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Occupant Protection by Side Airbags in Vehicle-to-Vehicle Collisions

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Wilhelmstraße 43/43G, 10117 Berlin
PO Box 08 02 64, 10002 Berlin
E-Mail: unfallforschung@gdv.de
Internet: www.udv.de
Facebook: www.facebook.com/unfallforschung
Twitter: @unfallforschung
YouTube: www.youtube.com/unfallforschung

Author: Axel Malczyk, PhD
Co-Author: Michail Wald, TU Berlin, Automotive Engineering
Layout: Franziska Gerson Pereira
Photo references: Cover photo Axel Malczyk, PhD, UDV
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Introduction

Side airbags (SAB) have become common standard safety equipment in modern cars since their introduction to serial production in 1994 [1]. While the first systems on the market were thorax side airbags (TSAB) which covered only the chest region the area of protection in lateral impacts was considerably extended with airbags intended to prevent the head from striking against the vehicle interior or external structures. This was attempted either by increasing the size of the side airbag in the top portion with so-called head-thorax side airbags (HTSAB) or separate airbag modules, the head side airbags (HSAB), deploying from the roof rail and intended to protect primarily the head and neck of the occupant, often covering the first and second seat row with one bag. While the latter systems are usually a standard feature on today's medium-sized and large sedan models, they are often available only as an option for many small and compact car models.

The wide-spread availability of side airbags in Europe is in part driven by consumer crash test programs like EuroNCAP which included a lateral impact test with a 950 kg moving barrier from the beginning on and introduced a lateral crash into a fixed pole later for vehicles equipped with side protection measures [2, 3].

While a number of studies have demonstrated the protective effect of frontal airbags there is relatively little body of research on the benefits of side airbags, particularly on the European market. In 2006, Page et al. published a comprehensive review of previous international research in that field [4]. They also presented the results of their own study on side airbags from real-world accidents which was not able to demonstrate a significant reduction of injury risk in lateral crashes [4].

Otte and Hüfner published results of a GIDAS analysis (German in-depth accident study) of lateral crashes occurring between 1999 and 2005 [5]. Their study was limited by small case numbers based on which no clear statistical evidence of side airbag protection could be established. A case-by-case analysis was then performed and indicated that side airbags are able to reduce the risk of AIS 3+ injury for the thorax and head, but may increase the frequency of injuries in these body regions, too.

Therefore, the question remains whether current side airbag systems which in combination with vehicle structural measures undoubtedly perform well in standard crash test situations provide the same level of occupant protection in real-world collisions scenarios. The present study intends to add to the knowledge about side airbag performance in real-world crashes by using an alternative approach to categorize crashes of comparable severity. The evaluated material is restricted to collisions between motor vehicles and does not take into account single-vehicle crashes resulting in collisions with obstacles or from vehicle roll-overs.

Contents

Methodology

For this study, cases from the German Insurers Accident Database (UDB) were analyzed. UDB contains approximately 8,000 cases based on data from claim files of German motor liability insurers. Only cases with personal damage and claim costs of at least 15,000 Euros are eligible for documentation in the database. Due to the nature of third-party loss insurance, single-vehicle crashes tend to be under-represented in the material and are therefore not the subject of the present evaluation. Pre-selection criteria were collisions between motor vehicles where a passenger car received damage to the vehicle side severe enough to potentially injure an occupant. Crash opponents included other passenger cars, vans, trucks and buses as well as other heavy vehicles like farm tractors. Collisions in which a motor-cycle struck the side of the passenger car were excluded.

