SEVERITY AND MECHANISM OF HEAD IMPACTS IN CAR TO PEDESTRIAN ACCIDENTS

Otte, Dietmar
Accident Research Unit, Medical University Hannover / Germany

ABSTRACT

This study will show results of 762 car to pedestrian collisions, documented in In-depth Investigations on the scene at the Medical University Hannover/ Germany. In-depth Investigations are carried out in Hannover since 25 years by a team of technicians and physicians by order of the Federal Highway Research Institute (BASt). Deformation pattern of cars, description of injuries and contact points on the car and characteristics of special traces on the scene and on the vehicle are documented for analyzing injury mechanisms. A comprehensive reconstruction of motions of the pedestrian body is carried out and the collision speed is determined. The situation for the injuries are described in relation to collision speed.

- 70% of all accidents with pedestrians happened at an impact speed of up to 40 km/h, 30% were higher.
- Collision speed of more than 40 km/h have an injury severity risk of 31% MAIS 1, 65% MAIS 2-4 and 4% MAIS 5-6.
- 4.7% of the pedestrian heads colliding in the speed range of up to 40 km/h did suffer injuries during an impact to windscreen region, but 63.6% of the heads with speeds of more than 40 km/h suffered injuries from that region.

The detailed impact situation of the head in the area of the windscreen was analyzed and the deformation patterns of the glass and the frame was compared to the injury pattern of the head.

It could be pointed out that most of all windscreen impacts with the head occurred to the lower half part of the screen and a very low number to the glass near or on the frame region. The injury severity of the head is not significantly higher in the frame region than in the middle-part of the screen.

In this study improvements for reducing the injury severity are postulated and a proposal for an optimized test procedure is described.

IN 1996 2.269 MILLION TRAFFIC ACCIDENTS occurred in the Federal German Republic, 373.000 of these included personal injuries (StBA - 1996). 501,916 persons were injured in these accidents. The pedestrians represent a proportion of 8.3% of the total number of injured victims in accident occurrences. 1,178 pedestrians were killed. For Europe 7,000 killed pedestrians are reported by Davies et al (1997).

During the past 15 years, the number of pedestrians in road accidents has been declining (Figure 1). In 1987 12.1% of persons injured in accidents were pedestrians. Ten years later, only 9.3% were registered. The severity of injuries to involved persons also shows a visible steady reduction. On the other hand an increase in the number of slightly injured was observed.

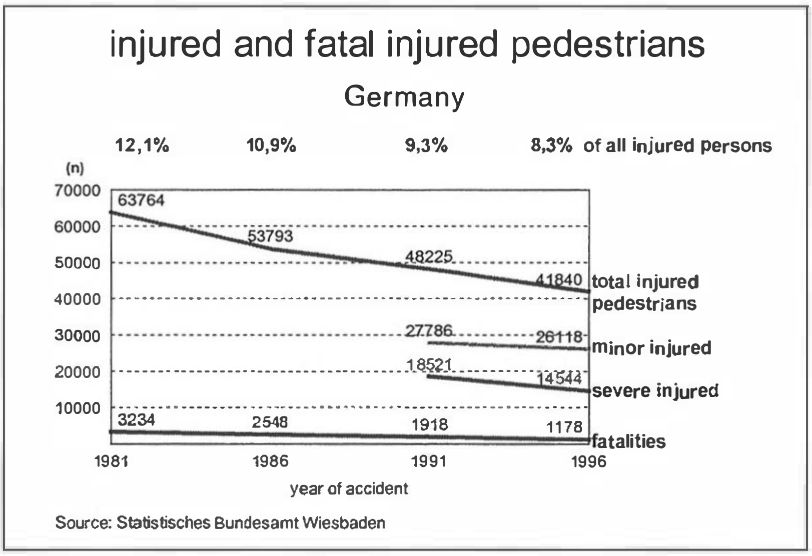

Figure 1 Number of victims in accidents car to pedestrian in entire Germany for a duration of 15 years

The cause for this very positive trend in low injury frequency for pedestrians in the road traffic scene can not be completely analysed. One reason for this is the fact that for the same period of time for nearly all traffic participants a similar trend for the reduction in the number of injured persons is evident. For this reason, the external shape of the vehicles can not exclusively be responsible for this result. Measures for reshaping of the traffic field and/or a change in the driving behaviour of traffic participants and possibly a reduced driving speed could have contributed to this reduction in injuries.

