ACCIDENT CHARACTERISTICS IN CAR-TO-PEDESTRIAN IMPACTS

Kramlich, Thomas
Langwieder, Klaus
Lang, Dina
Hell, Wolfram

GDV Institute for Vehicle Safety, Munich

ABSTRACT

Aim of this study was to show typical accident characteristics of car to pedestrian accidents. Data´s origin were insurance records of the GDV, Munich, (German Insurance Association – Institute of Vehicle Safety). 1.200 car to pedestrian accidents were investigated by engineers and physicians. Evaluation was purely done in a descriptive way.
The number of fatally injured pedestrians in car to pedestrian collisions has been reduced by 6,2% in 2000 compared to the year 1991 in Germany, but for there are about 9000 fatally injured and 200.000 severely injured pedestrians and bicyclists in the EU a year. The most severe accidents (MAIS 4 and 6) happened during frontal impacts (84% and 88%). The proportion of more serious and fatal injuries was higher in older victims (31 years and over). Half of all pedestrians killed on German roads were at least 60 years of age. Children at the age of up to 10 years are more often involved in side impacts than people at the age of 30 years and over (35% versus 25%). The most severe injuries in adults were seen in accidents where impact includes the windshield and/ or the windshield frame. The body region mostly hit in children up to 10 years are head (44%) and upper leg (33%), in people over 10 years lower leg and knee (54%) followed by head (43%).
This data show that older pedestrians carry higher risk of injury in general traffic occurrence. Children are more often involved in pedestrian side impacts than grown-ups.

KEYWORDS

- ACCIDENT ANALYSIS
- PEDSTRIAN
- EEVC IMPACTOR TEST
- CHILDREN
- HEAD

1. Introduction

No two accidents are alike. This fact presents accident research with one of its biggest problems, because it is almost impossible to identify a particular pattern for all accidents that adequately reflects each of the important influential factors, such as speed, area and angle of impact, and age of the victim. This statement is particularly true for accidents involving pedestrians. Since the parties involved in these accidents are so radically different, individual factors have a much more drastic effect on the course of the accident and consequently on the resulting injuries, making this the most sensitive area in accident research. It is therefore necessary to try to identify a correlation between the most important criteria in a collision and a typical pattern of injury.

2. Historical and official statistics

Of all road users, the pedestrian is by far the most vulnerable. Pedestrians are at a serious disadvantage compared with all other users, both in terms of speed and of weight. Nor do they have any safety devices such as crumple zones or even seatbelts and airbags, which mitigate the consequences of a collision as far as possible. For this very reason, those responsible for legislation, the automotive industry and accident researchers have long been attempting to devise some form of safety feature for these participants in road traffic. As far back as 1970, Appel of Berlin University introduced the "UNI-CAR", /1/ which was designed, among other things, to improve pedestrian safety. In 1987, Working Group 10 /2/ was established by the *EEVC (European Enhanced Vehicle-safety Committee)* and in 1991 published results in the form of an initial crash configuration (**Figure 1**), with which it was possible to evaluate the impact inflicted by a vehicle on a pedestrian. In 1998, Working Group 17 /3/ developed these testing methods further, using the latest findings to test and to optimize them.

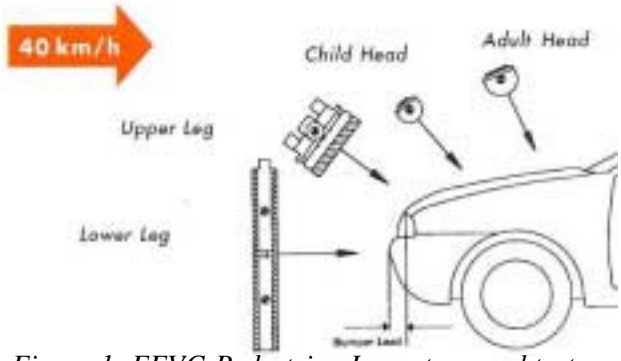

Figure 1: EEVC-Pedestrian Impactor-crashtest

Over the past few years, the statistics relating to accidents involving pedestrians in Germany reveal a positive trend (**Figure 2**).

