The Increasing Role of SUVs in Crash Involvement in Germany

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Abstract Like in many other western countries, the number of Sport Utility Vehicles (SUVs) in Germany is increasing. This study investigated their involvement in injury crashes based on national statistics and data from liability insurers. In addition, SUV driver attitude and self-reported driving behavior was determined in two surveys. Almost parallel to the growth of the SUV share in the car fleet, their accident involvement has increased. The SUV driver population is less accident-prone than that of conventional cars, but SUVs have a higher risk exposure due to higher annual mileage. SUVs are underrepresented in single-vehicle accidents, but demonstrate a threat to occupants of passenger cars in two-vehicle crashes. The lack of compatibility becomes evident particularly in frontal collisions. This must be attributed not only to the larger mass, but also to the raised front structure and younger vehicle age of SUVs. Pedestrians who were struck by SUVs did not demonstrate a significantly higher injury risk than in accidents with conventional cars.

Keywords Sport Utility Vehicle, accident data, national statistics, compatibility, pedestrian

I. INTRODUCTION

Sport Utility Vehicles (SUVs) have seen a rapid increase in sales not only in North America, but also in other regions, like Europe, where their share among new cars reached 8.7 % in 2010 [1]. With a growing number of such vehicles on the road, public criticism was raised, too. Higher fuel consumption than conventional passenger cars has been cited as one downside. Regarding their impact on road safety, it is contended that SUV drivers display a more aggressive behavior in traffic and that SUV structures lack crash compatibility in collisions with other cars and put pedestrians at a higher injury risk due to their raised vehicle front.

Fredette et al. [2] analyzed police-reported two-vehicle accidents with approximately 334,000 injured drivers in Canada between 1993 and 2001. They found an increased risk for injuries leading to hospitalization or death for car drivers when the crash opponent was an SUV or a pickup vehicle.

Keall and Newstead [3] evaluated the effect of sport utility vehicles on road safety in New Zealand in comparison to other groups of passenger cars. They matched files from injury crashes in 2005 and 2006 with characteristic data of vehicles and owners, like gender, age and whether living in rural or urban regions, to draw conclusions about the driving behavior. When controlling for exposure, the results showed that SUVs had the lowest crash rates and injury rates per vehicle. However, medium sized SUVs were overrepresented in rollover crashes.

In the Netherlands, Margaritis et al. [4] analyzed 650 SUV accidents with injuries or fatalities, most of them based on the national accident statistics of 2001 and 2002, and compared them to passenger car accidents as a control group. Of 192 collisions between an SUV and a car, 45 % were rear-end collisions, 40 % were side impacts and 12 % were frontal collisions. From the results, it was concluded that the risk for fatal or serious injury is significantly lower for SUV occupants than for occupants in the opponent car. Mass was seen as the most relevant factor for self-protection, regardless of vehicle category.

IMPROVER [5], an EU research project completed in 2006, aimed at determining the impact of new vehicle concepts, namely SUVs and multi-purpose vehicles (MPVs), on safety and the environment. Among other activities, accidents between SUVs and other passenger cars were extracted from national statistics of the United Kingdom, Sweden, the Netherlands and Germany. Various statistical years between 1998 and 2004 and six passenger car categories (including SUV and MPV) were analyzed regarding the outcome for their

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occupants. While SUVs were found to have a higher risk of single-vehicle rollovers, the risk for serious injuries of their occupants appeared to be similar to other cars in single-vehicle accidents in general. In comparison with conventional cars, SUVs were associated with higher injury severity both for occupants of cars and for riders of motorized two-wheelers. For pedestrians, accidents in Sweden showed a higher injury risk from SUVs, but data from the other three countries provided no such indication.

The influence of different vehicle front designs on injury patterns and severity in pedestrians was investigated by Roudsari et al. [6]. Approximately 540 cases collected in the U.S. between 1994 and 1998 in which pedestrians had been struck by the front portion of passenger cars, vans or light trucks (LTVs) including SUVs were available. After adjusting for impact speed and pedestrian age, LTVs and vans both showed three times higher odds for severe injury (MAIS 4+) than passenger cars, but only collisions with LTVs had a 3.4 times higher risk for death compared with passenger cars.

Thomas and Walton [7] conducted a survey among 570 car and SUV drivers in New Zealand by means of mailed questionnaires focused on the perception of vehicle safety and self-reported safety-related driving behavior. On average, SUV drivers traveled greater distances annually and drove younger vehicles than car drivers. There were indications that SUV drivers behaved less safety-conscious in traffic, e.g. regarding cell phone use when driving.

Although most studies on safety issues related to SUVs in road traffic accidents point in the same direction, there appears to be no common understanding of the accident involvement of these vehicles, the associated injury risks for SUV passengers and crash opponents and their causation. This may in part be due to diverse compositions of car fleets and use patterns across the world. For instance, many SUVs in North America used to share their chassis with pickup trucks and tend to be larger than in most European countries. The definition of small, medium and large SUVs, as found in some studies, may therefore vary between different markets. In addition, the designs and the safety of SUVs have changed considerably over the last years and new vehicle concepts, e.g. marketed as “sports activity vehicles” or “crossovers”, have been introduced that combine limited off-road capabilities like increased ground clearance with characteristics of minivans or life-style cars. A common definition of what constitutes a sport utility vehicle does not exist and most related accident studies do not provide tangible criteria to differentiate this segment from conventional passenger cars. Often, the categories set up by the manufacturers are adopted. Hence, caution should be exercised when applying research results from one country to another.

The objective of our study was therefore to describe the role of sport utility vehicles in accidents in Germany based on more recent data and to provide an assessment of the impact on road safety. Furthermore, it is desirable to determine whether any potential threats result from vehicle characteristics or rather the way SUVs are used by their drivers, especially in comparison to conventional passenger cars and their users.