It is the task of this study to analyse the influence of the vehicle on the injury situation of pedestrians in a collision and to comprehend the development on the vehicle, due to modification of the vehicle front. Investigations at the place of accident offer very valuable information. For this purpose a scientific team of technicians and medical scientists drive to the scene of accident, immediately after the accident[1]. Accidents are documented within the framework of a statistical spot check plan, under a similar method, carried out continuously since 1985. The collecting of data starts directly on scene, where accident traces, vehicle deformations and injuries are documented.

METHOD AND BASIS OF DATA

762 accidents with cars and pedestrians who collided with a car front were documented, with special attention to the shape of the vehicle front. Exclusively cars with a standard front shape were included in the evaluation. The so-called box vehicles (among other trucks and small buses) were not included. The

[1] By order of Federal Highway Research Institute (BASt)

accident documentation can be taken as representative for the investigation region, that is town and suburban districts of Hannover. Details regarding the documentation methods are described by Otte (1990). The injuries are investigated in detail and stored in a data bank, according to type and severity AIS of the Abbreviated Injury Scale (American Association for Automotive Medicine, 1990). Traces found on the road, such as braking marks, final positions of vehicles and persons were documented in a true-to-scale drawing and will serve as an important factor for the determination of the collision and driving speed. The kinematic of the pedestrian is established by traces found on the vehicle and the road, which will be compared to the respective injuries. The cognition about the physical process of a pedestrian accident and the connected details will be used exclusively for the study. Test trials are carried out with dummies in order to establish throwing and slipping ranges. These will serve as a device for the determination of speed (Otte, 1989).

Within the framework of the study the investigated vehicles of the production years before and including 1990 are called "old vehicles" and those after production year 1990, are called "new cars" were comparatively analysed. The year of introduction to the market of each car model was defined as production year. The injuries to pedestrians were correlated with the different impact regions, such as bumper, edge of the vehicle front, front hood and windscreen pane, regions which within the framework of component test procedures according to EEVC, with the exception of the windscreen pane are regarded as test point (EEVC, 1996). Within the framework of this study special attention will be paid to these impact regions.

INJURY SITUATION OF THE PEDESTRIAN

It is generally shown in the statistical weighted analysis that 61% of all pedestrians suffered minor injuries (MAIS 1), 25.3% with MAIS 2 and 10.3% with MAIS 3 were seriously injured. Only 3.4% suffered MAIS 4 and more (MAIS 4+) severities (Table 1). This correlates with the generally low number of seriously injured pedestrians. Officially all patients that are treated stationary in hospital are registered as seriously injured. Those treated as out-patient were registered as "slightly injured". This correlates with the scientific AIS scale MAIS 1 as slight, MAIS 2-4 as serious, and MAIS 5/6 as severely injured or killed (Otte, 1995).

When comparing accidents before and after 1990, it becomes evident that the accident severity is more often less serious. The proportion of newer cars in the accident scene of the years after 1990 is 19.7%. This relatively small proportion of newer vehicles in the accident scene could be explained by the fact that less than 5% of vehicles involved are at the time of the particular accident year only up to one year old. This is demonstrating the effect, that not exclusively new cars are responsible for this.

Table 1 Injury severity of pedestrians

	total	year of accident 85 - 90	91 - 95
total accidents	762	425	337
proportion newer cars	11,7%	5,0%	19,7%
maximum injury severity of pedestrian			
MAIS 1	61.1%	58.3%	64.5%
MAIS 2-4	37.4%	40,8%	33,3%
MAIS 5/6	1.5%	0.9%	2.2%
children up to 12 years old			
maximum injury severity of pedestrian			
MAIS 1	73.0%	72.6%	73.4%
MAIS 2-4	26.8%	27.4%	26.1%
MAIS 5/6	0.2%	-	0.5%
adults more than 12 years old			
maximum injury severity of pedestrian			
MAIS 1	56.5%	53.4%	60.3%
MAIS 2-4	41.5%	45.4%	36.7%
MAIS 5/6	2.0%	1.2%	3.0%

Children up to 12 years of age in general suffered more minor injuries than adults. Altogether only 0.2% of injury severity grades MAIS 5/6 were registered.

It was observed that 60% of all pedestrians sustained head injuries, in old as well as in new cars (Figures 2a and 2b). In newer vehicles fewer injury frequencies were established, for the thorax 14.6%, for the pelvis 12.6%, for the thigh 10.1%, the knees 23.5% and for the tibia 22.8%, which means for nearly all body regions. Higher injury frequencies, however, were established for the abdominal as well as the lumbar vertebra region and for the cervical vertebra (7.4%).