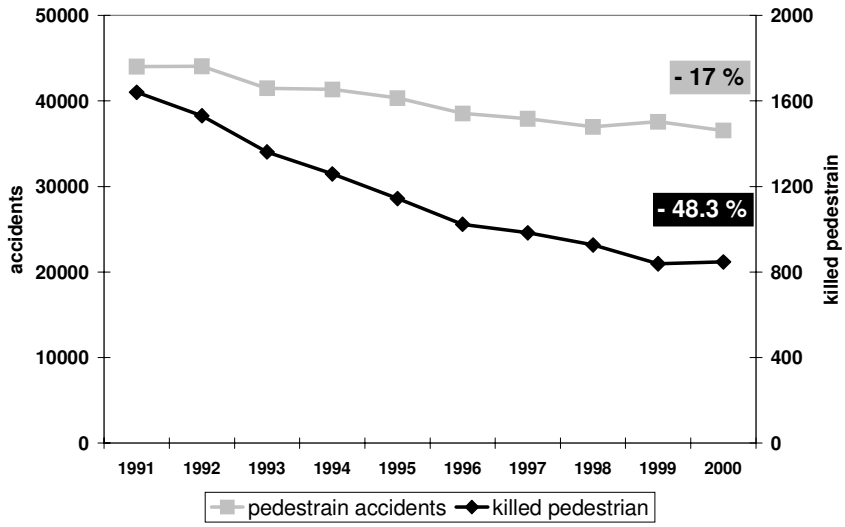

Figure 2: Trend in pedestrian accidents in Germany, 1991 - 2000 /4/

Between 1991 and 1999, the number of accidents involving pedestrians fell by 17%; the number of pedestrians killed by nearly 50%. One plausible reason for this positive development might be the trend to a construction of modern aerodynamic front-end structures. They mainly displaced stiff, sharp-edged fenders with high injury risk. But also the optimisation of medicine, improvements in infrastructure and especially the imposition of speed limits in German urban areas from 50 km/h to 30 km/h in many built-up areas show positive effects. The fundamental trend in this type of accident can be seen particularly when observing the number of pedestrians who were fatally injured (**Figure 3**).

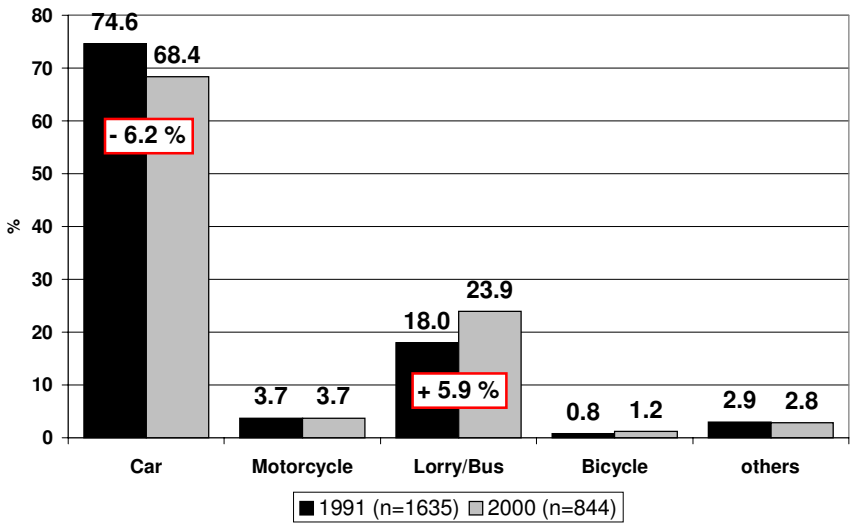

Figure 3: Distribution of road users in accidents where pedestrians were killed, 1991-2000

The proportion of accidents involving passenger cars fell by 6.0% in the observation period. The proportion involving trucks and buses increased by roughly the same amount. This represents a relative growth of approximately 30%. This shift is explained by the huge growth of this vehicle group in German road traffic. Between 1992 and 1997, the stuck of trucks rose the same relation /5/.
Significant changes have been made to the form and structure of passenger vehicles in the nineties. These changes go a long way to explaining the radical shifts in trends for accidents involving pedestrians. In this phase of vehicle development, it is particularly important to place renewed emphasis on the safety of unprotected parties involved in road traffic, for still there are about 9000 fatally injured and 200.000 severely injured pedestrians and bicyclists in the EU a year.

3. GDV data

The pedestrian´s database of GDV is based on the 1994 published study "Vehicle Safety 90" (VS 90) /6/. In a joint venture of all German car insurance companies 140.000 accidents with personal injury of the year 1990 were reported to our institute. Out of those cases different subject-associated relevant samples were randomised and interpreted by a number of parameters. Figure 4 shows the structure of the VS 90 database [VS 90]. The data´s origin were insurance records including police records, technical expertise, medical records or post-mortem examination papers. The evaluation of this information was done in the Institute of Vehicle Safety by engineers and physicians (**Figure 4** shows the structure). The main database, covering 1185 incidents, provides a reflection of the actual course of accidents involving pedestrians and is very appropriate for deriving a real pattern of injuries. The two supplementary sets of data "with new vehicles (year of manufacture 1995+)" and "with pedestrian fatalities" make it possible to focus on these two issues but were not used in this investigation, because they are not representative for overall accident patterns if the data is consolidated.