II. METHODS

Definition of SUV

Any subsequent data collection and analysis in the course of the present research should be based on an unequivocal definition of a sport utility vehicle and employ objective criteria which are useful for accidentology. While the German central vehicle registry (Kraftfahrt-Bundesamt) sorts newly-registered cars by categories, including an “off-road” category, the assignment of an individual model is done in agreement with the manufacturer and does not necessarily build on technical attributes.

A pragmatic approach to address this problem had been developed in the course of the IMPROVER project [5]. IMPROVER formulated geometrical requirements according to which passenger cars (M1 or M1G class in European regulation 70/156/EG) are considered as MPVs or SUVs if their vehicle height exceeds 1600 mm. An SUV is differentiated from an MPV by ground clearance if it exceeds 180 mm under the axles and 200 mm between the axles. In addition, ramp and departure angles larger than 20° and an approach angle of more than 25° are deemed to be characteristic for an SUV. We adopted this definition mainly, but limited the requirements to total height (≥ 1590 mm) and ground clearance (≥ 170 mm). All-wheel drive does not prove to be a meaningful factor for discrimination because many SUVs are meanwhile offered without this feature, but maintain their clearance dimensions. At the same time, four-wheel drive is an option on many passenger car models to improve traction, e.g. during the winter time.

In the first step, 32 base models of SUVs on the German market were identified from the national vehicle register that constituted 80 % of the sales in this segment from 2002 until 2008. In a second step, the range of evaluated vehicles was extended to 83 models to include both older vehicles which were already identified by IMPROVER and other SUVs with smaller sales figures. For each of these, the manufacturer code (Hersteller-Schluesselnummer HSN) and model code (Typ-Schluesselnummer TSN) were determined as assigned by the national register. The combination of these two codes describes a certain vehicle model and generation. Through its vehicle identification number (VIN) an individual car, e.g. one involved in an accident, can be linked to the HSN/TSN and to the vehicle model, respectively, and vice versa.

For some of the following analyses, the chosen sport utility vehicles were grouped by characteristics that may be of significance for crash incidence or crash outcome:

SUV size: Without doubt, mass is one important factor in crash severity and compatibility between opponents. However, the curb mass for a single model may vary widely depending on trim level, engine size and the drivetrain concept, like two-wheel or four-wheel drive. Some models are also available with different wheelbases which affect their total length and their mass. Actual mass is a factor which is difficult to determine from statistical data. Therefore, mass and length were considered unsuitable to describe the size of an SUV for the purpose of evaluating crashes, especially between motor vehicles. Vehicle track width was used as a representative for vehicle size instead as it is independent of mass and length variations and largely correlates with the overall size. For models with different track dimensions on the front and the rear axle, the mean value was determined and applied. SUVs with a track width up to 1550 mm were defined as “small”, models with more than 1550 mm track width were considered as “large” sport utility vehicles, dividing the 83 models into two groups of similar numbers of models.

SUV age: This attribute is intended to describe indirectly the model’s state-of-the-art passive safety. 2003 was the first year that EuroNCAP included SUVs in their consumer crash testing program and it is assumed that by this time at the latest manufacturers put emphasis also on crashworthiness of these vehicles, albeit not necessarily on compatibility. SUV models entering the European market before 2003 are therefore designated as “old” sport utility vehicles; vehicles sold for the first time in 2003 or later are considered as “new”. An SUV that was introduced to the market in 2002, for instance, is “old” according to this stipulation, even if it was still being manufactured in 2004.

SUV structure: The chassis design of an SUV may be of influence for the protection of its occupants in a frontal collision, but decisive also for the crash compatibility between vehicular opponents. A front structure that absorbs energy in a controlled way for crashworthiness and decent compatibility will be found more likely on a unibody construction than on an SUV with a separate frame. Hence, sport utility vehicles are sorted also by “frame chassis design” and “unibody design”.

The combination of these three attributes yields eight categories of SUVs, ranging from “small/old/frame-chassis” to “large/new/unibody”, and can be used to analyze large-scale data sets by SUV character (Fig. 1).

Fig. 1. Example of large SUV, introduced before 2003 (with frame chassis) and of small SUV, introduced after 2002 (with unibody).

Vehicles that saw relevant design changes with the introduction of a new model generation or a major facelift, even if the sales name remained the same, are accounted for separately. If the new generation goes along with, for instance, increased size, i.e. wheel track width, or changes of the body concept from frame chassis to unibody, it will consequently fall into a different category.

Accident Statistics on National Level

Annual registration figures for the 83 selected SUV models were determined from the national vehicle register between 2003 and 2008. The federal statistical office conducted a special analysis of road traffic accidents with bodily damage that involved SUVs for the period from 1997 until 2008. The relevant cases were identified by linking vehicle data through HSN/TSN combinations to the 83 SUV models. Various analyses were conducted for different variables that are gathered by the German police for their accident report. Crash outcome is given in terms of slight (outpatient treatment), serious (inpatient treatment) or fatal (deceased within 30 days) injuries. Additional variables include the so-called "accident type" (conflict leading to the accident), "kind of accident" (actual course of crash) and weather and road conditions, among others. Actual collision configurations between opponents, e.g. whether a frontal or rear-end collision occurred between vehicles, or whether a single-vehicle accident included a rollover, are not available on a national level.

Insurers' Data

In order to gain further insight into crashes between SUVs and other passenger cars as well as with pedestrians, the accident database of the German Insurers Accident Research was evaluated. It contains information on more than 5,000 injury crashes with a cost of 15,000 Euros or more obtained from claim files of the German motor liability insurers. The sampling procedure ensures the representativeness of the database for the injury crashes handled by motor liability insurers. Since this type of insurance covers only third party claims, single-vehicle accidents are underrepresented. Crash-involved SUVs were identified through relevant HSN/TSN combinations. Additional cases were collected from insurers for the study. Altogether, 361 accidents with at least one injury were available. Due to the limited number of cases, no differentiation regarding SUV categories was possible.