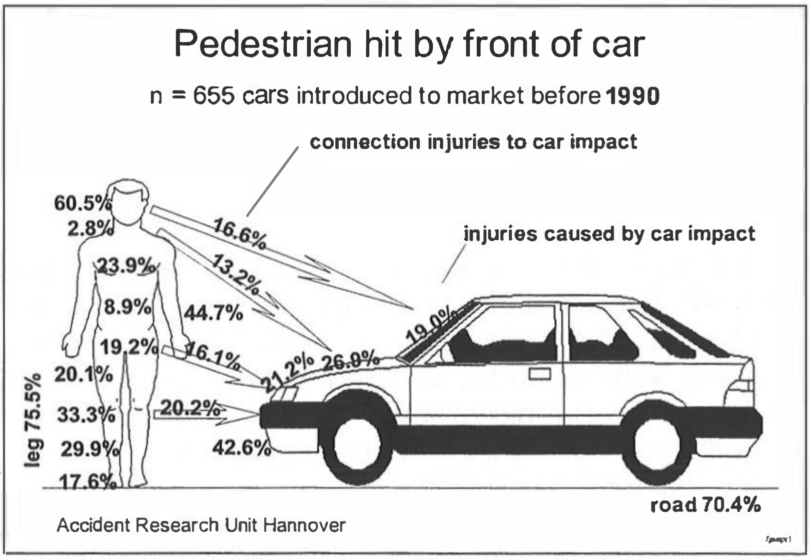

Figure 2a Causes of injuries related to the body shape and frequency of injured body regions (100% all pedestrians) - example: 60.5% of the heads suffered injuries, 16.6% of the injured heads suffered injuries by windscreen contact and 19.0% of the injuries were caused by windscreen impact

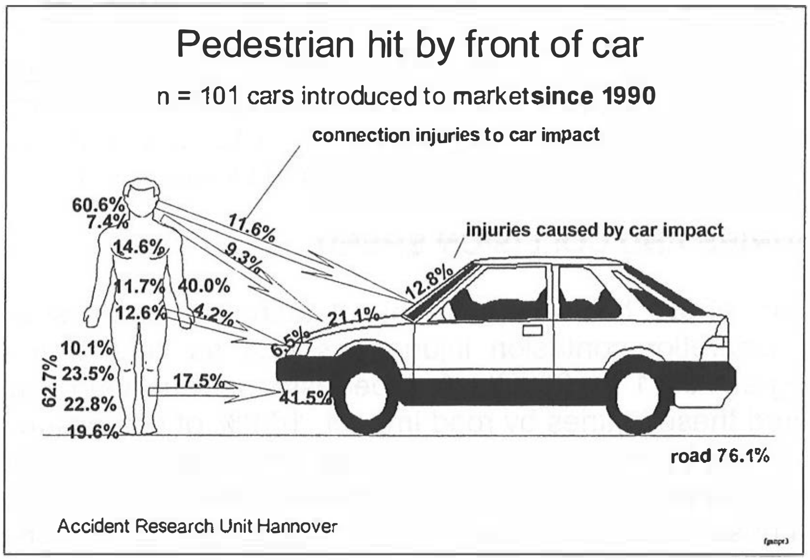

Figure 2b Causes of injuries related to the body shape and frequency of injured body regions (100% all pedestrians)

When observing exclusively the serious injuries MAIS 2+, Figure 3 shows a domination for head injuries. 24.9% of pedestrians suffered a severity grade MAIS 2+ were affected with serious head injuries in collision with older cars. But Figure 3 also shows a lesser frequency for serious head injuries and for all other body regions too in collisions with newer cars.

