COMPARISON OF REAL WORLD SIDE IMPACT / ROLLOVER COLLISIONS WITH AND WITHOUT THORAX AIRBAG / HEAD PROTECTION SYSTEM: A FIRST FIELD EXPERIENCE STUDY

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ABSTRACT

After the introduction of the Thorax Airbag (TA) and the Head Protection System (HPS) by BMW there has been a significant reduction of injuries in real-world collisions. Comparison of similar collisions (in-depth collision analyses) of vehicles with and without HPS/TA indicates that the effectiveness of the system was credible. Minor injuries (AIS 1) increase while serious injuries (AIS 3+) are reduced. Based on the limited cases available, a proper statistical sampling could not be achieved at this time, however the results are to be understood as indicative of a trend.

METHODS

GENERAL - BMW Accident Analysis performs in-depth investigations of serious collisions involving injured occupants in BMW vehicles in Bavaria. Knowledge gained from these investigations is made available to Research and Development.

CRITERIA - For the evaluation, side collisions with front seated occupants (side impact direction between 1 and 5 o'clock and/or 7 and 11 o'clock) and rollovers with front seated occupants involving the following were included: old 3-series (production between 9/90 and 12/97), new 3-series (production since 1/98), 5-series (production since 2/95) and 7-series (production since 10/94). For both collision types only injuries to the following body regions were considered: head, thorax, cervical spine and upper extremities. A further criterion was that the injuries were caused by impact with the following vehicle parts: side window, side window frame, roof rail, B-pillar, door trim with armrest, TA and HPS.

SIDE COLLISION CRITERIA - Side collisions were considered, provided that EES ≥ 20 km/h. Only near side occupants were taken into account. Hand injuries were excluded, as they could not always be matched up to the vehicle parts mentioned in the above paragraph.

ROLLOVER CRITERIA – EES was not considered as a limit for rollovers due to multiple collisions and the complexity of such. Due to the complexity of the occupant kinematics, the origin of cervical spine injuries is difficult to ascertain. Therefore, these injuries were excluded. However, injuries from ejection (partial and complete) through the side window were included. It should be mentioned, that HPS/TA only deploy in conjunction with a severe side impact.

NUMBER OF CRASHES– Considering the evaluation criteria, the following number of crashes were evaluated (Table 1).

	Side Collision		**Rollover**		**Total**
	no HPS/TA	with HPS/TA	no HPS/TA	with HPS/TA	
Crashes	**14**	**10**	**40**	**9**	**73**
Occup.	**14**	**10**	**50**	**12**	**86**

Table 1 – Number of crashes (Source: BMW Accident Analysis)

SIDE COLLISIONS

SIDE COLLISIONS/FATALITIES – Of all severe collisions (BMW Accident Analysis – in depth accident investigation in Bavaria with severely injured occupants in current BMW models), side collisions in Germany occur with a frequency of app. 20%. This generally concurs with the US data where the frequency is reported to be 21% [NHTSA, 1999]. However, when focusing solely on fatalities, side collisions (without protection system) are disproportionately represented with 36% of fatal injuries (Fig. 1).

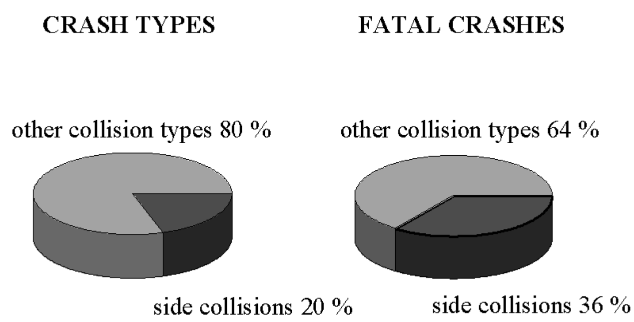


Fig. 1 – Side impact frequency and fatality representation of BMW vehicles (Source: BMW Accident Analysis)

FREQUENCY OF INJURY IN SIDE COLLISIONS - The risk of severe injury for the occupants in a side collision is, according to data collected by BMW Accident Analysis, significantly higher than in frontal collisions. The distribution of injuries by body region is shown in Fig. 2. The head and thorax are particularly susceptible to injury during side collisions.