Pre-selection of the material yielded 296 cases with an occupant sitting on the side where the impact occurred. No discrimination with regards to the belt status was made because only a small effect on the person was assumed for a near-side lateral impact. Occupants younger than twelve years were excluded from analysis as these will likely differ in height from adult occupants and should be transported in suitable child restraints systems. The case material was further restricted to crashes with sufficiently documented impact location and direction and extent of vehicle damage. Depending on the level of documentation of injuries and side airbag deployment, the number of available cases varied slightly for some specific evaluations. Impact direction and location on the struck vehicle was estimated from sketches describing the course of the accident and the collision situation and from vehicular damage. The severity of damage to the struck vehicle is categorized by the location where the major lateral deformation occurred (forward of the occupant compartment, occupant compartment, rearward of the occupant compartment) and the depth of intrusion. The latter was assigned a "degree of damage" as regularly used in analyses of the UDB database. With this method, actual damage of a vehicle is compared to a standard set of sample pictures to categorize intrusion depth in degrees ranging from DoD1 for small deformation and DoD2 for moderate intrusion to DoD5 with massive deformation (Fig. 1).

Side airbag deployment was determined from scene photos or repair documentation. Where no airbag deployment could be established, this may have been due to either a vehicle with a side airbag, but which was not fired, or a vehicle not fitted with a side airbag. These two reasons for non-deployment were not discriminated when cases without deployment were considered.

Injury severities were coded according to AIS 98 (Abbreviated Injury Scale) [6] and the highest AIS value for separate body regions was determined for near-side occupants as well as their MAIS value (Maximum AIS).

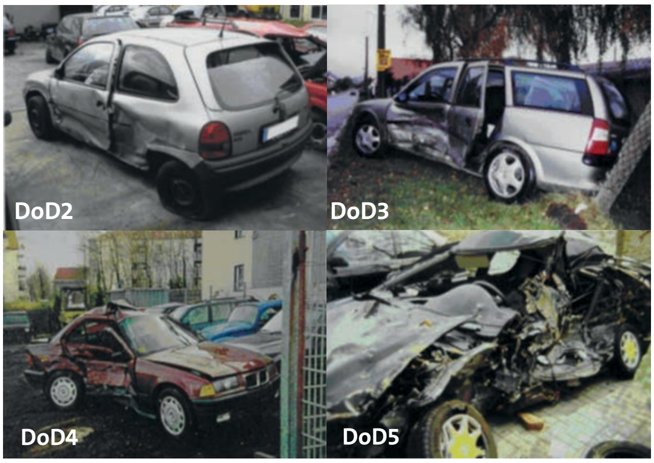

Figure. 1:
Examples for Degree of Damage (DoD) according to German Insurers Accident Research definition

The effect of a side airbag is estimated by comparing injury outcomes in the group of lateral crashes with deployed side airbag with the group of lateral crashes without deployed side airbag, or without fitted side airbag, respectively.

Many variables have influence on the severity of a side impact and the loading on the person in the vehicle which makes direct comparison between cases with and without side airbag deployment difficult. While deep door intrusion is likely to cause injury by direct force acting on the occupant, he or she may also be injured when the car is violently struck in the portion in front of or behind the occupant compartment. In order to control for this disparity a weighting scheme was developed. Major factors, like degree of damage or impact location on the vehicle, are differentiated separately in two or three classes depending on their assumed effect on the occupant and are assigned weighting points accordingly. The weighting points are then summed up and the final score value is assigned to one of three categories that are intended to represent different overall severity levels of the crash event. Weighting point assignment was as shown in Table 1:

Table 1:
Weighting point assignment for crash parameters

Impact direction	1, 5, 7, or 11 o'clock	1 point
	2, 4, 8, or 10 o'clock	2 points
	3 or 9 o'clock	3 points
Impact location	forward or rearward of compartment	1 point
	compartment	2 point
Roll-over	no roll-over	0 points
	quarter turn or half turn	1 point
Degree of damage	DoD 1 or DoD 2	1 point
	DoD 3, DoD 4 or DoD5	2 points
Crash opponent	"light" vehicle: passenger car or van	1 point
	"heavy" vehicle: truck, bus or farm tractor	2 points

Multiple impacts are common in severe lateral collisions and were therefore not excluded from the study as long as the side impact constituted the major event for occupant loading. Cases with roll-overs succeeding lateral crashes were excluded if they exceeded a half turn. Crash opponent vehicles were categorized as "light" opponents if weighing a maximum of 3.5 tons or as "heavy" opponents with larger vehicle mass.