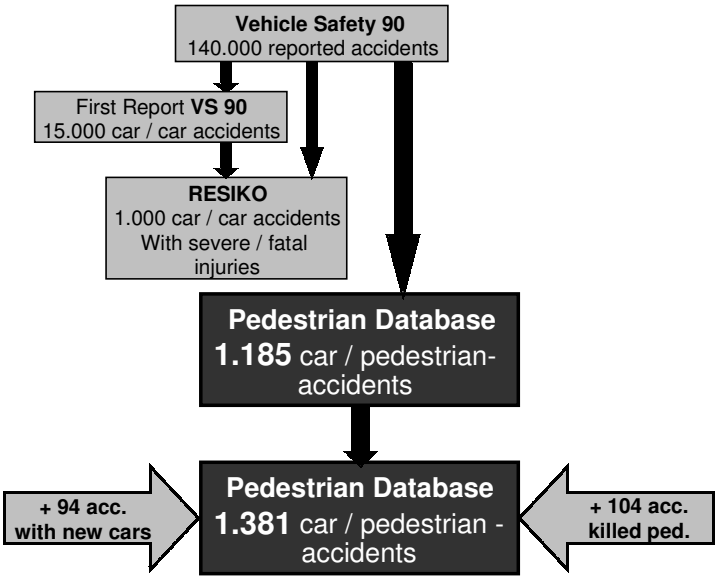

Figure 4: Structure of the GDV material

4. Accident analysis

4.1 Influential accident parameters

4.1.1 Influence of the initial area of impact with the vehicle

The database, covering 1185 incidents, was used to identify the key factors which represent risks or which are liable to cause injury to pedestrians. The initial contact between pedestrian and vehicle occurs mostly at the biomechanical highest loading, which means that this impact is decisive in the resulting pattern and severity of injuries. This is depicted in **Figure 5**, with reference to the initial point of impact with the passenger vehicle.

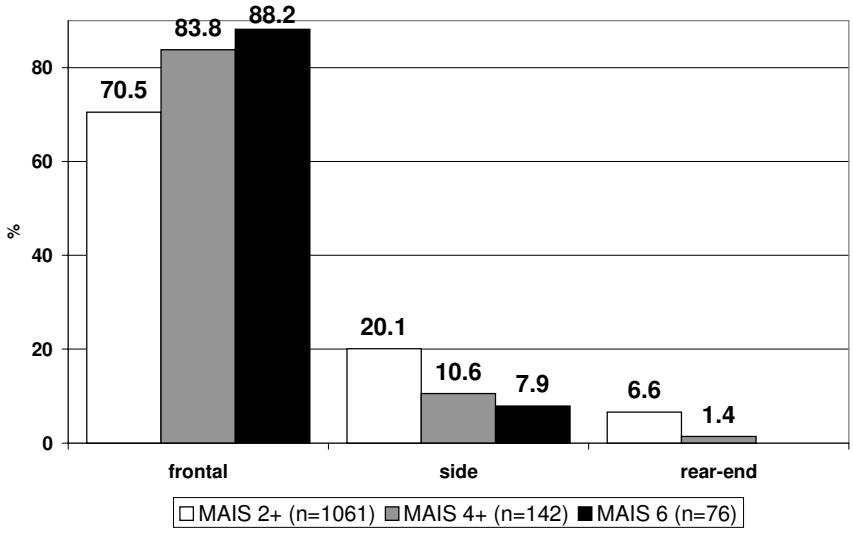

Figure 5: Severity of the injury /7/ vs. initial area of car impact

Front-impact accidents represent the key issue in pedestrian accidents, due both to their frequency and the risk of injury. But one should not overlook the fact that in disregarding side-impact collisions, one in five injuries of Maximum Abbreviated Injury Scale (MAIS) level 2 and above is ignored.

4.1.2 Influence of pedestrian age

As in all accident types, the age of the person affected plays an important role. Thus, it is particularly necessary to examine the potential for injury in relation to age for these road users who are so radically different (**Figure 6**).

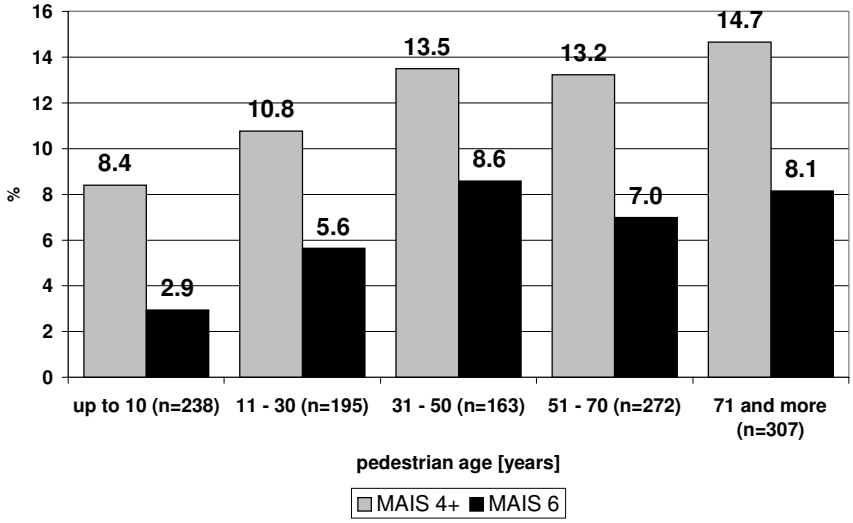

Figure 6: Injury severity / pedestrian age

It is clear that the proportion of serious (MAIS 4+) and maximum injuries (MAIS 6) in older victims is significantly higher. In children up to 10 years of age, 8,4% are seriously injured (MAIS 4+), where in older people this figure is nearly by 50% higher. This trend is even clearer when one examines the proportion of maximal (AIS 6) injuries in each age group. With 8,1%, pedestrians over 70 years of age suffer almost three times as many fatal injuries as children (2,9%). It is also important to point out here that the MAIS value only indicates the probability of the injury being fatal, and is therefore not a definitive reflection of the number of people who were in fact killed in each age group, since older victims may be more likely to die of injuries which for younger people do not even represent an acute danger. Thus, **Figure 7** depicts the age of all pedestrians in the GDV database who were killed. In contrast, it is also possible to look at the age distribution in official statistics, which highlight the impressive degree to which the GDV data is representative regarding severely and deadly injured pedestrians.