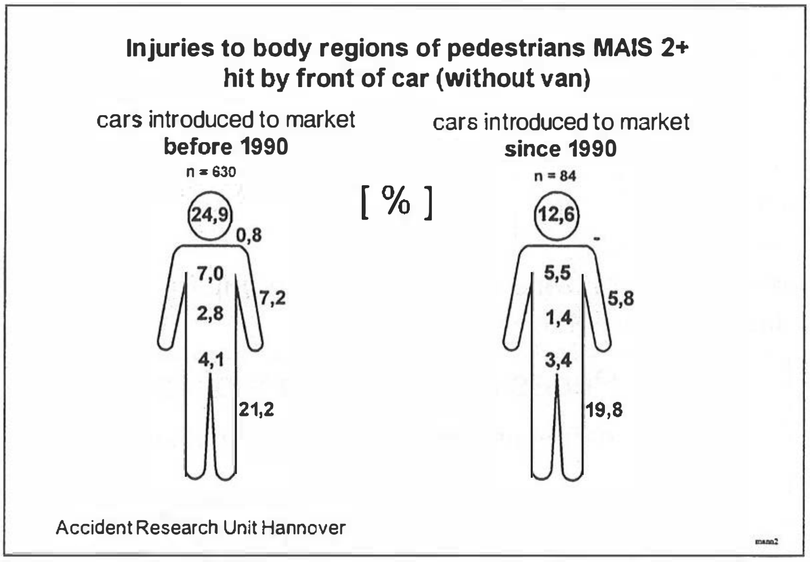

Figure 3 Frequency of injured body regions for older and newer cars (100% all persons each group)

In old cars 42.6% of pedestrians were injured by the bumper. In new cars these were 41.5%. Injuries by the edge of the front hood were caused in older cars to 21.2%, in new cars, however to only 6.5%, this means a considerable reduction. Injuries by the front hood area are with 21.1% for new cars only slightly less, when compared with 26.9% for old models. Injuries by the windscreen pane from newer cars also caused a reduction from 19% to 12.8%. When comparing vehicles according to the production year, newer cars are, due to the whole front design, inclined to cause fewer injures. A rotation of the pedestrian, however appears to be more frequent, when considering the fact that neck injuries with 7.4% and abdominal or lumbar vertebra injuries are registered with 11.7%. When analysing these injuries, concerning the cause, it can be stated that in newer vehicles 11.6% of head injuries occur by impact with the windscreen pane and 9.3% are caused by front hood impact.

HEAD INJURIES AND COLLISION SPEED

Two-thirds of all head impacts are leading to soft-tissue lesions, with abrasions, laceration-contusion injuries as well as cuts of the skin, mostly severity degree AIS 1 for 91.5% of all pedestrians with head injuries. 51.1% of them suffered these injuries by road impact. 16.9% of soft-tissue injuries on the car were caused by the hood and 19.8% by the windscreen pane. Fractures of the skull are frequent to the vault of the cranium and the middle face. Fractures of the skull base are rare. Another frequent injury type is the concussion, which is a low degree skull-brain trauma with short time concussion. 7.9% of pedestrians with head injuries receive this type of injury by an impact to the glazing pane. It was observed that the windscreen quite often causes injuries and is also responsible for fractures of the vault of the cranium, the skull base, the middle face and the skull-brain trauma (Table 2)

Table 2 Different types of head injuries and their impact location

pedestrian with head injuries n=543 (100%)	total	street	localisation of impact car				
			front	hood	screen	pillar	other
soft tissue	91,5	51,1	2,7	16,9	19,8	2,4	5,8
fracture of face	5,7	2,1	0,2	1,5	1,5	0,5	-
skull fracture	5,2	2,0	0,1	0,7	2,0	0,4	0,2
fracture of skull base	1,9	0,3	-	0,3	0,8	0,5	0,1
concussion	28,8	14,0	0,7	5,0	7,9	0,1	0,5
contusio	9,0	2,3	-	2,1	3,3	1,2	0,8

The probability of occurrence for the different injuries is definitely depending upon the collision speed of the car (Figure 4).

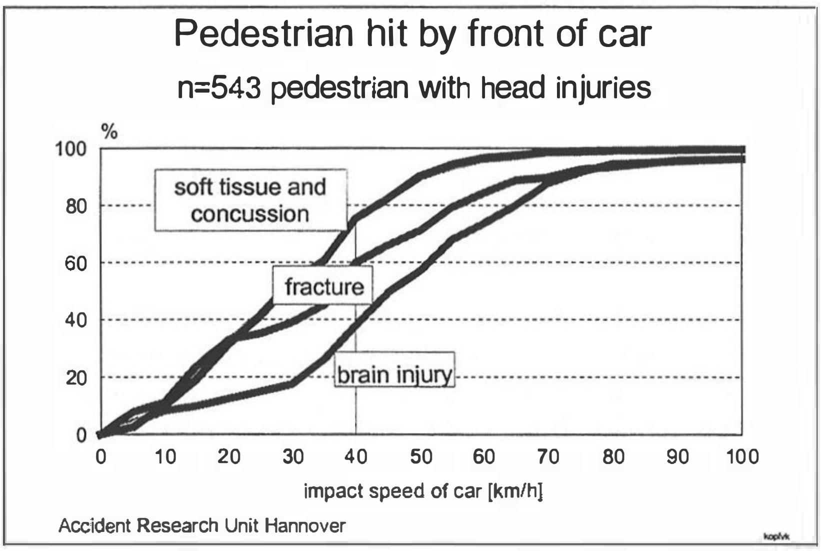

Figure 4 Cumulative frequency of different types of injuries in relation to the impact speed of car