The resulting score values are assigned to one of the overall severity categories according to Table 2.

Table 2:
Overall side impact crash severity categories for analysis

"minor severity" side impact (type I)	4 to 5 point sum
"medium severity" side impact (type II)	6 to 7 point sum
"high severity" side impact (type III)	8 to 10 point sum

The relative frequencies of injury severities found for the group of crashes with deployed side airbag and the group of crashes without deployed side airbag will be compared separately for each overall crash severity level to provide similar loading conditions for the occupants.

In the first step, crashes with activated thorax side airbag and crashes with non-activated thorax side airbag will be evaluated. The material contains passenger cars of all model years including a number of vehicles that did not feature side airbags when they were produced. Earlier vehicles not only lacked side airbags, but presumably had also weaker structures resulting in less overall side impact protection for the occupant.

Therefore in the second step, the evaluation of crashes with activated thorax side airbags and crashes with non-activated thorax side airbags will be restricted to car models which were introduced to the market in 1997 or later. It can be assumed that the influence of consumer crash tests is reflected in the design of many of these models, thus providing a more homogeneous basis to identify differences in protection by side airbags.

For cars introduced in 1997 or later, also crashes with activated head side airbags and crashes with non-activated head side airbags will be compared though they are usually intended to work together with thorax airbags. Thus, this analysis will be limited to their effect on head injuries.

Results

After excluding cases with unknown impact direction, location or degree of damage for the struck vehicle, 200 cases with known MAIS for the near-side occupants remained for analysis. Nine of these occupants were fatally injured. Seventy-five of the investigated cars were models introduced before 1997 and 125 belonged to models entering the European market in 1997 or later.

Occupant ages and distribution of gender were very similar between the two groups of car models. In cars before 1997, occupant age averaged 42.0 years and men constituted 54%. In cars from 1997 on, the average age was 43.2 years and the proportion of men was 59%. Approximately three in four of the near-side occupants (76%) involved in lateral impacts, regardless of vehicle age, were drivers. Front seat passengers accounted for 17% and near-side passengers in the second seat row for 7%, respectively.

Impact directions were distributed similarly for both model year groups with 38% of the impacts coming perpendicularly from the left or right of the struck vehicle. Also, distributions of impact locations on the car were similar with the occupant compartment being struck in 52% of all cases. The proportions of "degree of damage" differed considerably between the two groups. Severe or extensive damage (DoD 3 to 5) was seen in 61% of vehicles before 1997, but only in 22% of cars from 1997 onwards. Consequently, the distributions of side impact severity categories were different, too. While vehicles from both groups presented a medium severity type (type II) in over 60% of cases, each (before 1997: 61%, 1997 onwards 64%), cars before 1997 had high severity crashes (type II) in 25% of cases as opposed to only 10% of high severity crashes (type III) among cars from 1997 onwards.

Evaluation of the effect of thorax side airbags (TSAB) was performed in the first step by considering all laterally struck cars irrespective of age. Taking into account the three different crash severity categories defined previously, the differentiation by MAIS categories indicates that deployed TSAB's reduced particularly the risk for MAIS 2 in type II crash severities, but not in the more severe type III crashes (Figure 2). The latter, however, are relatively small in number. For crashes of minor severity (type I), deployed TSAB's were associated with a small percentage of MAIS 2 and MAIS 3+ injuries that were not seen in cases without deployed TSAB's.