SUV User Surveys

Data on SUV usage and driver attitudes and self-reported behavior were obtained from two different surveys. Any previous involvement in an accident was not a selection criterion. Socio-demographic data came from a customer panel of a tire manufacturer who regularly conducts surveys among car owners (n = 36,917), among them 686 SUV owners. Furthermore, the 2010 survey "Traffic Climate in Germany" conducted by the German Insurers Accident Research provided information on the safety-related attitude and driving behavior of passenger car and SUV users alike (Gehlert and Genz [8]). 306 SUV drivers were recruited particularly for this purpose in addition to 1,114 users of conventional cars.

III. RESULTS

During the observed period from 2003 until 2008, the number of registered sport utility vehicles in Germany increased considerably (Fig. 2). Analysis of the national statistics shows that the number of injury crashes involving SUVs rose, too. This increase is almost parallel to the development of vehicle registrations and does therefore not necessarily imply an elevated risk from SUVs. In 2008, the average age of sport utility vehicles, regardless of accident involvement, was 4.5 years whereas the entire fleet of passenger cars in Germany was 8.1 years old.

Analysis of injury accidents between 1997 and 2008 with the selected 83 models provides a more detailed picture if the numbers are differentiated by SUV category (Fig. 3). While accidents in the late 1990s were dominated clearly by small models with frame chassis, their share decreased gradually over the years. Instead, involvement of small, but also large unibody vehicles grew. Due to their definition, new SUVs appear only from 2003 onwards. Those numbers have seen a rapid increase particularly for the large unibody constructions. They rank first in 2008 injury crashes, together with old, small unibody vehicles. While it appears natural that the involvement of old models slowly declines as more and more of these vehicles vanish from the fleet due to ageing, it is striking that unibody vehicles have been clearly on the rise during the last years. This is true for new, small vehicles, but especially for new, large models. In contrast to this, the role of new SUVs with frame chassis in injury crashes is insignificant. Beside the overall development where SUV involvement has doubled from 1.1 % in 1997 to 2.2 % in 2008, the composition of involved models has changed considerably and reflects a general trend towards an increase in size and towards an SUV design that has become in many ways closer to passenger cars than to rugged off-roaders.

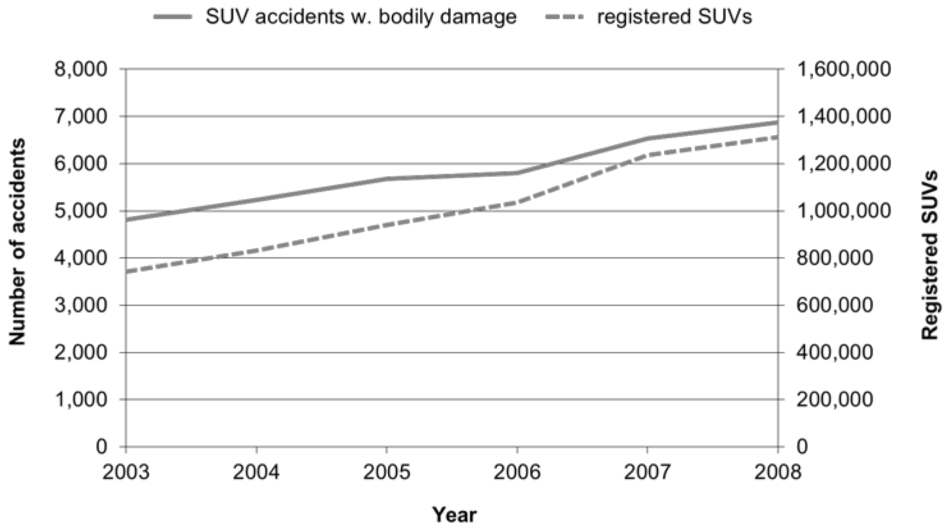

Fig. 2. Development of registered SUVs in Germany and number of injury crashes involving SUVs.

