurrence of AIS 2+ severity levels in the different body regions (Fig. 6), there are similarities with the results of the GIDAS analysis (see Fig. 4). In both data sets, AIS 2+ injury levels are found most frequently in the lower extremity and the thorax region, whereas AIS 2+ head injury appears to play a smaller role. The data from the study on multiple severe injuries does not indicate a higher vulnerability of small drivers in comparison with the taller ones when judged by their proportion (ratio 8 : 6) among the 14 cases.

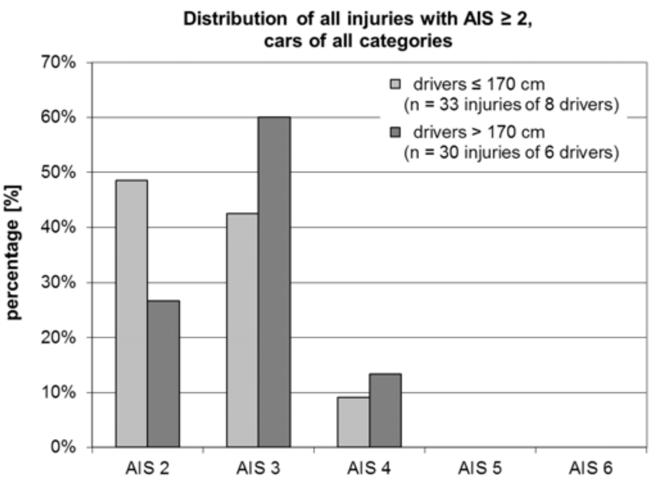

Fig. 5. Distribution of all injuries with AIS ≥ 2; drivers with MAIS 3+ in frontal crashes of cars of all categories.

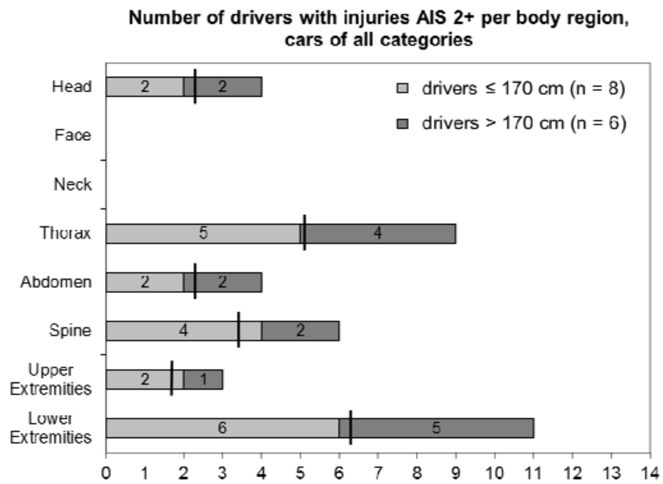

Fig. 6. Number of AIS 2+ injury levels per body region; drivers with MAIS 3+ in frontal crashes of cars of all categories.

Analysis of Data from Insurers Accident Database (UDB)

The injury outcome for belted drivers of passenger cars in frontal impacts was also examined with data from the German Insurers Accident Research database (UDB). Here also only vehicles with deployed driver airbags were selected to ensure a contemporary level of passive safety on the one hand and a minimum crash severity on the other hand. Discrimination by body height proved difficult because this information is rarely provided in the documentation. Instead, the drivers were grouped by gender since women are usually shorter than men, on average. The frequencies of injuries were determined for the body regions of 609 drivers of passenger cars of all categories. Cases were categorized as involving either no or minor injury (AIS 0 – AIS 1) or moderate to severe injury (AIS 2+) in the respective body region. Fig. 7 shows that female drivers sustained a higher percentage of AIS 2+ injuries to the head, the pelvic region, the legs and the feet. Males, however, displayed a slightly higher percentage of AIS 2+ injuries to the thorax. The differences were not statistically significant on a p-level of 0.05

though the difference in foot injury came close to that.