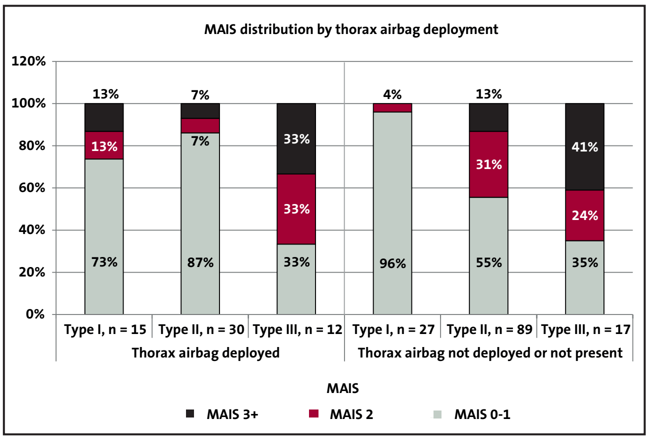

Figure 2:
MAIS distribution for cars with deployed and non-deployed thorax side airbags (cars of all model years)

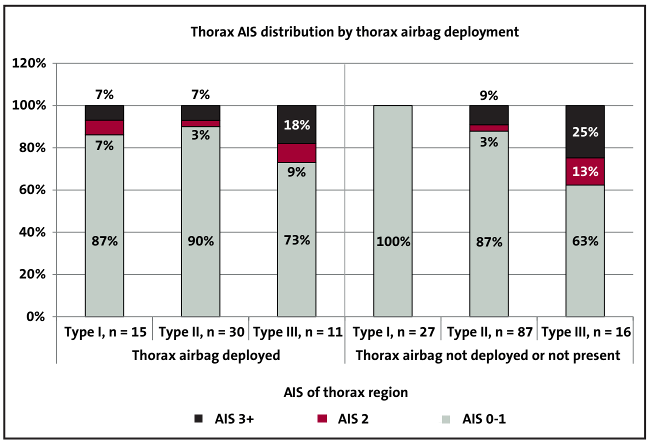

Figure 3:
Thorax AIS distribution for cars with deployed and non-deployed thorax side airbags (cars of all model years)

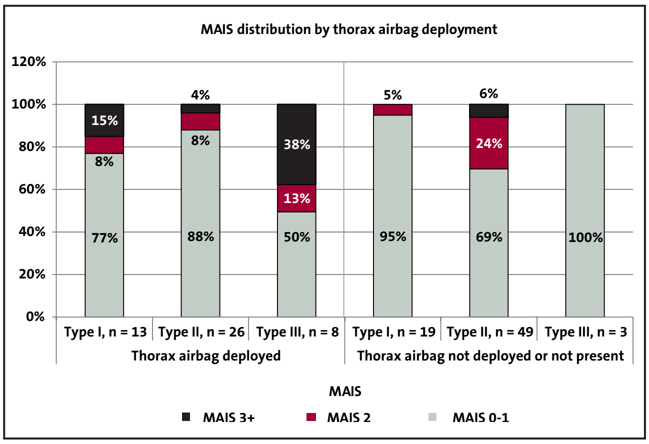

Figure 4:
MAIS distribution for cars with deployed and non-deployed thorax side airbags (models 1997 and later)

When only thoracic injuries – the region where a deployed TSAB is most likely to show an effect - are considered, a reduction of AIS 2 and AIS 3+ frequency can be conduded at best for type III crash severities, though on a small case number basis (Figure 3). The effect in type II crashes is minor and for type I crash severity there is a slight increase in injury frequency.

In the second step of the analysis of TSAB influence on injury frequency, the evaluation was restricted to cars belonging to models introduced in 1997 or later, assuming a more homogeneous structural performance in side crashes. Case numbers were smaller, consequently. Here also, the risk of sustaining MAIS 2 in type II crash severities is reduced while both other categories (type I and type III) involved some cases of MAIS 2 and MAIS 3+ with deployed TSAB's (Figure 4).

A closer look was taken at TSAB effects on injury frequencies of different body regions. Figure 5 presents the distribution of head injuries by AIS severity levels. The reduction in head injury risk by a TSAB was relatively small in type I crash severities. The potential influence of deployed head side airbags (HSAB's), if vehicles were fitted with them in addition to TSAB's, is included here. One case of AIS 3+ head injury was found in the type I category for a deployed TSAB and requires some explanation. In this case, a convertible was struck by an oncoming truck at a narrow angle which left comparably low intrusion depth in the side structure, resulting in a relatively small score for overall crash severity. However, the deployed TSAB could not prevent that the driver's head was forced towards the left window by the impact where it likely hit the truck structure. The driver died in hospital of the head injuries sustained.