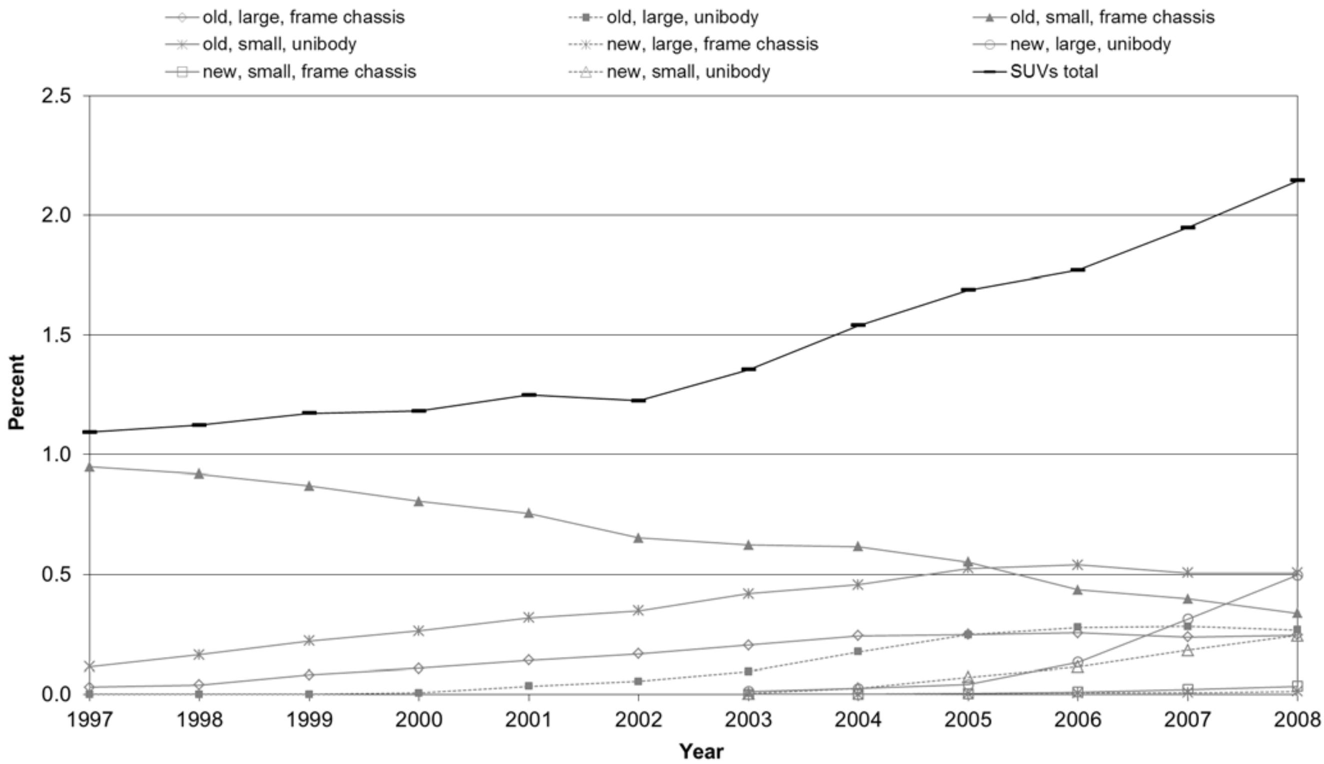

Fig. 3. Development of share of SUV categories in injury crashes.

The 2008 national accident statistics were analyzed in more detail in order to identify any particularities between SUV categories. No major differences were detected, either with regards to the relative frequency of crashes with bodily injury or the type of conflicts preceding the accident. There were no substantial differences, either, when comparing these figures to the crash involvement of conventional passenger cars built after 2002. SUVs were slightly overrepresented in accidents between vehicles traveling in the same direction, which include rear-end crashes and accidents during overtaking. Small models with frame chassis were the only exception as they were underrepresented in this accident type. Instead, their involvement in crashes following a loss of vehicle control was above average according to police reports. They were also found more often leaving the roadway which is a characteristic usually associated with single-vehicle accidents.

In order to assess crash compatibility, the data subset of collisions between SUVs and passenger cars was evaluated. During 2008, six occupants in SUVs and 24 in the opponent cars were killed, and 130 persons in SUVs and 305 in cars were seriously injured. When these figures are set in relation to the number of collisions, the fatality risk, or risk for serious injury, respectively, for occupants of an SUV and a passenger car can be compared (Fig. 4 and Fig. 5). In Fig. 4 and Fig. 5, the consequences are further discriminated by SUV attributes, for instance, small versus large SUVs. Even though caution should be exercised because of small case numbers for fatal collisions, the imbalance between consequences for occupants in SUVs and in passenger cars becomes visible. The ratio between the number of fatalities in passenger cars and the number of fatalities in SUVs is 4 : 1; for seriously injured the ratio is 2.3 : 1, thus indicating a lack of compatibility. In particular, large and new SUVs appear to produce a higher rate of fatalities among car occupants while, at the same time, protecting their own occupants relatively well against both fatality or serious injury. Old models and those featuring a frame chassis display a slight tendency for reduced crashworthiness, i. e. less protection for their own passengers. Further discrimination of SUVs by categories yields too small numbers for analysis.

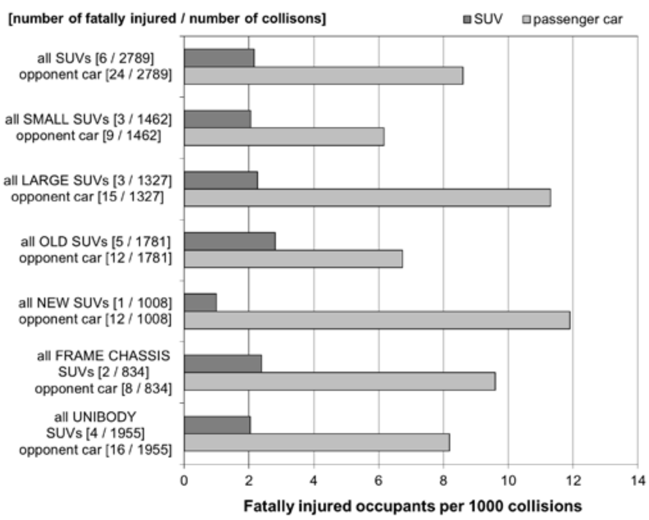

Fig. 4. Fatalities per 1,000 SUV-to-car collisions, 2008, by SUV category.

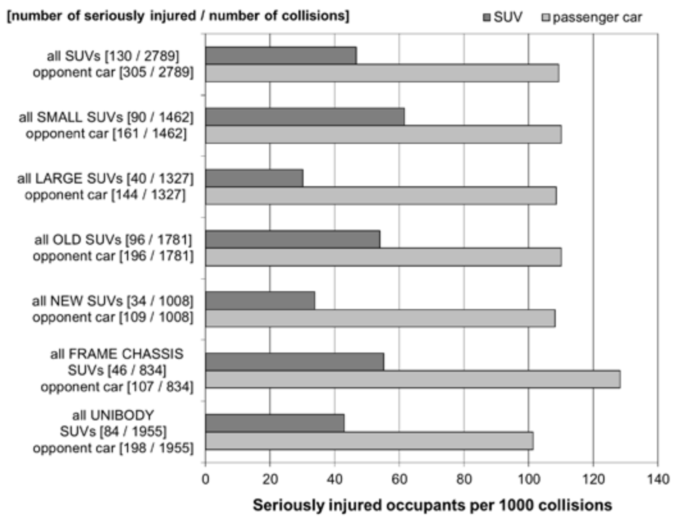

Fig. 5. Seriously injured per 1,000 SUV-to-car collisions, 2008, by SUV category.