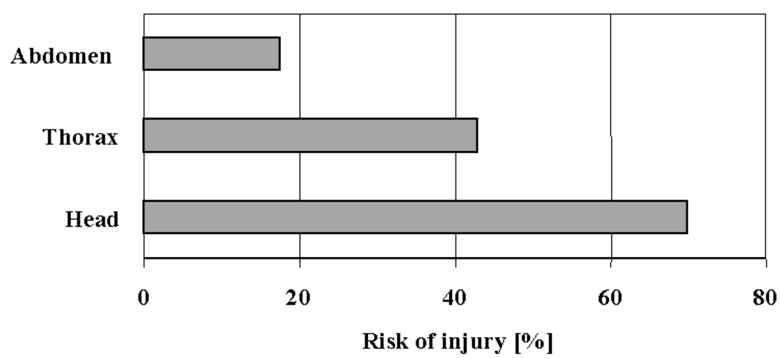


Fig. 2 – Distribution of injuries from side collisions by body region (Source: BMW Accident Analysis)

INJURY MECHANISM – Our own data of crash tests and real world crashes provides results regarding the injury mechanism similar to results already published by other researchers [Morris, Hassan, Mackay, 1993]. Principally, there are two injury mechanisms in side collisions (Fig. 3). The left photograph shows the direct contact of the head (black circle) with an object (e.g. side window, B-pillar, tree or light pole) in combination with a lateral flexion and shear, possibly in combination with an axial compression (flexion compression) of the cervical spine (gray circle) (see also Fig. 5 and 6). The right photograph shows a lateral hyper flexion of the cervical spine (gray circle) without head contact, e.g. in cases of side collisions with a broken side window and a lateral motion of the head through the plane of the side window.

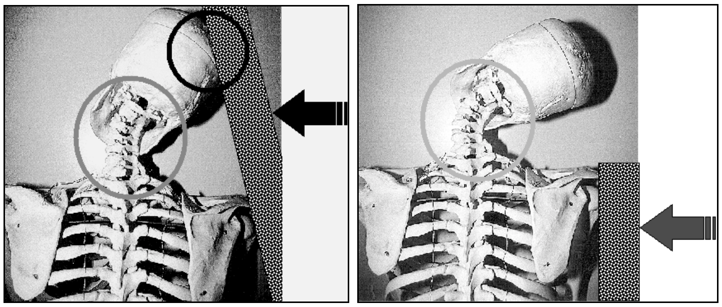


Fig. 3 – Injury mechanism in side collisions

SIDE PROTECTION SYSTEM

The BMW side protection system consists of a Thorax Airbag (TA) and a Head Protection System (HPS) [Yaniv, Romeo, Kompass, 1996; Kompass,1995]. The TA deploys between the occupant and the intruding side structure and protects the thorax (Fig. 4). The TA was initially installed by BMW in the 5 and 7-series in the spring of 1996 and later as standard equipment in all other models. Based on the high risk of serious head injuries in side collisions, BMW developed the completely new HPS (Fig. 4). Starting in the summer of 1997, the system was initially available in the 7 and 5-series vehicles as standard equipment. Since the summer of 1998, all BMW vehicles have been equipped with HPS as standard equipment. Exceptions are special models, such as convertibles.

Fig. 4 - HPS and TA

In a non-deployed stowed position, the HPS is fitted in the upper area of the A-pillar and in the roof rail under their respective trims. The relatively long duration of the inflation after deployment offers protection against multiple collisions, as well as, side collisions with accompanying rollover. The HPS achieves a tension of 5kN, which makes a supporting surface for the bag (e.g. the side window, which frequently shatters during the collision phase) unwarranted.

IIHS SIDE IMPACT TEST

The effectiveness of HPS and TA was proven by various test procedures (e.g., FMVSS 214 or EURO-NCAP). At the Insurance Institute for Highway Safety (IIHS), comparison tests were performed in 1997 with and without HPS [IIHS, 1997]. During the tests, following today's FMVSS-201-criteria, a 5-series BMW was driven sideways against a pole. The speed chosen was 32 km/h (FMVSS 201, 29 km/h).

Fig. 5 – Dummy kinematics with and without HPS

The test comparisons clearly indicate the effectiveness of HPS with regard to neck kinematics and head contact (Fig. 5). The different load values of the head and neck (Fig. 6) support the value of the system.