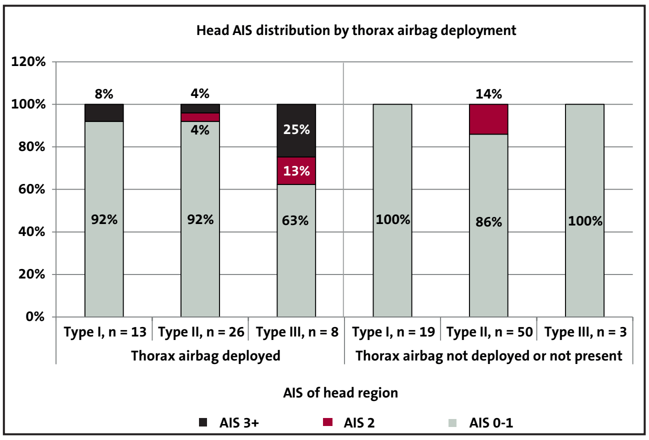

Figure 5:
Head AIS distribution for cars with deployed and non-deployed thorax side airbags (models 1997 and later)

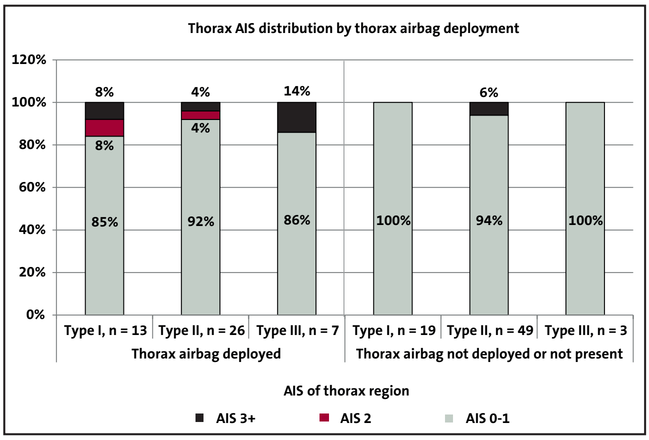

Figure 6:
Thorax AIS distribution for cars with deployed and non-deployed thorax side airbags (models 1997 and later)

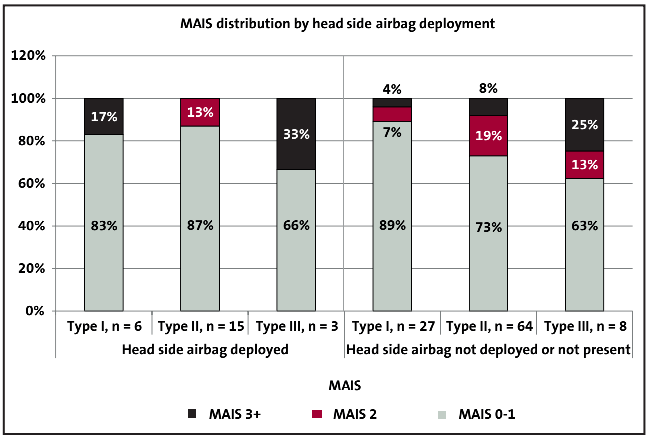

Figure 8:
MAIS distribution for cars with deployed and non-deployed head side airbags (models 1997 and later)

For thoracic injuries, the data shown in Figure 6 do not suggest a benefit by TSAB's in any of the three crash severity categories.

Abdominal injuries beyond AIS 1 were so rare in both deployed and non-deployed TSAB cases that no conclusions can be drawn for this body region. Likewise, only one AIS 2 and one AIS 3+ injury to the lower extremities was seen in the material. Since a TSAB barely covers this body region no effect on injury frequency can be expected here.