Single-vehicle crashes had a share of 6.4 % among SUV accidents resulting in bodily damage. This proportion is lower than that of conventional cars with 10.7 %. Nevertheless, more SUV occupants were killed in single-vehicle accidents (n = 9) than in collisions with passenger cars (n = 6).

437 pedestrians were injured in accidents with SUVs. Comparison with pedestrians who were struck by passenger cars did not show any major difference in crash outcome, in terms of slight, serious or fatal injuries. Discrimination between old and new SUVs indicated a minor decrease in the proportion of seriously and fatally injured, the latter based on merely seven fatal cases, however.

There were no substantial differences between SUV accidents and car accidents regarding crash circumstances like month or time of day of the incidence. Only small SUVs with frame chassis were slightly prominent in accidents occurring in rural areas and crashes on slippery roads due to black-ice or snow.

The database of the German Insurers Accident Research provided SUV cases with more detail information on the circumstances of the accident, vehicle damage and injury patterns. The emphasis was on SUV crashes with conventional passenger cars (n = 156 accidents) and with pedestrians (n = 49 accidents). Nevertheless, the case material also contained a considerable number of collisions with cyclists, motor-cyclists and commercial vehicles. Single-vehicle accidents were few, presumably due to liability cases being the source of information.

Crashes between SUVs and passenger cars were often side collisions, followed in frequency by frontal collisions and rear-end crashes (Table I). Two thirds of these accidents involved the SUV front. The imbalance between rear-end collisions of SUVs into the rear of a car (n = 31) and of cars into the rear of an SUV (n = 9) is partly due to the fact that many claim cases from liability insurers were collected by selection of the insured SUV. Hence, SUVs that cause an accident are slightly overrepresented. Crashes in which an SUV struck the rear of another vehicle are a typical example of that. With 11 % of all SUVs, only a small portion turned or rolled over following the impact, however more frequently than their opponents (4 % of cars). On average, the occupancy rate in crash-involved vehicles was 1.43 persons in SUVs and 1.69 in passenger cars. There were no major differences in the gender of drivers (approximately 75 % males in both groups) and vehicle owners (approximately 80 % males in both groups). The mean SUV drivers' age was 44.5 years (median: 43 years).

TABLE I
COLLISION CONFIGURATIONS BETWEEN SUVS AND CARS, PRIMARY IMPACT

n = 156 accidents		Passenger Car				
		Front	Left Side	Right Side	Rear	Unknown
SUV	Front	41	23	8	31	0
	Left Side	16	2	3	0	0
	Right Side	17	2	0	0	0
	Rear	9	0	2	0	0
	Unknown	1	0	0	0	1

Evaluation of the Maximum Abbreviated Injury Scale (MAIS) demonstrated that occupants of passenger cars were injured more frequently and on average more severely than SUV users (Fig. 6). The risk of minor to moderate injuries (MAIS 1 and 2) was two times higher than for SUV occupants, and the risk of serious injuries (MAIS 3+) almost three times higher. In contrast to this, half of all SUV occupants remained uninjured. Reliable information about seat belt use was available only for a limited number of cases, but there was no indication that belt wearing rates would differ significantly between SUVs and conventional cars. The majority of severe trauma occurred in frontal collisions between the opponents and was found in the region of the head, the chest and particularly the extremities, also in belted occupants (Fig. 7). In a number of cases, crash scene photography indicates that overrunning of the car's longitudinal members was responsible for intrusions of the occupant compartment. The assumption that passenger cars suffered more deformation is supported by the fact that – although rarely necessary after the crash – four times more car drivers than SUV drivers had to be extricated from their vehicles with hydraulic tools by the fire department.

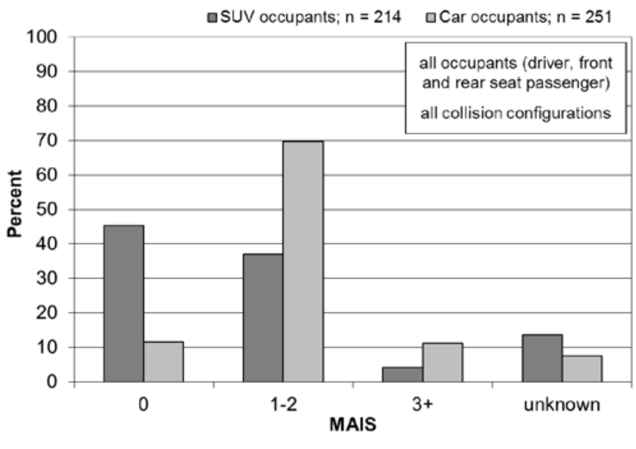

Fig. 6. MAIS distribution for all occupants in all SUV-to-car collisions.

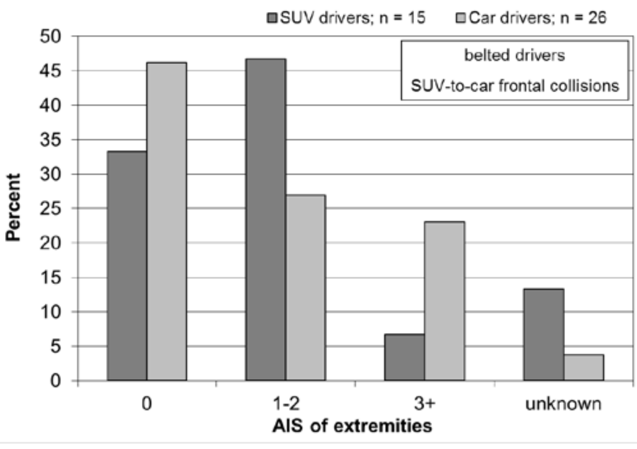

Fig. 7. Distribution of highest AIS of extremities for belted drivers in frontal collisions between SUVs and cars.