In order to determine a possible bias in the data, selected characteristics of female and male drivers and their vehicles were compared where the respective information was available (Table II). On average, men were 5.2 years older, 9.9 cm taller and weighed 15.8 kg more than women. These results are roughly in line with general anthropometric data. Cars driven by women and men were of nearly the same age, derived from the year of first registration, but differed regarding curb weight. Females drove cars that were 126 kg lighter on average than those driven by males. Since there were no substantial differences in mean vehicle age these were likely models that belonged to smaller vehicle segments like subcompacts or compacts.

TABLE II
CHARACTERISTICS OF DRIVERS AND THEIR VEHICLES IN INSURERS' DATA

		Male		Female	
		417	n = …	192	n = …
Driver	Age (mean ± std.) [yrs.]	44.8 ± 17.0	405	39.6 ± 15.6	188
	Height (mean ± std.) [cm]	177.6 ± 6.1	31	167.7 ± 8.3	24
	Weight (mean ± std.) [kg]	84.1 ± 12.1	28	68.3 ± 13.0	24
Vehicle	Curb weight (mean ± std.) [kg]	1,335 ± 275	212	1,209 ± 287	107
	Year of Registration (mean ± std.)	2000.2 ± 3.8	304	2000.8 ± 3.7	144

In the second step, the analysis of injury data was repeated, but this time the involved cars were additionally grouped by age. By the mid and end of the nineties, frontal protection of new car models was brought forward by European legislation (ECE-R 94, Economic Commission for Europe, Regulation 94) and particularly by the EuroNCAP consumer test program (European New Car Assessment Program). To account for this influence, vehicles in the case material were distinguished by the year of their first registration. Cars that were registered before or in 2000 (range: 1988 – 2000, median: 1997) were presumed to consist primarily of models developed and introduced to the market before EuroNCAP testing. Vehicles registered in 2001 or later (range: 2001 – 2008, median: 2003) were assumed to reflect already efforts to fulfill EuroNCAP's requirements. Fig. 8 shows the percentage of MAIS 2+ injured male and female drivers within each of the two vehicle registration groups.

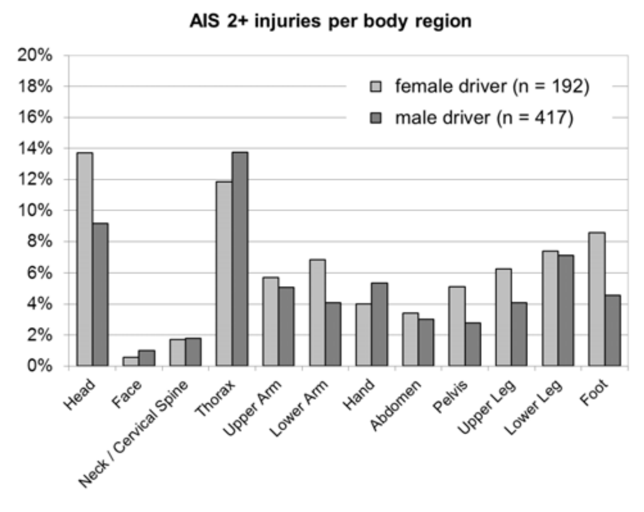

Fig. 7. Percentage of AIS 2+ injuries per body region for female and male drivers; frontal crash.