While 80% of all soft-tissue injuries arose in collision speeds up to 40 km/h, 60% of the fractures and 40% of serious skull-brain traumas, the so-called contusion were registered. Due to this fact, it is not surprising that serious head injuries occur in higher collision speeds as a rule. The accumulated frequency reveals that for old as well as for new cars approximately 75% of all established collision speeds were exceeding 25 km/h, while in comparison for all pedestrian collisions 80% were registered in speeds up to 45 km/h (Figure 5).

It is remarkable that in newer cars in collision speeds up to 20 km/h almost no head injuries were registered. The severity of head injuries also determines the injury severity of the entire body. In collision speeds of 41 to 60 km/h for instance, 33.2% of the pedestrians were slightly injured (MAIS 1) and it can be stated with a 66.8% probability that injuries of MAIS 2+ are incurred (Figure 6). In all collision speeds above 60 km/h 14% only remain slightly injured (MAIS 1), but 23.1% get severely injured or are killed (MAIS 5/6).

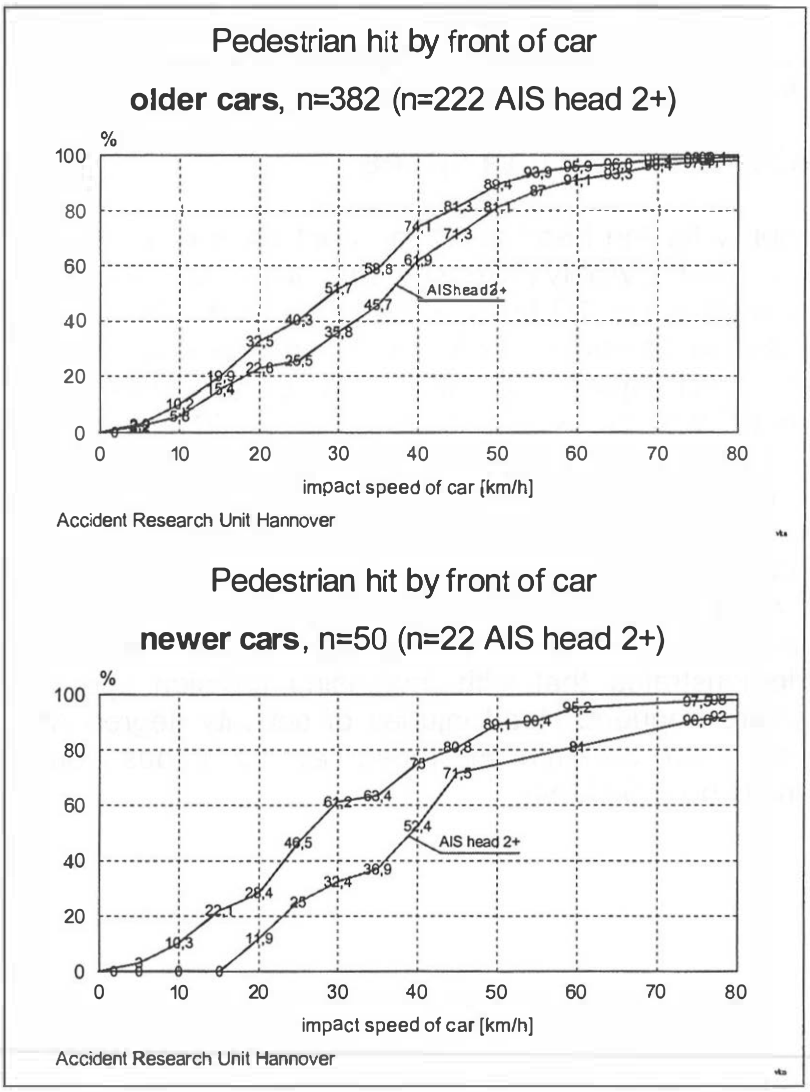

Figure 5 Cumulative frequency of impact speed of cars distinguished between all pedestrian and those with AIS head 2+ for older and newer cars