Where vehicle mass and age, determined by the year of first registration, were documented, the distributions demonstrate that the SUV was the heavier and younger opponent in the majority of collisions. While none of the conventional cars had a curb mass of more than 1,600 kg, the larger portion of crash-involved SUVs weighed more than this (Fig. 8). Approximately half of the sport utility vehicles in the data material was registered between 1996 and 2000, and the passenger car was often older, although the share of vehicles built after 2000 was higher than in SUVs (Fig. 9).

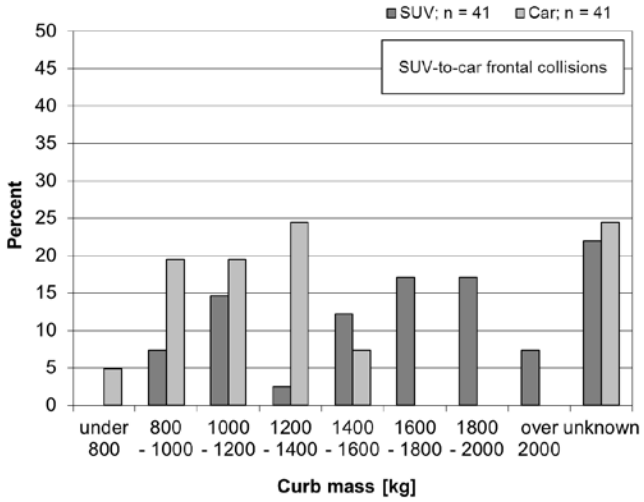

Fig. 8. Distribution of vehicle curb mass in frontal collisions between SUVs and cars.

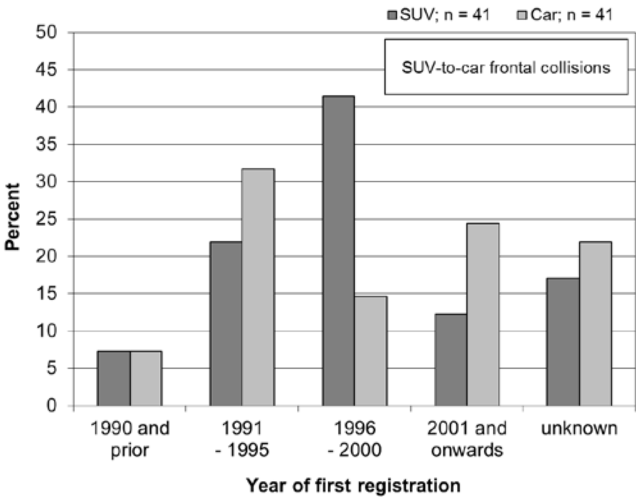

Fig. 9. Distribution of vehicle age in frontal collisions between SUVs and cars.

The database contained 17 single-vehicle accidents of SUVs with injuries to one or more of their occupants. Although small in total number, the outcome was very severe in many cases. Four drivers and three front seat passengers were killed and 27 occupants were seriously injured, as defined in the national statistics. Three in four SUVs turned or rolled over, sometimes in combination with striking a guardrail or a roadside tree. A number of occupants who were not wearing their seatbelt were ejected from the vehicle. The majority of SUVs had registration dates before 2000 and their drivers were significantly younger (mean: 26.6 years, median: 23 years) than those in SUV-to-car accidents.

Pedestrian crashes constituted another considerable portion of SUV accidents. In 49 collisions, 52 pedestrians sustained injuries (Table II). In the large majority of cases, the pedestrian was struck by the front of the SUV. In approximately one quarter of accidents, the impact occurred at the rear when the vehicle was reversing, e. g. on a parking lot. However, evaluation of the database regarding collisions between conventional cars and pedestrians revealed a similar proportion of these situations.

Injury patterns of pedestrians hit by SUVs were compared also to those from collisions with passenger cars. The overall injury severity measured by MAIS was slightly higher with SUVs, but not statistically significant. 42.3 % of the pedestrians sustained MAIS 3+ trauma compared to 39.0 % of those struck by cars (Table II).

TABLE II

PEDESTRIAN INJURY SEVERITY IN COLLISIONS WITH SUVS

n = 52 Pedestrians		Overall		Head		Chest		Spine		Legs		Pelvis	
		abs.	%	abs.	%	abs.	%	abs.	%	abs.	%	abs.	%
MAIS / AIS	0	1	1.9	29	55.8	45	86.5	47	90.4	23	44.2	39	75.0
	1 - 2	27	51.9	14	26.9	1	1.9	3	5.8	17	32.7	7	13.5
	3+	22	42.3	7	13.5	4	7.7	0	0	10	19.2	4	7.7
	Unknown	2	3.8	2	3.8	2	3.8	2	3.8	2	3.8	2	3.8

When differentiating between body regions, slightly more serious injuries to the legs and the pelvis and slightly fewer serious injuries to the head and the chest were visible in collisions with an SUV, but also not statistically significant. Altogether, the legs and the head were primarily affected in both groups while injuries to the spine were rare. On eleven of 23 SUVs for which documentation about a front-mounted “bull bar” was available such a device was present. It may have contributed to injuries in some, but not all of the collisions, since the impact did not always occur in this area, especially in reversing accidents.

The survey which was conducted among users of sport utility vehicles and conventional passenger cars regarding driver attitude and driving behavior provided further insight into the two groups of drivers and the way they use their vehicles.