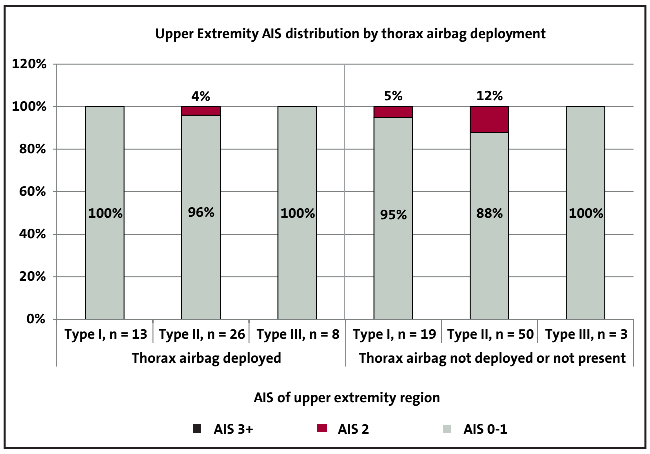

Figure 7:
Upper extremity AIS distribution for cars with deployed and non-deployed thorax side airbags (models 1997 and later)

Upper extremity injuries of MAIS 2 were rare, too, but appear to be reduced in frequency with deployed TSAB's in type II and type I crash severities (Figure 7).

Lastly, the effect of head side airbags (HSAB) was analysed. Only separate HSAB modules were considered since combination head-thorax side airbags were few and their effect on head injury reduction questionable given the small area that is covered by the head portion of the bag. In accordance with the concept of HSAB's, only their effect on head injuries and on the overall injury situation, expressed by the MAIS, was examined. Due to their lower fitment rate, deployed HSAB's were fewer than deployed TSAB's. When evaluating HSAB effects some TSAB influence can be expected, too, as both modules are often activated together. HSAB's positively affected the frequency of MAIS 2 and MAIS 3+ injury severities in medium severity crashes (type II) (Figure 8).

Type III and type I crash severities with HSAB deployment were too few to draw conclusions. Looking at head injuries, a reduction of the frequency of AIS 2 and AIS 3+ injury severity was seen for deployed HSAB's in medium

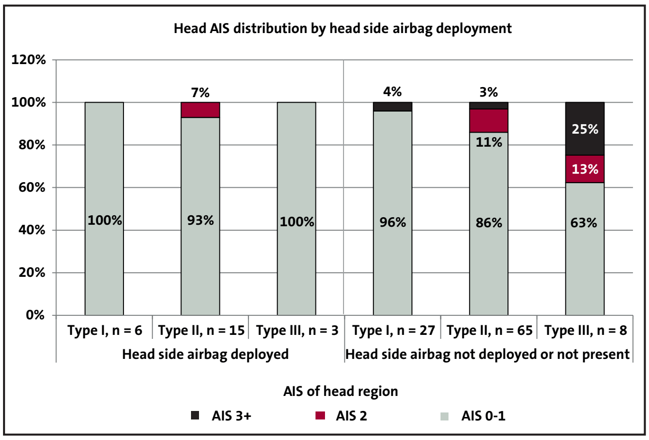

Figure 9:
Head AIS distribution for cars with deployed and non-deployed head side airbags (models 1997 and later)

and high severity crashes (type II and type III) (Figure 9). Again, caution should be exercised when interpreting the results due to the low number of available of cases, particularly for type III crashes.

Discussion

This study aimed at identifying the effect of side airbags on injury mitigation in side collisions among vehicles. In contrast to frontal or rear end crashes where integrity of the occupant compartment can usually be assumed, the loading conditions of occupants are often more complex in lateral crashes. Forces acting on the occupant can occur due to direct loading through intruding side structures as well as due to impacts on the vehicle that violently accelerate the side structure and cause rather distributed contacts with the occupant. In addition, a wide variety of impact directions can be seen in real-world crashes while current side crash test specifications in Europe call for perpendicular impacts only.