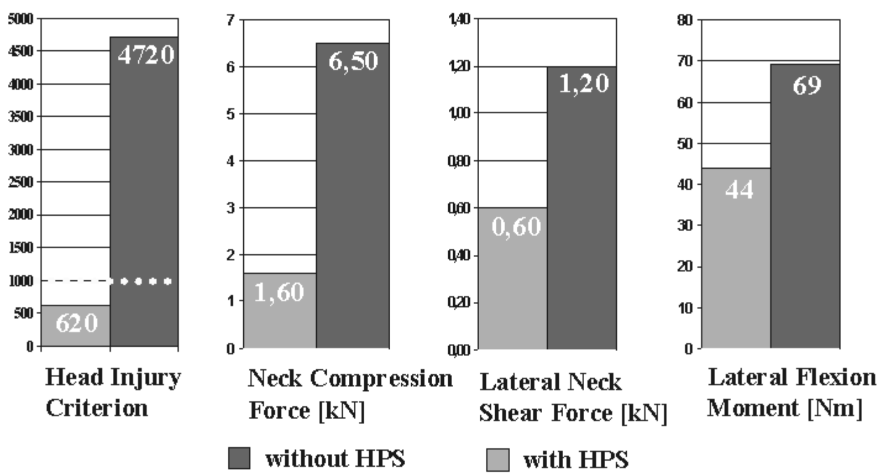


Fig. 6 – Load values with and without HPS (Source: IIHS)

CASE STUDIES OF SIDE COLLISION CRASHES

The following examples compare collisions with and without HPS/TA, and indicate the benefit of these devices. At the same time the methodology of BMW Accident Analysis is demonstrated.

SIDE COLLISIONS AT INTERSECTIONS – Two examples of side collisions at an intersection are shown as a comparison regarding HPS/TA in the following.

<u>Collision without HPS/TA</u> - A BMW 316i Compact drove into an intersection with a green light. A Mitsubishi Pajero (midsize utility vehicle) coming from the left ran a red light and frontally collided with the left side of the BMW (impact speeds: BMW app. 43 km/h, Pajero app. 77 km/h). The Compact was struck (Δv_y app. 30 km/h) at a 9 o'clock position (Fig. 7). The trailer of the Pajero uncoupled during the collision. The Compact was hit behind its center of gravity and rotated counter-clockwise. In addition, the vehicle collided frontally with a traffic light pole and the driver front airbag deployed.

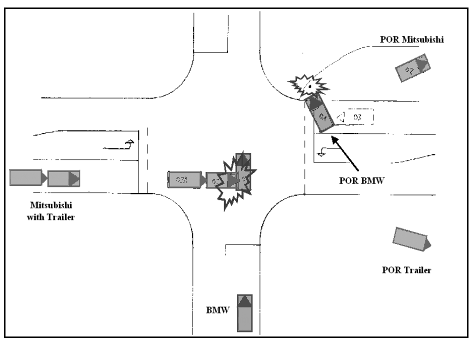


Fig. 7 – Collision scene

The BMW was damaged from the driver door to the rear; the deepest intrusion, app. 20 cm, was in the region of the rear axle. The lower region of the B-pillar intruded 10 cm into the passenger compartment (Fig. 8). The damage corresponds to an energy equivalent speed (EES) of app. 25 km/h.

Fig. 8 – Damage to the BMW 316i Compact

Using the software package PC-Crash (Version 5.1) [Steffan, 1993], this collision was reconstructed and animated three-dimensionally. The collision was videotaped by the police (red light monitoring). The police video impressively confirms the collision reconstruction. The vehicle movement calculated with PC-Crash was imported into the MADYMO simulation program [Lupker, 1996] and used as the basis for the occupant kinematics. A 50th percentile H3 dummy was used as a passenger model. With this simulation the occupant injury kinematics could be determined.

The driver was belted. She suffered an extensive head laceration app. 10 cm long, with a large surface skin abrasion on her left temple (resulting in a permanent scar) (AIS 1) (Fig. 9) and a cerebral concussion caused by contact with the breaking side window. Furthermore, she obtained a cervical spine distortion (AIS 1) caused by a lateral bending and two fractured ribs on the left side (AIS 2) caused by the interior side structure of the door panel.