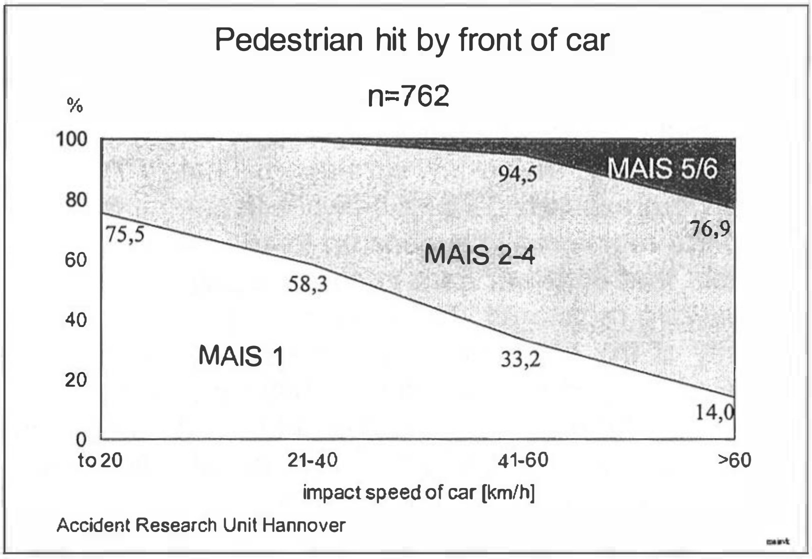

Figure 6 Injury severity for pedestrians for different impact speed ranges of car (100% all pedestrians for each speed range)

HEAD IMPACT POINTS ON CAR SHAPE

The probability for the head to hit the front pane or the lateral cross-beam the so called A-pillar is visibly increasing with higher collision speeds (Figure 7). In collision speeds up to 30 km/h a frequency of windscreen contacts below 10% is established. In speeds of 31 to 40 km/h already 38.4% of pedestrian accidents with head impact to the front pane or the A-pillar occurred. Injuries were sustained by 26%. With speeds of 51 to 60 km/h already 60.4% of pedestrian accidents occurred and with speeds of more than 70 km/h 90% were registered with head impact to the glazing structure of the front pane region or the metal structure of the upper A-pillar respectively the lateral windscreen frame. Not all contacts to the front pane region lead to injuries. This is apparent when comparing the different frequency curves for contacts and injuries of the head and serious head injuries of AIS 3+ as illustrated in Figure 7. It also demonstrates that with increasing collision speed serious head injuries are more frequent. Head injuries of severity degree AIS 3+ occurred only in speeds above 30 km/h and those severity grades significantly started more frequently above 50 km/h.

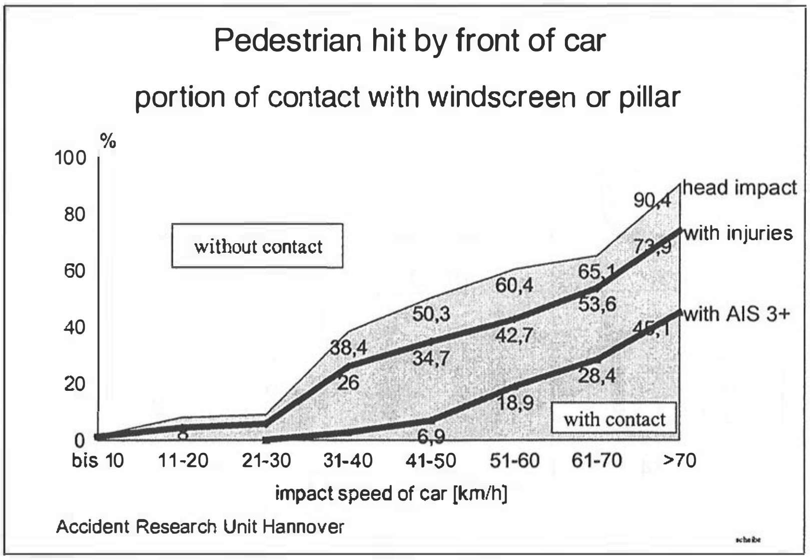

Figure 7 Frequency of injuries of head contact to the windscreen or A-pillar compared to contacts at all to this region in relation to impact speed (100% all persons per speed range)

Within the framework of this study, all documented and measured impact points on the windscreen pane or the lateral frame the A-pillar respectively were analysed in each case and transferred to a standardised drawing of a windscreen pane in Figure 8. It is attempted to evaluate the location of the head impact, i.e. the A-pillar, the upper roof edge region as well as the lower front pane or the front-hood part below the windscreen.