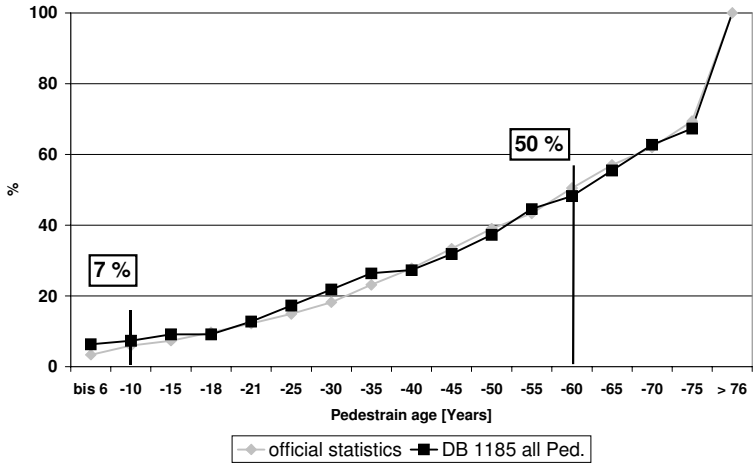

Figure 7: Age distribution of pedestrians killed; GDV database / official statistics

Half of all pedestrians killed on the roads in Germany were at least 60 years of age. It is essential that this fact is kept in mind when discussing the effectiveness of safety devices on passenger vehicles. 7% of all pedestrians killed in Germany were children up to 10 years of age. This result should in no way detract from the seriousness of the subject of child fatalities, but clearly shows that this age group - regarding the absolute numbers- does not represent the greatest for this type of accident, but in terms of lost of life years, the proportion of children would be higher, although no investigation in Germany has ever calculated this.

Children, therefore, are a special case in accidents involving pedestrians. This is not only apparent in the human kinematics of a collision as a result of their size, but also when examining the entire accident situation. **Figure 8** shows the distribution of the initial area of impact of the vehicle in relation to the age of the pedestrian. Here only cases with first contact between pedestrian and vehicle proved by photos, witness statements or accident reconstruction are shown.

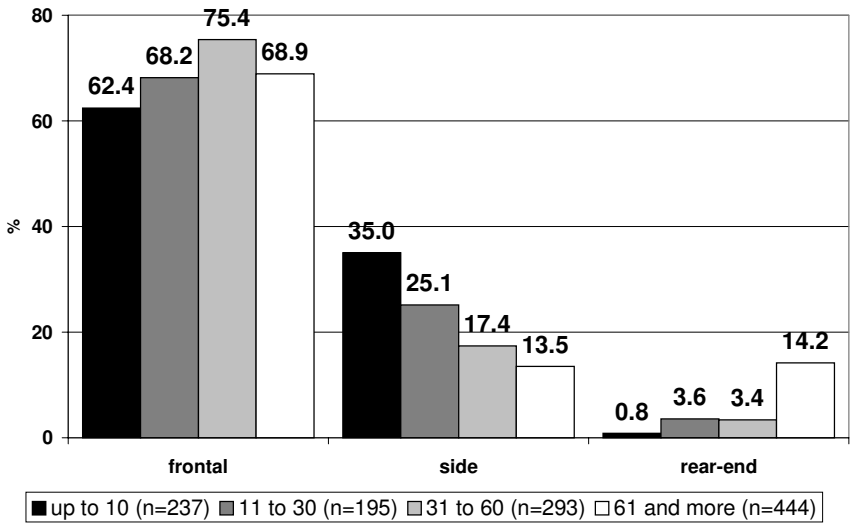

Figure 8: Initial area of impact / pedestrian age

There is a clear correlation between pedestrian age and the area of impact. In over one third of cases, children 10 years and younger run into the side of the passenger vehicle. At higher age within the regarded group, this proportion declines and for pedestrians over 60 years of age, the proportion is only half that of the children. The age of the pedestrian, therefore, is not only decisive in terms of kinematics during the collision and in the resulting injuries, but also in the pre-crash phase.

4.2 Course of collision and risk of injury

4.2.1 Course of collision and kinematics groups

Front-impact accidents are the most common and most dangerous form of collision from the pedestrian's point of view. It is essential that measures are taken to increase pedestrian safety.
The Institute's data have been examined in this context in an attempt to identify a typical course of human kinematics from the initial contact with the vehicle to the final impact on the road and to quantify the risk of injury posed by different vehicle zones, both with regard to the frequency and severity of the injury. The whole data have been sorted into six kinematics groups, as depicted in **Figure 9**.