Fig. 9 – Head and neck injury

Collision with HPS/TA - A VW Golf crossed a highway and frontally collided with the left side of a 3-series BMW (impact speeds: BMW app. 85 km/h, Golf app. 35 km/h). The impact (Δv_y app. 25 km/h) to the BMW 318i came from the 10 o'clock direction to the vehicle (Fig. 10). Both vehicles rotated counter-clockwise. The positions of rest of the vehicles were app. 50 m from one another.

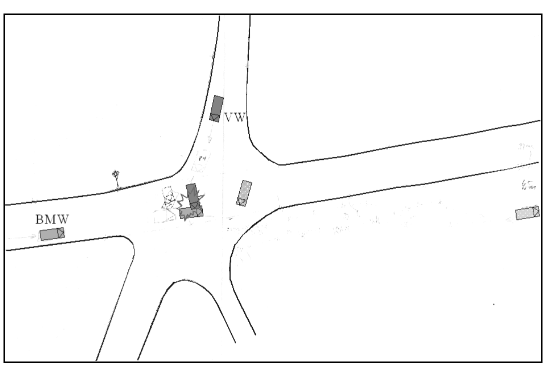


Fig. 10 – Collision scene

The primary damage to the 318i occurred in the area of the A-pillar and the driver door. The deepest intrusions were in the region of the A-pillar, app. 6 cm and in the region of the B-pillar, app. 5 cm. The EES was estimated at app. 23 km/h (Fig. 11).

Fig. 11 – Damage to the BMW 318i

In this collision the driver suffered only a minor cervical spine distortion (AIS 1) – no definite causation detectable, possible injury mechanism e.g. lateral neck bending (near side and/or rebound) - and was otherwise uninjured. No load marks were found on the belt.

Comparison of these collisions shows that the points of impact, the relative position of the vehicles to each other and the vehicle speed at impact differ. For this purpose the interior padding and side structure in relation to the occupant is identical for both vehicles. The EES values are, however, virtually the same. The MADYMO simulation for both collisions showed that they can be compared since the occupant loading and kinematics of the occupants are similar. In both collisions the driver moved against the side structure. The effectiveness of HPS/TA is shown by comparison of the injuries.

SIDE COLLISIONS WITH TREES – The accident type "side collision with a pole or tree" provides the greatest amount of loading to the vehicle side structure. In the following examples, the benefits of the HPS/TA are particularly striking.

<u>Collision without HPS/TA</u> - A BMW 525i lost control on a gentle left curve, spun clockwise and collided with the left side into trees (Fig. 12).

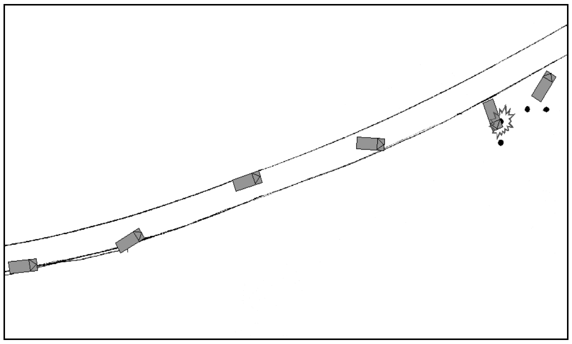


Fig. 12 – Collision scene

One of the trees intruded at a 9 o'clock position app. 45 cm into the vehicle in the region of the A-pillar (impact speed app. 47 km/h, Δv_y app. 27 km/h). The EES was app. 35 km/h (Fig. 13).

Fig. 13 – Damage to the BMW 525i

The belted driver was seriously injured in this collision. A direct impact trauma of the head with the interior roof frame led to intracerebral bleeding (white circle, Fig. 14) (AIS 4). There were numerous contusions to the thorax (AIS 1) - no definite causation detectable - in addition to superficial lacerations to both ankles (AIS 1) caused by the side panel in the foot well.