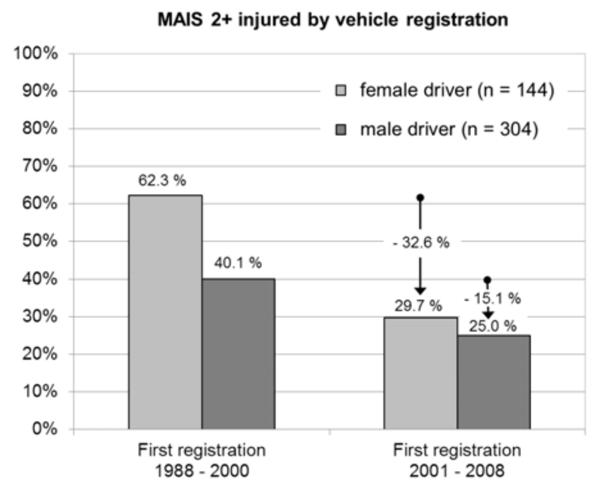

Fig. 8. Share of MAIS 2+ injured among female and male drivers in cars registered 1988 – 2000 and 2001 – 2008; frontal crash.

In cars which were registered until 2000, female drivers had a significantly higher risk of MAIS 2+ injury than males (p < 0.01). Overall, the percentage of drivers with MAIS 2+ injuries declined remarkably in cars registered after 2000. However, with a reduction by 32.6 % this effect was greater for women than for men (- 15.1 %). The remaining differences in risk of moderate to severe injury between the two genders were not significant in the group of vehicles with registration from 2001 on.

Field Study on Driver Seating Position and Posture

The drivers in the experimental group displayed a mean body height of 162 cm as opposed to 179 cm in the control group. Members of the experimental group were slightly older (mean age: 45.9 years) than those in the control group (mean age: 42.7 years). Measurement of the seat and control adjustments chosen by the participants and their seating posture in the car revealed several differences between the two groups. Details of the measured parameters are provided in Fig. 9 and Fig. 10 and in Table III.

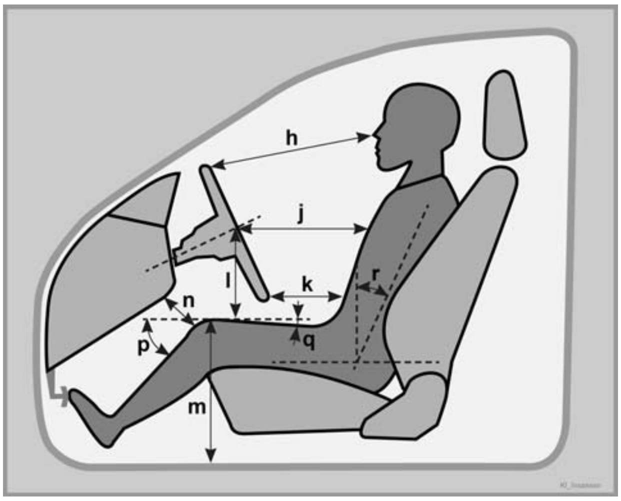

Fig. 9. Key dimensions of the driver in the vehicle environment.

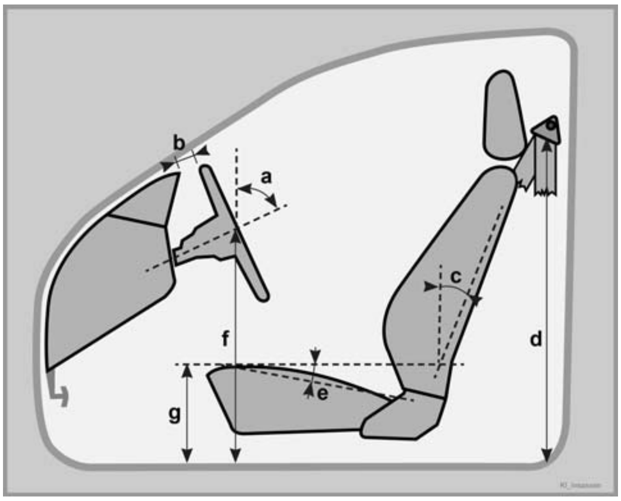

Fig. 10. Key dimensions of vehicle components.