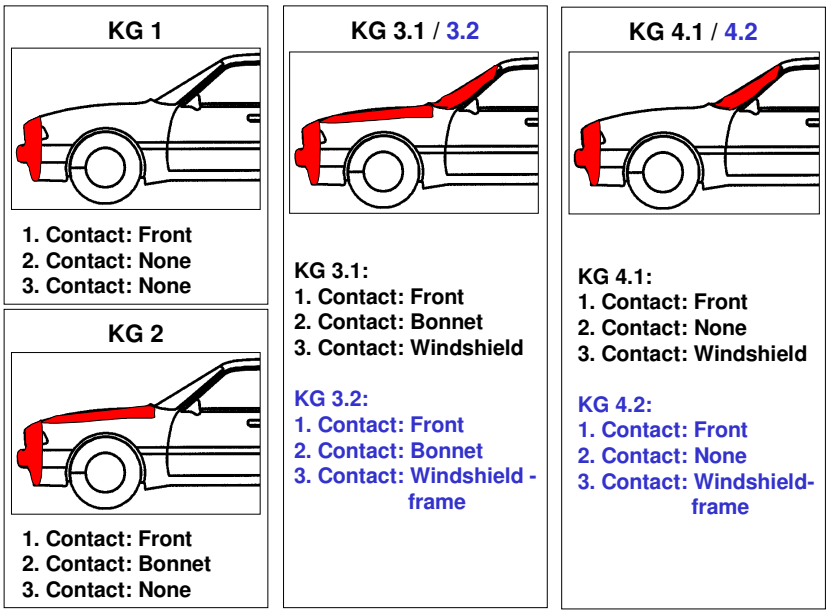

Figure 9: Kinematics groups (KG) in the GDV material

The determination of the kinematics groups out of all insurance data was done by proving accident photos, medical records, witness statements and accident reconstruction material. For all cases with

unclear movement course of the victim during collision were eliminated, data were notably reduced. Thus not in all kinematics groups enough numbers of cases were left to make statistical announcements. However data are appropriate for tendentious assessments of the potential injury risk of different parts of the frontal car.

4.2.2 Pattern of injury

Figure 10 displays the risk of injury for the individual kinematics groups (KG).

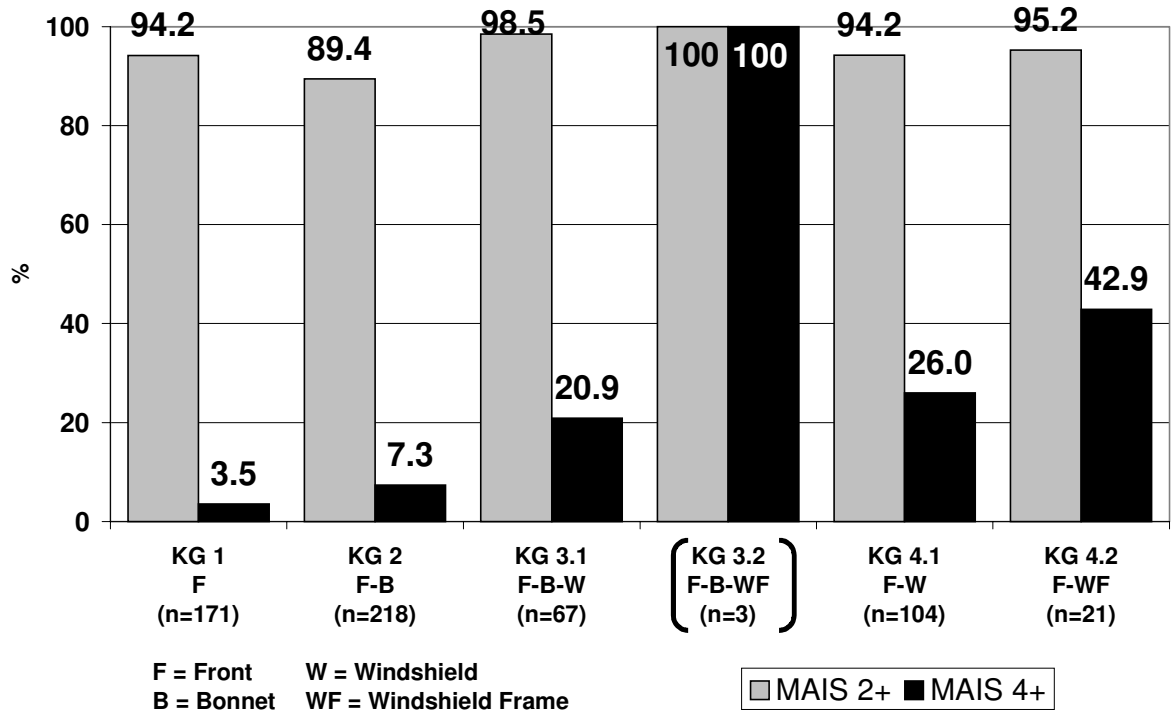

Figure 10: Maximum severity of injury in the kinematics groups (KG)

Clear contrasts can be seen in the frequency and resulting severity of injuries for the different collision categories. Whereas group 1 and 2 show the highest absolute numbers of cases (n=171 and n=218) the highest part of severely injured (MAIS 4+) and maximal injured (MAIS 6) pedestrians are found in the kinematics group 3.1, 3.2 and 4.2. Here the victim suffered from an impact to the most rigid parts of the vehicle like windshield pane, its frame or A-pillar. Theoretically even in these kinematics groups there is the possibility that these severe injuries were caused by secondary impact, but the sharp head impact could clearly be proved by reconstruction and accident photos so that the origin of injury seems more than likely. Similar results are found by D. Otte /8/ /9/ in his studies.
It is important that divisions are made according to age when looking at the individual areas of injury, since a vehicle will impact different areas on a child's body from that of an adult.