The interviewed drivers were of almost the same age on average (SUV drivers, mean: 51.2 years; car drivers, mean: 51.0 years) in the first survey. In the second survey (“Traffic Climate in Germany”), SUV drivers had a mean age of 45 years; car drivers were 50 years old. Despite these similarities, the age distributions differ between the two groups (Fig. 10). While young people and the elderly constitute a considerable portion among car drivers, these two age categories played a much smaller role among SUV drivers. Almost 60 % of SUV drivers were between 35 and 54 years of age. 56 % of SUV drivers were male as opposed to 51 % among drivers of conventional cars. Larger differences were found with respect to occupation and annual mileage driven. More SUV owners than car owners were self-employed, had higher incomes and reported to travel approximately 30 % kilometers more per year.

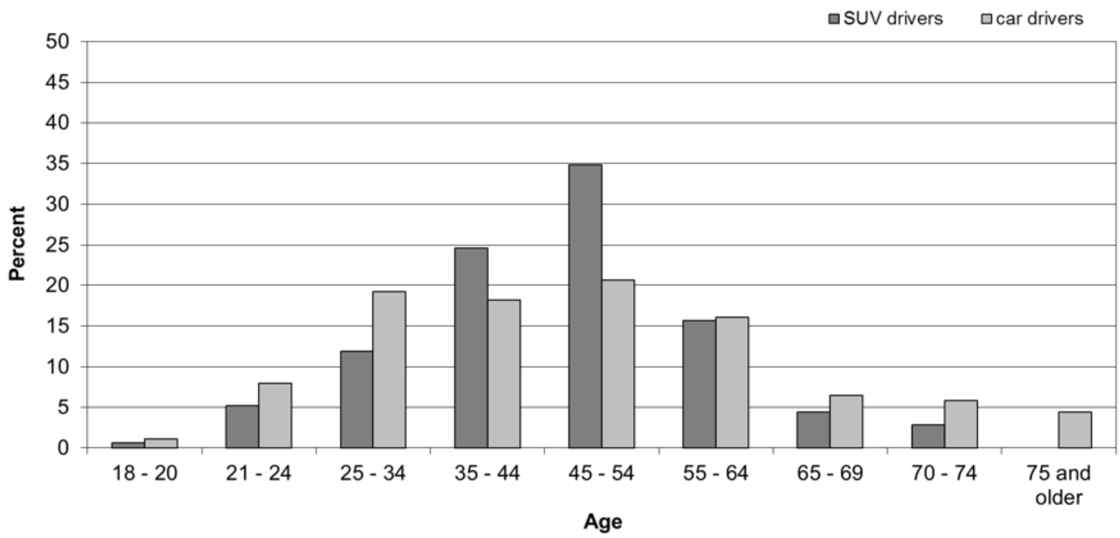

Fig. 10. Distribution of age of SUV and passenger car drivers in survey.

When interviewed about their driving behavior, the group of SUV drivers did not deviate significantly from car drivers. Misdemeanor directly related to traffic safety, like speeding and running red lights, was not stated more frequently. However, when asked about certain traffic environments, e. g. driving on motorways, SUV drivers generally tended to feel slightly safer than car drivers. SUV drivers also reported more frequently that they operate the car radio, a navigation device or use their cell phone during driving.

IV. Discussion

The growing number of sport utility vehicles in European countries, among them also Germany, raises the question whether these vehicles are more dangerous for their occupants and crash opponents than conventional passenger cars. Experience from North America indicates that occupants in other cars or vulnerable road users are at a higher risk for serious or fatal injury in collisions with an SUV. Greater mass and higher front structures reduce compatibility with lighter and lower vehicles in principle. In addition, SUVs are criticized for their driving characteristics and lack of occupant protection especially in single-vehicle rollover accidents. However, it is not clear whether these findings apply to the fleet of SUVs in other countries and the environment in which they are driven.

Above all, a universal definition of what constitutes a sport utility vehicle is necessary. Categorization by the automotive industry does not provide objective criteria for this purpose. The proposal which was developed in the course of the IMPROVER research project [5] appears to be a useful definition that is based entirely on geometric properties. Therefore, it includes also new SUV concepts that do not emphasize off-road capabilities, but present the same characteristics that are important factors in a crash with another road user. Based on this definition, 83 out-of-production as well as current models were identified to represent the fleet of SUVs in Germany. As their proportion in the general car fleet increased, the number of accidents with bodily damage and involvement of these vehicles doubled between 1997 and 2008. A first analysis of the national accident statistics did not indicate that SUVs would be more involved in injury crashes or cause more severe outcomes than cars in general. Neither analysis of typical conflicts, nor of driver errors displayed any particularities of this vehicle segment.

Differentiation among SUVs was possible after the models were categorized by size, year of market introduction and body concept. Comparison of the outcome for occupants in the SUV and in the opponent car demonstrated a much higher risk for fatal or serious injury for the latter. The fact that passenger cars feature a slightly higher occupancy rate than SUVs, thereby raising the chance for a casualty, does not explain this discrepancy entirely. Comparisons of small versus large, old versus new and frame chassis versus unibody SUVs in collisions with passenger cars show that large and new SUVs cause more fatalities in the opponent vehicle while providing clearly better protection for their own occupants than small and old models. Models with frame chassis tend to be less safe not only for the opponent, but also for their own users. While SUVs have seen the same advances as cars in passive safety in recent years, many SUVs have changed in other ways as well over time. SUVs have grown in size, and consequently in mass, and frame chassis concepts have been replaced by unibodies on most models. Thus, the proportion of large unibody models has increased with new models entering the market. Nevertheless, very large sport utility vehicles that are prominent in North America are almost absent in the German and European fleet. The potential discrepancy between two crash opponents, at least among passenger cars, is therefore smaller.