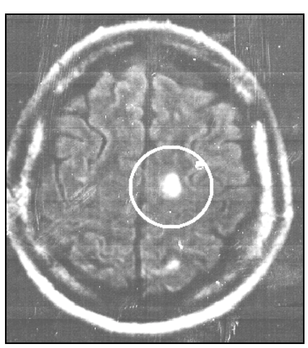


Fig. 14 – Head Injury

Collision with HPS/TA – A 730d went out of control in a left curve, spun clockwise off the road and collided into a tree on the driver's side (impact speed app. 52 km/h, Δv_y app. 30 km/h) (Fig. 15).

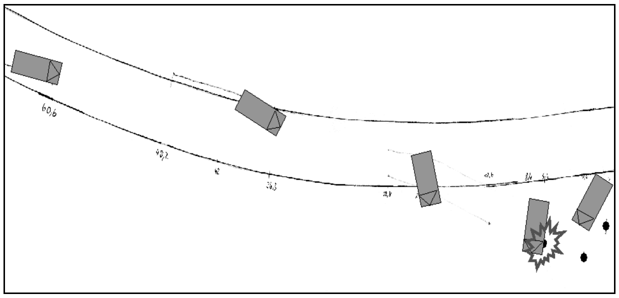


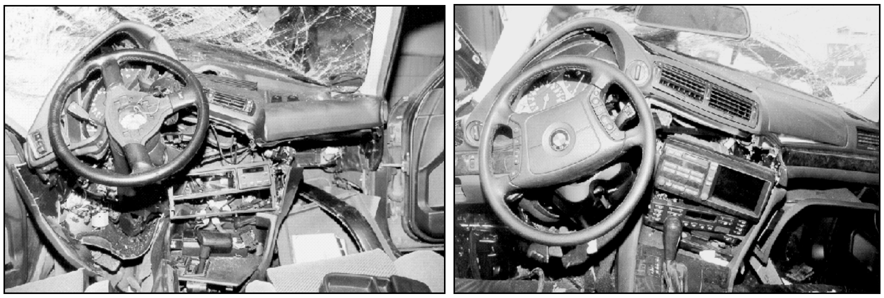
Fig. 15 – Collision scene

The tree penetrated the A-pillar region app. 42 cm into the vehicle from a 9 o'clock direction. The EES was estimated to be 35 km/h. The TA and the HPS (white circle) deployed (Fig. 16).

Fig. 16 – Damage to the BMW 730d

The belted driver suffered only a minor cervical skin laceration (AIS 1) caused by the seat belt webbing, contusions of both lower legs (AIS 1) caused by the side panel in the foot well and a contusion of the coccyx (AIS 1) – no definite causation detectable.

Comparison of the damage – Looking at the interiors of both vehicles (Fig. 17), it can be observed that the damage to both vehicles is quite the same. The intrusion, as well as, the impact directions are almost identical, inviting the comparison.



525i, without HPS/TA 730d, with HPS/TA

Fig. 17 – Interior comparison

ROLLOVER

Single rollovers occur with a frequency of app. 11% of all severe collisions and the rate of fatalities is app. 20% (BMW Accident Analysis). The causation of all severe and fatal injuries (AIS 4+) in cases without a protection system is a partial or complete ejection.

Due to the complexity and uniqueness of rollovers, a comparable pair of events was not available. At this time only a statistical approach on the value of side protection is available.

RESULTS

SIDE COLLISIONS - The individual injuries are listed by body region and seriousness (AIS) (Table 2). To date there have been no AIS 2+ injuries in side collisions with HPS/TA.

	no HPS/TA				with HPS/TA			
AIS	Head	Thorax	Upper Extr.	Neck	Head	Thorax	Upper Extr.	Neck
0	**5**	**9**	**7**	**11**	**5**	**9**	**9**	**8**
1	**3**	**1**	**2**	**2**	**5**	**1**	**1**	**2**
2	**4**	**2**	**4**	**0**	**0**	**0**	**0**	**0**
3	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**
4	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
5	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
6	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**0**

Table 2 – Distribution of injuries in side collisions by body region and severity (Source: BMW Accident Analysis)

Fig. 18 and 19 show the percentage of injuries to different body regions, comparing side collisions with and without HPS/TA. Principally, there is an increase in AIS 1 injuries (head by 29%, thorax by 3%, neck by 6%), with the exception of upper extremities, which were reduced by 4%. There were no AIS 2+ injuries anymore.