Figure 11 displays a typical pattern of injury on a victim with adult body height (i.e. over 10 years of age) in a front-impact accident.

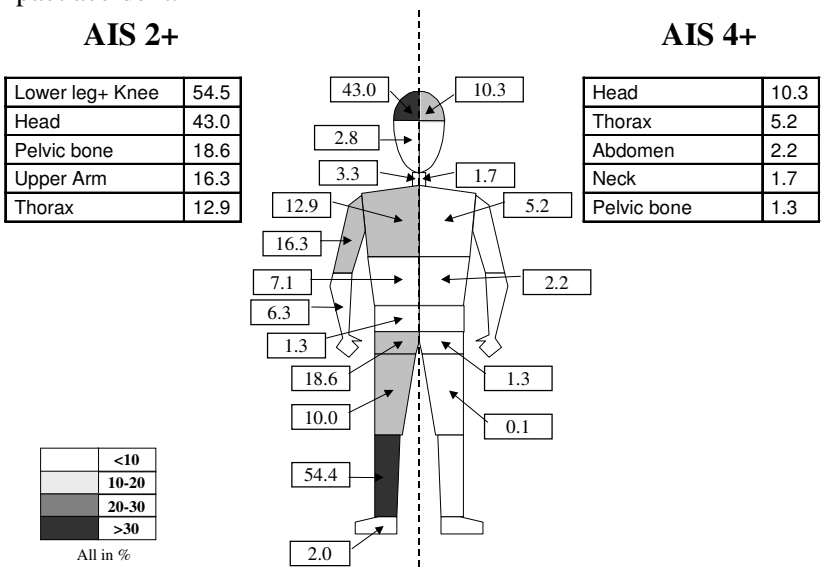

*Figure 11: Injured areas on pedestrians **over 10 years** of age in front-impact collisions (n=688)*

Life-threatening injuries (AIS level 4 and above) occur most frequently in the head region. According to the results for the kinematics groups (Figure 13), the cause is largely attributable to impact with the windshield and its frame. Injuries to the chest or abdomen with a AIS level 4 and above (5,2% and 2,2% respectively) represent a lower risk.
More than one in two (54,4%) of injured pedestrians suffer injury to their lower leg or knee, which are not life-threatening but costly both with regard to the financial resources and time required for them to heal. The most common cause of such injuries is impact with the fender.
Injuries of MAIS level 2 and above on the pelvis (18,6%), upper arm (16,3%) and chest (12,9%) are common. For the car as cause of injury these values, should be regarded as the upper limit, since it is impossible to exclude the road as a cause of injury in such an investigation.

Figure 12 depicts injuries to individual regions of the body on children up to 10 years, caused by front-impact collisions.

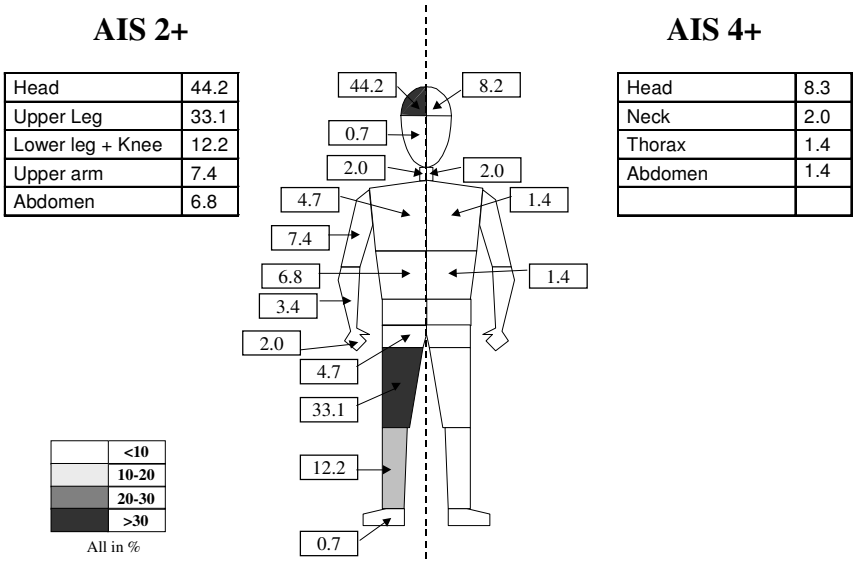

*Figure 12: Injured areas on pedestrians **up to 10 years** of age in front-impact collisions (n=148)*

This injury chart shows a number of typical characteristics of injuries to people of this size.
Although, as with the adults, the head region is clearly subject to the most serious injuries, the proportion is somewhat lower, only 8,3%. Due to their size, the cause of children's injuries is more likely to be contact with the radiator grille or the front of the engine hood. Impact with the road is a more

common cause of injury here, since children are seldom lifted on to the engine hood, but are mostly thrown directly on to the road. Other body regions are less at risk from serious injury. Due to the fact that they are smaller, initial impact occurs around the children's thighs, as opposed to the lower leg area. The proportion of injuries of AIS level 2 and above for this region is accordingly high. To illustrate this, **Figure 13** contrasts the locations of injuries of AIS level 2 and above for children and adults.-

Injuries AIS 2+ [%]		
Body part	up to 10 years	over 10 years
Head	44.2	43.0
Thorax	4.7	12.9
Upper arm	7.4	16.3
Lower arm	3.4	6.3
Pelvic bone	4.7	18.6
Upper leg	33.1	10.0
Lower leg	12.2	54.4

Children are a special case in every aspect of accidents involving pedestrians. This is not only due to the severity of their injuries, but also to the human kinematics during the collision. Their size means that it is very rare for a child to be lifted on to the engine hood or to have any form of contact with the windshield. The points of contact on the vehicle and also the causes particularly of serious injury are fundamentally different.