When measured in their own cars, the smaller participants were sitting closer to the steering wheel and the instrument panel. On average, their head was closer by 6.2 cm (nose to upper steering wheel rim) and their abdomen was closer by 7.8 cm (abdomen to lower steering wheel rim) to the steering wheel than in the group of taller persons. The distances of the knees to the lower instrument panel fascia differed by 2.5 cm. All these differences were highly significant (p < 0.001). While short stature drivers positioned their thighs at distinctly smaller angles than taller drivers (p < 0.001), the lower leg angles did not differ significantly between the groups. The torso was more leant back by 4 degrees in the experimental group (p = 0.02). However, the measured torso angles should be regarded rather as relative values between the two groups than absolute values since they were determined indirectly from superimposing the contours of a small female ATD over side view photos of the driver in the car. The adjustments of the seat back, steering wheel and shoulder belt anchorage point were quite similar, however. The seat height adjustment was set 2.0 cm higher by the smaller participants (p < 0.001). Nevertheless, the experimental group displayed a considerable variation regarding the seating postures of individual drivers (Fig. 11 and Fig. 12). In general, it appears that short stature drivers do not adjust the seat back, control elements and seat belt height much differently than the average driver, being 179 cm tall. However, they adopt a more stretched posture which is reflected in a flatter upper leg position and a slight forward position of the buttocks. This may be motivated by the necessity to reach the pedals while maintaining an acceptable distance to other control elements. When asked about their satisfaction with the ergonomics, 40 % of the participants in the experimental group and 26 % in the control group rated the conditions as not optimal.

TABLE III
MEASUREMENTS OF SEATING POSITION IN EXPERIMENTAL AND CONTROL GROUP

Measure	Experimental group (mean ± std.)	Control group (mean ± std.)	p-value
a: Steering column angle [°]	64.3 ± 1.5	64.7 ± 1.7	n.s.
b: Steering wheel rim to instrument cluster hood [cm]	6.3 ± 1.7	6.9 ± 2.4	n.s.
c: Seat back angle [°]	22.2 ± 5.8	22.1 ± 5.5	n.s.
d: Floor to shoulder belt anchorage (belt height) [cm]	87.9 ± 3.9	89.7 ± 4.7	n.s.
e: Seat cushion inclination [°]	14.9 ± 3.2	17.1 ± 2.9	n.s.
f: Steering wheel center to floor [cm]	68.5 ± 3.2	68.3 ± 2.0	n.s.
g: Floor to seat cushion surface (seat height) [cm]	32.2 ± 2.0	30.2 ± 2.0	p < 0.001
h: Nose to steering wheel rim [cm]	41.6 ± 5.3	47.8 ± 4.1	p < 0.001
j: Thorax to steering wheel center/ airbag cover [cm]	35.2 ± 5.3	41.9 ± 4.1	p < 0.001
k: Abdomen to steering wheel rim [cm]	19.7 ± 4.5	27.5 ± 5.0	p < 0.001
l: Steering wheel center to left upper leg [cm]	25.7 ± 2.1	23.1 ± 2.4	n.s.
m: Knee to floor [cm]	45.2 ± 2.9	47.5 ± 3.2	n.s.
n: Knee to lower instrument panel fascia[cm]	12.3 ± 4.0	14.8 ± 3.4	p < 0.001
p: Lower leg angle [°]	49.6 ± 5.7	47.9 ± 5.7	n.s.
q: Upper leg angle [°]	6.7 ± 6.5	13.4 ± 6.1	p < 0.001
r: Torso angle [°]	22.9 ± 8.0	18.7 ± 4.1	p < 0.02
Angle between torso and upper leg [°]	106.2 ± 9.4	92.3 ± 7.4	p < 0.001

Fig. 11. Small driver (153 cm) with forward posture.

Fig. 12. Small driver (164 cm) with rearward posture.