Our study has a number of limitations, one being the still relatively small number of cases with deployed side airbags available for analysis. As mentioned above, the large variety of crash conditions found in real-world accidents constitutes another problem which makes comparability between cases challenging. These aspects were found to be major issues in previous studies like the one by Page et al. [4]. With our study, we not only restricted the material to side collisions among vehicles, thus excluding single-vehicle crashes, but we also accounted for different impact variables by defining categories of overall crash severity. With this concept, we attempted to improve comparability of crash conditions regarding their effect on occupant loading for cases within the same severity category. Page et al. [4], for instance, tried to address this problem by defining three categories of energy-equivalent speed (EES) for vehicle damage, but admitted difficulties in calculating and harmonizing these measurements among different research institutes.

Even with impacts directed on the immediate occupant compartment, differences can be found when taking a closer look at the individual deformation patterns. For instance, a near-side driver may not have been subjected to direct intrusion force if the major deformation of the compartment occurred in the area of the left rear door. Likewise, loading on the compartment may be different depending on whether a door structure is deformed only in the center portion or whether a rigid structure like the door sill or B-post is involved. Consequently, a number of cases with considerable door intrusion were seen in the material in which the side airbag system was not triggered whereas it deployed in, for instance, side-swipe crashes with little deformation depth, but some involvement of rigid structures.

The comparison of cases, regardless of vehicle age, with and without thorax side airbag deployment demonstrated only a small reduction of thoracic injury risk for type II and type II crash severities. Since these differences may have been due not only to airbag deployment, but also due to improvements in structural strength, the analysis was repeated only for cars belonging to models introduced in 1997 or later. No reduction could be determined for thoracic injury risk from airbag deployment, rather some increase in minor severity crashes (type I). Analysis of upper extremity injuries, though few in number, indicated a slight reduction of risk for this body region. It may be speculated that a deployed thorax side airbag keeps away concentrated load from the arm and shoulder. As could be expected, no positive effect of a deployed TSAB could be established for the injury risk in the head, abdomen and lower extremity region since these areas are usually not directly covered by this type of airbag. The evaluation of effects of separate head side airbags on head injury risk, however, demonstrated reductions for all crash severity types (type I to type III), though based on small numbers for deployed HSAB's.

While the results from the analysis by body region were not always clear, both types of side airbags appear to have a positive effect on the overall injury risk for a near-side occupant in medium severity crashes. The risk for MAIS 2 and MAIS 3+ (Maximum AIS) was reduced by thorax and by head side airbags for type II crash severity. Presumably, it represents the range of crash severities that are currently addressed in laboratory tests for side airbags.

Our case material included a number of AIS 2 and even AIS 3+ injuries in conjunction with deployed side airbags that were not seen – or at least less frequently – without side airbag deployments. While this may be explained in part by the relatively small case numbers for type I and type III crash severities or possibly unfavorable factors in very severe crashes, adverse effects of side airbag deployments are conceivable, too. Similar findings were also reported in Page et al's review of previous side airbag studies [4].

Conclusions

Due to the large complexity of side collisions and the variety of side airbag concepts on the market, it has proven difficult to quantify the effectiveness of side airbags in field studies.

Under the crash conditions evaluated in our study, thorax airbags were not able to demonstrate clearly that they diminish the risk of thoracic injury whereas separate head side airbags reduced the frequency of serious head injury. Nevertheless, both airbags appear to reduce the risk of overall injury as expressed by MAIS. In conclusion, side airbags may currently fail to prove beneficial for the risk of injury in certain body regions while they still enhance occupant protection on the whole.

There is apparently a large variance in whether side airbags become activated or not activated in real-world crashes of minor to medium impact severity. This suggests that triggering algorithms for these systems may be geared too much to standard crash test scenarios. Potentially adverse effects by unnecessary or delayed side airbag deployment need further investigation. Besides case-by-case analysis of individual collisions, crash testing at lower speed and under different impact angles may be helpful to shed light on these issues.

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German Insurers Association

Wilhelmstraße 43 / 43G, 10117 Berlin
PO Box 08 02 64, 10002 Berlin

Phone: + 49 (0) 30 2020 - 5000, Fax: + 49 (0) 30 2020 - 6000
Internet: www.gdv.de, www.udv.de