Figure 13: Comparison of injured body parts; adults / children

Most impressive this body height-depending difference can be seen when directly comparing the injuries of the lower extremities. Caused by the first vehicle contact with the fender adult pedestrians are injured four times more often at the lower leg than children. The proportion of upper leg injuries however is three times as high for the much smaller children than for adults. Thus, it is particularly important to consider the number of children in the kinematics groups described above, if one is to identify the main areas of injury.
Figure 14 shows the kinematics groups for children up to 10 years of age.

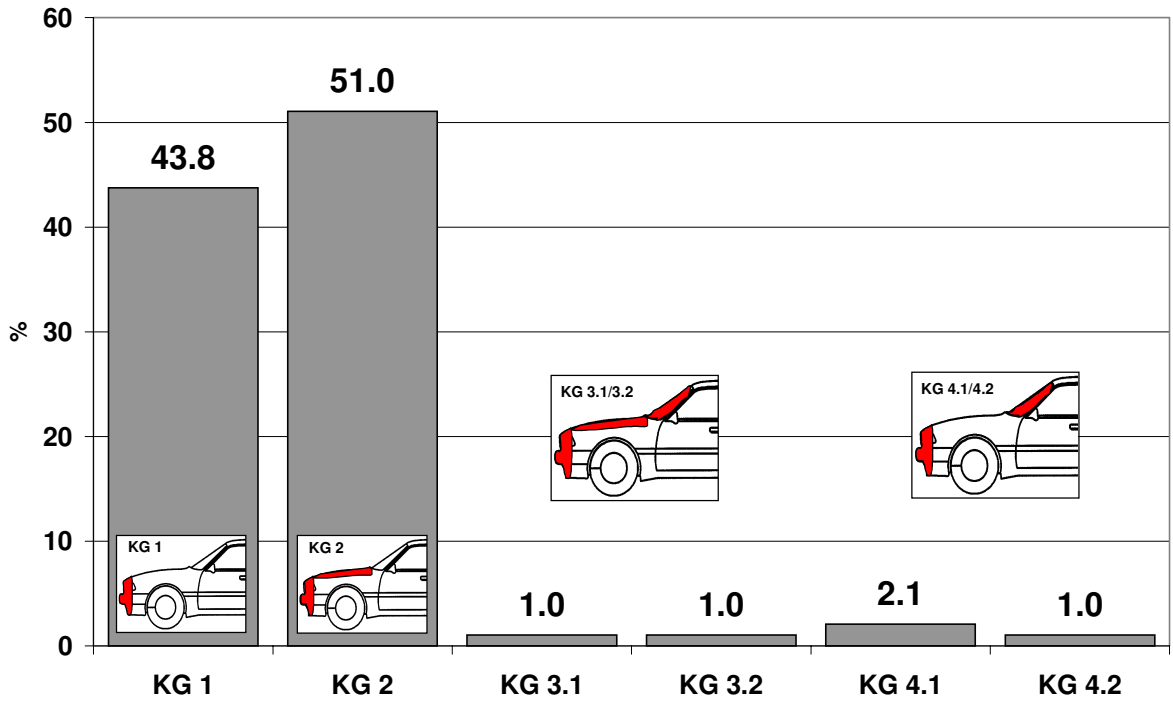

Figure 14: Kinematics groups for children up to 10 years of age (n=96)

Two typical courses of movement can be identified. After initial contact with the front of the vehicle, the child is either lifted on to the engine hood, or is propelled by the impact directly on to the road. As expected, there are few collisions where the child is thrown on to the windshield.

5. Discussion

Considering the aim of this study -a description of accident characteristics in car to pedestrian accidents- the complete documentation and the huge number of cases in play an important role. There was the possibility to make use of an enormous database including reliable technical expertise, photo documentation as well as police reports and medical records.

The selection of relevant samples was done by randomisation without any tendency nor personal influence. Thus the results of this study can demand full recognition in terms of accident specific characteristics on German roads.

Regarding the pattern of injuries (MAIS) it seems remarkable that medical information is based on statements given by the treating physician. Consequently those announcement are subjective and underlying the physician´s full competence and precision. Many indications may tend to be in favour of the patient´s insurance company compensation amount.

It strikes into one´s eyes that children up to the age of 10 years are twice as often involved in side impacts than adults at the age of 31 to 60 years.(35.0% versus 17.4%). This result should be subject of further discussion. It seems possible that children due to their body height are more often victims of the blind angle. Furthermore they seem to be hit by passing cars when playing or running after a ball. Of course their attention, visual perspective and traffic perception is less trained compared to adults.

Considering that the stature of children changes enormously from the age of 1 to the age of 10 years it seems not reasonable to create such a broad age group. Being aware of this we decided that the disadvantage of to small case numbers would be worse.