IV. DISCUSSION

Several scientific publications have addressed the issue of higher injury risk for small drivers in frontal crashes in the past. It is well known that body size is closely interconnected with gender. On the whole, women are 14 cm shorter than men in the German adult population, though both gender groups have been growing in size over the past decades [7]. It has remained largely unclear whether the fact of being smaller in size – and lower in weight – or being a woman is of more importance. Our study was not able to answer this question conclusively.

Most previous studies that looked at the injury risk for small drivers used primarily material at MAIS 2+ level. It may be speculated that a large portion of these injuries were rather simple fractures of the extremities, the rib cage and concussions. As airbag equipment was just on the rise, research work from the nineties included only a small portion of cases with airbag deployment. In the first part of our accident analysis, we used in-depth data of MAIS 3+ injured drivers and constrained the material not only to frontal crashes and belted drivers, but also required a deployed driver airbag in order to include only cases with contemporary passive safety equipment. The comparably few cases with known height of the driver that German in-depth databases could provide are the strongest limitation of our study.

Therefore, the second part of accident analysis used larger scale data from the German Insurers Accident Research database UDB. The scope was widened to look at AIS 2+ injuries among all frontal car crashes while retaining the previous constraints, like driver airbag deployment. Due to the lack of data on body height in most cases, drivers were discriminated by gender, thus indirectly comparing two groups of drivers that differed by approximately 10 cm in height. The inadequacy to account for body height of the drivers and the suspected higher vulnerability of women represents another limitation of the accident analysis part of our study.

Nevertheless, real-world accident data provided some interesting aspects. The material of 19 drivers from GIDAS and 14 drivers from the prospective study on multiple severe injuries indicates that lower extremity fractures and chest injuries are the dominant AIS 2+ injuries sustained by MAIS 3+ drivers whereas head injury appears to play a smaller role. However, no clear differences in injury risk between small drivers (up to 170 cm) and taller drivers could be identified and therefore no statistical significance established.

Earlier studies, for instance McFadden [11] in a survey of driver seating positions, stressed the higher risk of head injury for small drivers. It was hypothesized that short stature drivers would have a higher risk of a head strike because of closer proximity to the steering wheel. Welsh et al. [4] reported an increased risk of AIS 2+ and AIS 3+ head injury for small drivers. However, this pertained particularly to those of very short stature (up to 160 cm) and lacking airbag protection. The minor importance of head injuries in our material of drivers with MAIS 3+ suggests that airbags were able to prevent many such injuries. In the insurers' material of frontal crashes with driver airbag deployment female drivers displayed a higher risk of AIS 2+ head injury than males, however on a low level.

Our accident analysis demonstrates the great importance of thoracic injuries as these ranked second in frequency both in the MAIS 3+ cases and among the AIS 2+ injuries in the UDB material. However, the data showed no significant difference in the probability of thorax injuries between small and taller drivers and female and male drivers, respectively. At most, the data suggested a slight trend towards fewer AIS 2+ thoracic injuries in women. Welsh et al. [4] could not identify differences in thorax injury risk between small and taller drivers, either, and Frampton et al. [12] in their study of serious injuries in post-EuroNCAP cars showed a slightly, however not significantly, higher percentage of serious thorax injury in male drivers.

It may be speculated that modern protection systems with airbags, assisted by seat belt pretensioners and force limiters, provide an early restraint, yet with distributed loads, especially for smaller occupants who sit closer to the steering wheel. This might help explain that the risk of thoracic injury did not seem to be elevated in small drivers or female drivers, respectively.