Analysis of more detailed two-vehicle collisions in the database of the Insurers Accident Research sheds more light on the factors that are suspected to influence injury outcome. The majority of injury crashes consisted of collisions with involvement of the SUV front, especially frontal crashes into the opponent car. This is a configuration where a lack in compatibility should be most recognizable whereas side collisions generally present a higher risk for the party which is struck laterally. Comparison of the injury severity and the affected body regions between occupants of SUVs and passenger cars in frontal collisions actually demonstrated a much higher chance for the car occupants to sustain MAIS 3+ injuries. Where vehicle damage documentation was available, it showed that older and frame chassis models did not engage the car's crash structure sufficiently, but rather overran it. This may result in a ramping effect which explains injuries caused by intrusion on the car's part and the higher rate of overturning on the SUV's part. Nevertheless, an imbalance between the masses of the crash opponents was clearly visible in the database, too. This is known to be principally disadvantageous for the smaller vehicle. It is conceivable that improvements of the SUV structure over time are offset by an increase in mass. Even most SUV models that formerly employed frame chassis display higher masses when a new generation in unibody design is introduced. Regardless of the mass and geometry factor, it has to be noted that currently the SUV fleet in Germany is several years younger than that of passenger cars. The increased structural strength and stiffness found in modern vehicles that are necessary to fulfill today's crash test requirements will load the structures of an older car even more in a collision. Although less prominent, SUVs were also the younger of the two vehicles in most cases from the database.

Single-vehicle accidents of SUVs are less frequent in comparison with both passenger car crashes in Germany and SUV accidents in the U.S. The Insurance Institute for Highway Safety (IIHS) [9] reported that 64 % of all killed SUV occupants as opposed to 46 % of all fatalities in passenger cars were found in single-vehicle accidents. German data yield a proportion of 39 % of SUV occupants, though based on small numbers, who died in single-vehicle crashes and 42 % among all fatalities in passenger cars in 2008. One category of SUVs appears to stand out in single-vehicle accidents. Small SUVs with frame chassis were prominent in police reports with regards to loss of control and running off the road. Some of these models are special in a way that they feature short wheel bases and simple suspensions with rigid axles and leaf springs. Especially under slippery road conditions, these vehicles can become difficult to control.

The fact that SUV accidents are not very noticeable in Germany despite the often severe consequences for their opponent must be attributed in part to the relatively small number of these vehicles on the road. The two user surveys showed consistently that novice drivers and elderly drivers who are known to be groups with elevated accident risk are underrepresented among SUV users. Instead, the large majority of them are in the mid-thirties to mid-fifties; a portion of the driver population which is usually inconspicuous in severe crashes. The very severe single-vehicle accidents found in the accident database, though few in absolute number, appear to confirm this picture such that their drivers were young and drove comparably old SUVs. That means that on average SUVs and their drivers are not an accident risk as long as other detrimental factors like lack of experience do not come into play. These aspects are similar to the findings by Keall and Newstead [3] in their study on SUV accidents in New Zealand. They found that SUVs were not overly involved in crashes, but some of them were prone to roll over. Studies from North America determined higher rollover rates per registered vehicle, like Subramanian [10] in an investigation of fatality rates in different types of passenger vehicles. This tendency is also visible in the material of the database of the insurers, particularly in single-vehicle accidents.

On the other hand, the higher mileage driven by SUVs increases the exposure to accident risk and apparently compensates for some of the safety gain provided by their driver population. The exact reason why these vehicles travel much longer distances on average is not known. The higher share of self-employed persons among drivers who may also use the SUV for their regular business trips may contribute to this. Data from the German Mobility Panel [11] endorse the assumption that in German households which own more than one car the older and smaller vehicle serves primarily for short trips and mobility in the urban environment while the large car is used to commute to work or for business purposes.

Accidents between sport utility vehicles and pedestrians did not display statistically significant differences in injury severity and pattern in comparison to cars as crash opponents. Based on small case numbers, newer models appear to pose a slightly lower risk for fatal injury to pedestrians. Bull bars as they were found on a considerable portion of SUVs in the accident database material have been banned from installation on new vehicles by European law in 2005 [12] unless they fulfill the statutory pedestrian protection requirements that apply to car front faces. Their potential role in producing lower extremity injuries should therefore decline in the future. German accident data currently do not support findings from the U.S. [6] that light truck vehicles, subsuming SUVs and pickups, present a much higher risk of fatal injuries for pedestrians than passenger cars. LTVs in the North American fleet, especially pickups, differ not only in terms of vehicle size, but also in front shape from most SUVs in Europe. This may explain the contrasting results.

The present study based on German accident data from the national statistics and insurers claim files has some limitations. Due to the relatively low number of SUVs in the German car fleet a large-scale analysis of very severe or fatal accidents is difficult. As in most countries, the national statistics do not provide information about the impact location on a vehicle, belt use by its occupants and their seating position, except for the driver. These data would be helpful particularly for assessing compatibility issues. Liability insurers' material is slightly biased towards accidents with other road users and may underestimate the number of single-vehicle crashes. Due to the data retrieval method used here, SUVs are more often involved as the party at fault which provides less information on the SUV damage and driver injuries than on the opponent who files the claim. Nevertheless, the fairly large number of SUV accidents in which the results are analyzed is considered to depict the situation in a large European country well.

V. CONCLUSIONS

Injury accidents with SUVs in Germany show many similarities with those in other countries. The fact that the absolute number of casualties is relatively small is due to the small, but growing proportion of SUVs in the fleet. At the same time, the SUV segment is changing from rugged off-roaders to life-style passenger vehicles, thereby influencing important physical properties in case of a crash. Even with recent models, incompatibility remains an issue due to the growing mass and increased structural strength and the typical raised ride height. On the other hand, the change from frame chassis and simple suspensions to unibodies with better load distribution is expected to influence compatibility in a positive way. Nevertheless, an increased risk for severe injuries exists for car occupants in a collision with an SUV. The fact that SUV involvement in injury crashes in Germany is only average must be attributed in large part to how these vehicles are used and to their driver population which does not include the typical groups at risk.

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