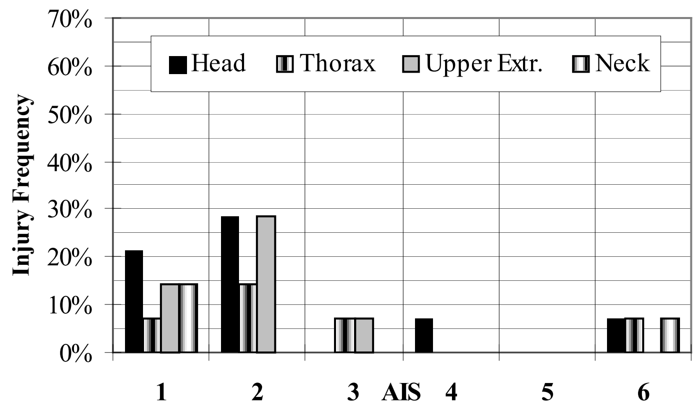


Fig. 18 - Injury frequency in side collisions without HPS/TA
(Source: BMW Accident Analysis)

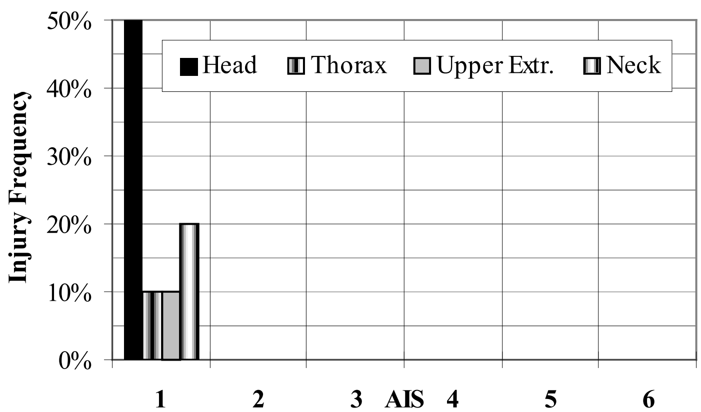


Fig. 19 - Injury frequency in side collisions with HPS/TA
(Source: BMW Accident Analysis)

ROLLOVER - The individual injuries are listed by body region and seriousness (AIS) (Table 3).

	no HPS/TA			with HPS/TA		
AIS	Head	Thorax	Upper Extr.	Head	Thorax	Upper Extr.
0	**30**	**46**	**42**	**3**	**11**	**10**
1	**11**	**0**	**5**	**8**	**1**	**2**
2	**2**	**1**	**3**	**1**	**0**	**0**
3	**2**	**0**	**0**	**0**	**0**	**0**
4	**0**	**1**	**0**	**0**	**0**	**0**
5	**0**	**1**	**0**	**0**	**0**	**0**
6	**5**	**1**	**0**	**0**	**0**	**0**

Table 3 - Distribution of injuries in rollovers by body region and severity (Source: BMW Accident Analysis)

Fig. 20 and 21 show the percentage of injuries to different body regions, comparing rollovers with and without HPS/TA. AIS 1 injuries increased (head by 45%, thorax by 8%, upper extremities by

7%) where there were no serious injuries (AIS 2+), with the exception of one AIS 2 head injury.

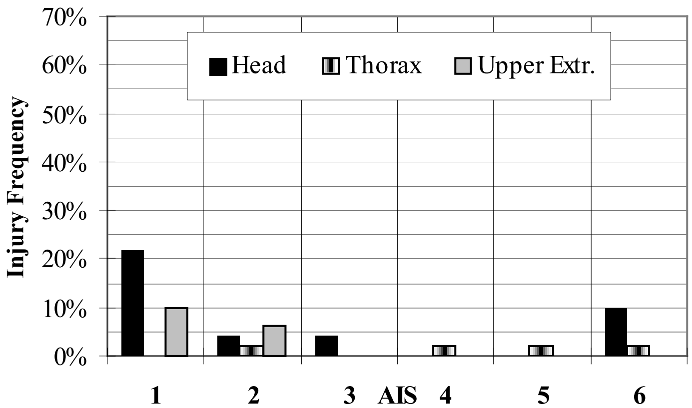


Fig. 20 - Injury frequency in rollovers without HPS/TA
(Source: BMW Accident Analysis)