As far as the frequency of all impact points is concerned Figure 8 illustrates impact patterns showing remarkably many points on the lower half part of the windscreen pane. This reveals a rotation of the entire body within the impact kinematic. During the ladling-up phase the head experiences a downward directed movement. An impact to the lateral A-pillar is with 5.1% quite rare, and it doesn't show a high injury severity in most cases. Children quite often, and in this study especially, contact the bonnet leading edge, compared to this adults contact the bonnet surface.

The detailed analysis of the head impact points shows that serious head injuries do not occur only on the border region of the pane to frame but very frequently on the pane surface also. The dominating influential parameter for the windscreen impact is the collision speed of the car. Only in speeds of more than 40 km/h are impacts of the hood often found on the pane surface and here regions also found in the centre of the pane and, therefore, are the cause for serious head injuries.

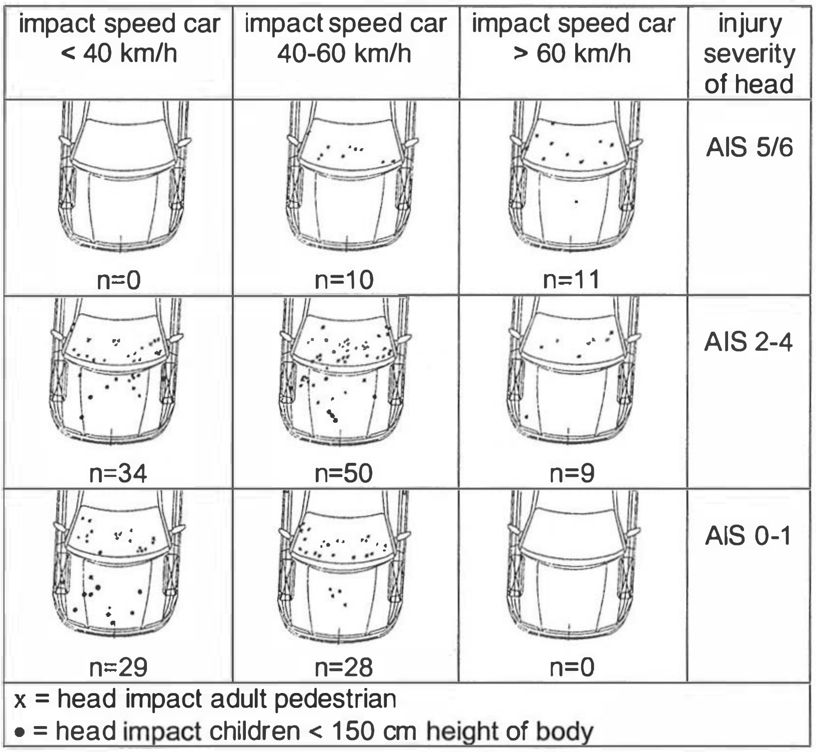

Figure 8 True to scale head impact location on the front shape by detailed case analysis on standardised front shape

The severity of an injury is depending upon the type and characteristic of the injury pattern. Obviously brain lesions are more severe than isolated fractures of the skull and soft tissue lesions. It could be established, that up to impact speeds of 40 km/h exclusively soft tissue lesions (74.1%), the concussion (20.5%) and fracture of the skull (2.8% only) happened. Compared to this in the speed range of more than 40 km/h fractures were registered with higher frequency. With speeds above 60 km/h 7.9% of the head injuries were fractures of the skull, 7.3% skull base fractures and very often a severe head brain trauma could be observed.

CONCLUSION

The safety for pedestrians in road traffic has clearly improved within the past few years. More than one third of pedestrians, however, suffered serious injuries. The head is regarded as the most seriously injured body region. 60% of all pedestrians suffer head injuries. 70% of all collision speeds are determined with speeds up to 40 km/h. Up to this speed level 60% of pedestrians are affected with head injuries. Most of the serious injuries are registered in this speed range. It could be established, that with higher speed levels, above 40 km/h, a still higher injury frequency with a probability of more than 80% occur, linked with often severe head injuries. For cars on the market with introduction year since 1990, so called newer cars, 93.6% of the pedestrians were registered with head injuries if the impact speed was above 40 km/h (Figure 9).