Advanced seat belt and driver airbag technology is less efficient in reducing the injury risk of the lower extremities. Welsh et al. [4] determined a significantly higher risk for the pelvis and the legs for drivers up to 155 cm, and Frampton et al. [12] reported a significantly higher percentage of females among drivers even in cars that entered the market after the implementation of EuroNCAP. The MAIS 3+ case analysis in the course of our study supports these findings. AIS 2+ injury levels were found most frequently in the lower extremity region. When broken down by pelvic, upper and lower leg and foot region in the evaluation of AIS 2+ cases in UDB, female drivers consistently presented a higher injury risk than males. There was a marked difference in risk of foot injury. In the early nineties, Dischinger et al. [1] had identified ankle/tarsal injuries as the most frequent type of lower extremity injury which were associated particularly with short stature drivers. Injuries to the legs, the feet and the pelvis are more likely when compartment intrusion in the area of the toepan and the lower instrument panel occurs. Smaller cars are more prone either to compartment intrusion or to high vehicle deceleration due to their lower mass and shorter crush space. Compact and subcompact cars not only represent a large portion of the vehicle fleet in Germany, but they are especially popular among women. Our study showed that these types of cars are particularly prominent when serious or severe injuries occur. This aspect should be taken into account when the injury risk for body regions, like the lower extremities or the pelvic area, is discussed.

Nonetheless, also small cars have improved in passive safety substantially since the introduction of consumer crash test programs. The UDB data demonstrated that vehicles which entered the market after implementation of EuroNCAP are associated with a lower risk for AIS 2+ injuries for their drivers than pre-EuroNCAP models. Female drivers appear to have benefited even more than males from this development and meanwhile have a comparable risk when assessed by the proportion of MAIS 2+ injuries. This is striking because EuroNCAP to date has been using only the mid-size male ATD on the front seats. This hypothesis surely needs scrutiny and confirmation on the basis of more data, but it would help in explaining deviations from study results from the nineties and early 2000's which reported relatively clear differences in injury risk between genders or small and taller drivers, respectively.

The field study conducted in the course of this project confirmed that short stature drivers adopt a different position than taller users. Similar to results of previous studies, i.e. by McFadden [11], it was found that short-stature drivers adopt a position closer to the steering wheel and the lower instrument panel fascia. This is mostly determined by the need to reach all controls while maintaining a certain level of comfort. However, the individual postures vary substantially and upright positions of the torso can be found as well as slouched positions. The positions of the lower legs are quite similar due to the fixed position of the control pedals. However, a large variety of interior architectures and designs can be found among car manufacturers and car models. These differences can easily mask the actual differences in seating positions of individual drivers. It is therefore recommended to conduct analyses of seating postures only in very similar vehicle models.

Most modern cars apparently provide the adjustment possibilities to provide an acceptable level of safety and comfort for drivers of short stature. However, the survey among the participants of the field study revealed that not all of these features are known or used by them.

V. CONCLUSIONS

Determining differences in injury risk between short stature and taller drivers in frontal crashes remains difficult, not least because of the small numbers available from real-world accidents. Moreover, it is not clear to which degree this would be caused by the seating position or an intrinsic higher vulnerability of small people.

Women constitute the overwhelming portion of short stature drivers. As small cars enjoy popularity particularly among women, but have an increased risk to sustain high vehicle deceleration or compartment intrusion in an accident, future analysis of injuries of small drivers or female drivers should ideally take into account not only the passive safety level, but also the size of the involved vehicle.

The field study conducted in the course of the present project indicated that many modern cars provide features, like seat height and steering wheel adjustment, to facilitate a safer and more ergonomic position also for this group of users. However, the large variety of seating postures found – often unfavorable for optimal occupant protection – demonstrates that adjustment of the seat and the steering wheel is often a compromise between crash safety and ergonomics. The pure necessity to be able to operate the control pedals governs how small drivers sit in their cars, though some of them do not seem to be aware of all adjustment possibilities that are provided. Adjustable pedals which have been available on a few car models have the potential to increase comfort and safety as they would allow a seating position for short stature people that is much closer to that of the average user.

Modern cars in Europe appear to have improved in frontal protection particularly for female drivers although the small female dummy is not yet incorporated in the test suites. This may be a result of enhanced structural integrity of the vehicle as well as of improved interior and restraint system lay-out. It would therefore be interesting to explore which test requirements or safety improvements have had the largest effect.

VI. References

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