Although half of all pedestrians killed on German roads were at least 60 years (figure 6) it seems in terms of “years of life loss” relevant taking in consideration the amount of children (age 1 to 10 years: 7%) for socio-economic reasons.

6. Conclusion

Although the both number of accidents involving pedestrians and the number of fatalities have fallen in recent years, they are still one of the most dangerous categories of accident and require intensive research.
Analysis of the GDV data showed that front-impact accidents are the key issue in pedestrian accidents, not only because of their frequency but also their potential danger. On examining the victims' ages, however, it is clear that children up to 10 years of age suffer impact from the vehicle side much more often than adults.
The proportion of serious and maximal injuries is significantly higher in older victims than in children. Over 20% of all injured pedestrians and 50% of all maximal injured persons in Germany are 60 years old. The impactors of the EEVC are not addressed to the biofidelity of the victims so that even when observing the limits a positive effect for all age groups can be expected, this effect however will be much smaller for the huge number of older people. Even when aggravating the EEVC limits there will not result any improvement for the older age groups. Only 7% of all fatally injured pedestrians were 10 years old or younger. This result should in no way detract from the seriousness of the subject of child fatalities, but clearly shows that when considering the absolute numbers this age group this does not represent the greatest problem for this type of accident. By dividing pedestrian kinematics into groups, it becomes clear that the most serious and maximal injuries are caused when the pedestrian comes into contact with the windshield or its frame. The results of D. Otte´s /8/ /9/ in-depth analysis confirm those findings: The head as main body region in severe injuries here as well hits depending on the collision speed mainly the lower part of the windshield pane or its frame.
Life-threatening injuries in the GDV Database occur in the head area for all age groups. Injuries to the chest, upper extremities or pelvis occur primarily in adults.
In the GDV database, Children up to 10 years of age rarely suffer such injuries. This can be explained by the different points of impact and corresponding kinematics of these age groups. This is most clearly demonstrated by the injuries to the lower extremities. More than half of all adults but only one in ten children receive injuries to the lower leg. In contrast, one in three children suffers injuries on the thigh. On initial impact with the vehicle, the influence of body size is thus clearly demonstrated. For this reason, children are rarely lifted on to the engine hood, but following the initial impact, they are propelled directly on to road. Due to their body size the movement course of children during an impact to a motor vehicle mainly differs from that of adults. The full-model-simulations of Y. Okamoto /10/ confirm those special body height-depending kinematics in children. A separate analysis of this group of persons seems absolutely necessary. Therefor it can not be excluded that factors representing an improvement in the situation for adults will have the opposite effect as far as children are concerned [Report TNO /11/]. This conflict could be created when automobile industry mainly focuses on fulfilling the component test.
The resulting test program of the EEVC treats important aspects when considering head and lower leg impacts. However it has to be kept in mind that a component test by his high abstractness especially in such a sensible accident research field is associated with special dangers. The measurements of the automobile industry to fulfil the EEVC criteria should be undertaken with ambitious diligence because i.e. changes in the frontal structure can obtain the desirable incrimination values at the impactor but can have further effect on lifting and propelling kinematics of the accident victim. Thus there is danger that when decreasing the aggressiveness of different vehicle parts the injury risk of the secondary impact (impact to the road) will enormously rise as shown in **figure 15**.

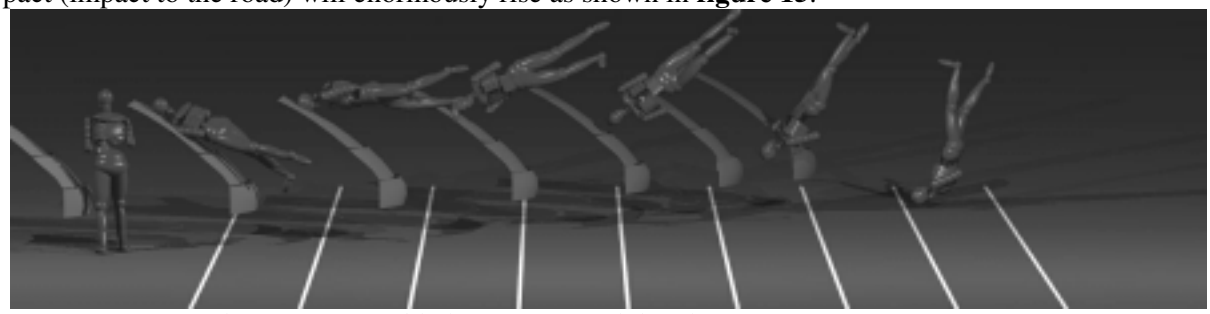

Figure 15: Example of unfavourable kinematics with head impact /12/

The EEVC component tests must be further developed not only in the light of the test requirements, but also of biomechanical values, because proved injury risks of the windshield pane, its frame and the A-pillar in the present test procedures are not taken in consideration as well as the biomechanical speciality of children (body height and resulting kinematics) was not included. The most critical, however, is to develop present features that will protect against head and lower leg injuries, and to guarantee their efficacy not only in tests, but also through research into real accidents.
The danger of aim conflicts that is imposed by the abstraction of the component test has to be avoided. Computer simulations seem to be a feasible medium in future.

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