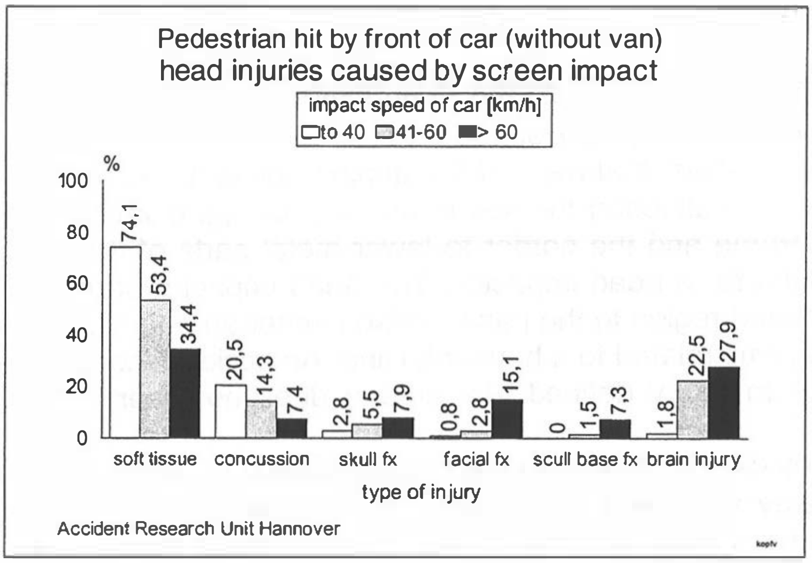

Figure 9 Frequency of types of head injuries in head impacts to the windscreen (100% head injuries of pedestrians per car impact speed range)

In impact speeds up to 40 km/h injuries caused by the windscreen region are, especially in newer cars with 4.7% relatively rare. In speeds exceeding 40 km/h the windscreen region is especially for newer cars with 63.8% very frequently documented as cause of injury. This may be due to the low number of cases in the investigation collective for this speed range. On the other hand, it could be due to a shorter front hood, which is often found in newer cars, especially in smaller, so-called compact cars.

The study clearly shows that the head impact often occurs to the lower half of the windscreen pane. Serious injuries of AIS 2+ are caused just as frequently in the lower and lateral edge region of the windscreen. This study demonstrates that the head of an adult pedestrian is mostly impacting the lower half of the windscreen pane and that this region is therefore responsible for severe head fractures and brain trauma (AIS 2+ injuries). The A-pillar is an area, which is seldom impacted by the head and no higher injury severity could be established than for the pane surface. It was analysed that the collision speed is the most important influence factor for the resultant injuries. Severe head injuries AIS 2+ exclusively happen with speeds of more than 40 km/h, while up to 40 km/h minor injuries such as soft tissue lesions and concussions are frequently.

The results from these investigations lead to the conclusion that there is no accident conformity of the test regulations within the framework of EEVC concerning the defined test speed related head injuries. Impact speeds of up to 40 km/h are not responsible for the severity of the head impact to the windscreen. The collision speed is the main indicator for the injury severity. The cause for serious injuries must be seen in the fact that the head often influence the grade of the trauma. Patients with poly-traumatic symptoms, who suffered injuries to at least three different parts of the body with injury severity degree MAIS 2+ nearly always suffer head injuries. The proportion of pedestrians with poly-traumatic symptoms amounts to only 4.7% of all injured pedestrians, but 61.4% of pedestrians suffered an impact to the windscreen. Beside the fact that the chances of survival for these patients are quite limited, there exists on the other hand also a high probability of long-term consequences. From the medical-traumatic point of view, measures are required for modification of the windscreen region, especially the pane itself. The head impact at least should be integrated in the EEVC test rules.

The study shows, that most of the impact points are found on the lower half of the pane. Considering this result an area of approximately 20 cm beneath the lateral frame and the border to lower metal parts of the bonnet should be used as point for a head impactor. The head impactor should impact with his lateral forehead region to the pane surface under an angle of 45 degrees of the body length axis related to a horizontal line. An accident-conform impact speed, diverging from today defined test criteria does not seem to be convincingly necessary.

The study clearly shows the following demands for future developments:

- An energy absorbing attachment of the pane in the anchorage system of the frame should be developed. On the other hand a more elastically material of the glass compound system could be used for such purpose.
- An optimising of the angle of the windscreen pane could help to reduce the head impact speed in connection with the kinematics of the ladling-up movement of the pedestrian body.

The results of this study should help for further development of car designs and finding measures. Some more in-depth research activities are needed for this purpose. The influence of the angle of the screens concerning the occurrence of head trauma must be analysed in detail by dummy-simulations and the variance of head impact angles on the pane surface should be evaluated in relation to the impact speed. With this approach optimised measures for the windscreen region can be carried out, leading to more protection of pedestrians in car collisions.

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