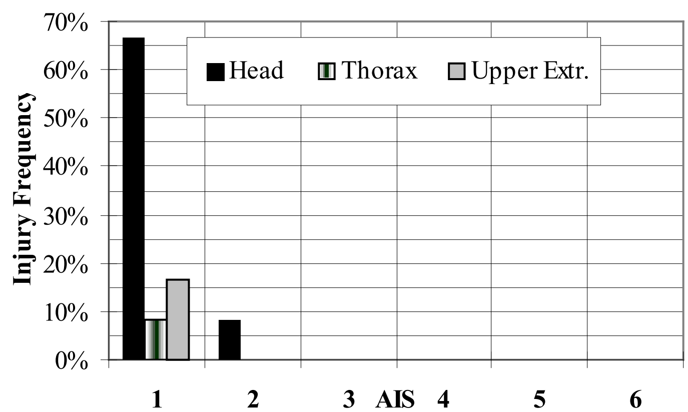


Fig. 21 - Injury frequency in rollovers with HPS/TA
(Source: BMW Accident Analysis)

DISCUSSION

Fig. 22 shows the benefit in its totality; while AIS 1 injuries increase, AIS 2+ injuries are reduced.

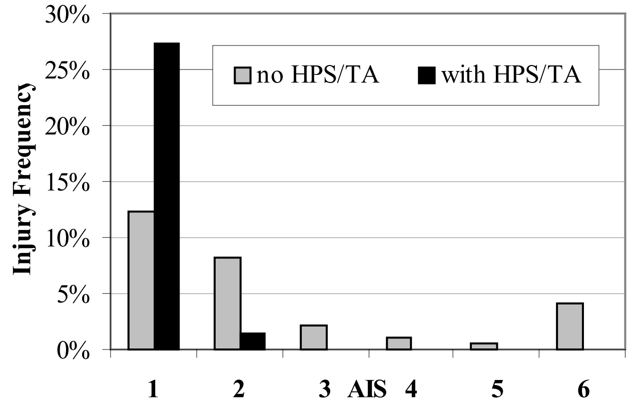


Fig. 22 - Frequency of all injuries (head, thorax, upper extremities) in side collisions and rollovers (Source: BMW Accident Analysis)

Although the scope of currently available data does not permit a statistically valid statement, it is presumed that this trend will continue. Otherwise, even in this limited quantity of cases, there would have been severe injuries (AIS 3+) expected, since the data used was based on observations of serious collisions only. It is interesting to observe that the HPS is responsible to a greater extent for the reduction of serious injuries than the TA.

Data gained from collisions involving vehicles equipped with other inflating protection systems should demonstrate whether the trend reported here is generally applicable, or is restricted only to the HPS/TA by BMW.

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(Presenter: Peter Baur)

Jim Pywell: The PC crash simulation you showed clearly showed a pretensioner being deployed prior to the head protection system and thorax bag being deployed. Is that part of BMW's design to deploy a pretensioner and, if so, can you attribute the degree of protection due to the belt system with a pretensioner?

P. Baur: We do have a pretensioner. I'm not so happy with the timing because it happens at the same time, but we do have a pretensioner in this car. What the benefit is in this type of accident, I assume, very little. I don't know, but I believe that the pretensioner is helpful in frontal crashes.

J. Pywell: But you do deploy it in the side impact scenario that you showed and simulated.

P. Baur: As you have seen, in this accident there is a forward component and because of that, it might actually help and you never know in advance how many degrees forward component you have.

D. Slavik: Are your pretensioners equipped now to fire in a rollover?

P. Baur: No, we don't have a rollover sensor and therefore the pretensioner wouldn't know that there is a rollover. But it is certainly something we should have in the future and as soon as we do have a rollover sensor that we can rely on, I'm certain we will have it.

Rolf Eppinger: You suggested that the thoracic bag did not provide much performance in the field. Were you anticipating from your dummy test that you would have a better performance from the thoracic bag?

P. Baur: I wouldn't say exactly that we would expect much better performance. The problem is that we have so few data and not extremely severe accidents. If you go with an EES of 35-40 kilometers then I would expect we could use other methods and get to the same result.

R. Eppinger: Did the dummy indicate that you would expect better performance with the bag rather than without the bag?

P. Baur: I can't answer that question, sorry.