Comparison of Head Impact Conditions and Injury Patterns of Pedestrians versus Bicyclists for German Traffic Accidents involving Cars

Otte, Dietmar
(Accident Research Unit, Medical University Hannover, Germany)

Abstract: Based on GIDAS (German-In-Depth-Accident-Study) a statistically representative overview of traffic accidents involving pedestrians and bicyclists in collisions with cars is given in the paper. The investigation of real accidents based on the methodology of in-depth-investigations at the scene in time offers a huge amount of information about impact points on the vehicle as well as detailed descriptions of injuries. A comprehensive reconstruction is carried out for each case and a determination of impact speed is taken into consideration. The focus of the study is to find major conditions of the head impact on the car and on the road surface, first to find the load conditions to the head of the primary and secondary impact. Secondly the injury pattern of primary and secondary impacts shall be described in detail. For this approach only cars colliding frontally with pedestrians or bicyclists are considered, no vans and no SUVs, Peds/Bikes coming from 2 o 4 or 8 to 10 o'clock and body heights of 150 cm or more have been selected for demonstrating the load conditions. This followed in a subsample of 402 pedestrians and 940 bicyclists. All head impacts were depicted in an x-y-coordinated scaled drawing with measurements showing the locations of head impact points. There is a major location on the windscreen area for severe head injuries AIS 3+. For bicyclists a more widely spread distribution of impact points was concentrated at the frame of the windscreen to the side. Based on a more relative movement of the bicyclist's body compared to the pedestrian's relative movement, more impacts onto the road surface had occurred for bicyclists.
The analysis of this study shows that it is important to understand the head impact mechanisms of pedestrians and bicyclists on the one hand. The results can be seen as accident parameters for the validation of computer modeled load analysis based on computerized simulation processes on the other hand. Even the general injury situation of Peds and bikes are similar the head impact location on the windscreen is different.

Keywords: pedestrians, bicyclists, injury severity, head impact, windscreen

1 Introduction and Objectives

In the European Union annually 8 000 unprotected traffic participants, pedestrians and cyclists die and 1.7 million are injured annually in the course of traffic accidents, 1.4 million slightly and 300 000 severely (CARE 2008[1]). Vulnerable Road Users play an important role in this context, as they participate in traffic as unprotected persons. In the references there are numerous studies dealing with the injury situation of this group, most of them refer solely to pedestrians, bicyclists or motorcyclists as total group or to motorcyclists as individual group. In particular pedestrians were in the focus of observation in the past years, as there the accident numbers in Europe were significantly high and required preventive measures. In 2005 the design layout of the vehicle safety was formulated based on new testing regulations for the pedestrian protection. New vehicles have to pass a number of tests to prove sufficient pedestrian protection (Directive 2003 / 102 /EG[2]), which has come into effect in October 2005 and been used in vehicle development since. From 2009 new vehicles have to be equipped with a brake assistant, which reduces the stopping distance of a vehicle in dangerous situations and they have to fulfill direction 2003 in phase 1. The important basic directive is the compliance with load factors in the course of so-called component tests, which have been prepared and optimized by the task force EEVC/WG 17. From 2010 phase 2 of the EC-agreement applies. The pedestrian test regulation consists of different component tests, there a dummy leg collides with the bumper, a dummy hip collides with the bumper as well as against the front edge of the hood and an adult as well as a child dummy collide with the hood. In all of these cases generally recognized biomechanical load limits may not be exceeded. It is the purpose of this directive to improve protection of pedestrians and other unprotected traffic participants in case of collisions with cars. Currently pedestrian protection is to be warranted through a combination of active and passive safety systems. Passive systems mitigate injuries due to yielding surfaces in case of a collision; active systems reduce the severity of an impact, by reducing amongst other things the speed before the collision and ensuring a faster action of the safety systems.

The question is now to what extent results for the injury situation based on data of pedestrian accidents also apply to bicyclists, who also are to be protected by this directive. The latter are, however, by using self-protection measures such as a bicycle helmet and the proper motion relative to the motorcar as well as because of the coupled mass system driver-bicycle on the one hand rather similar to vehicle /vehicle collisions, on the other hand also comparable as far as the occurring kinematics are concerned. Thus the question arises whether in consideration of the injury situation and the severity of the accident the demands on the test conditions can also be valued analogously.

It is the objective of this study to comparatively analyze the exact impact spectrum at the vehicle front of the motorcar and the resulting injury patterns of pedestrians and bicyclists.

To this end accident investigation at the site of the accident are particularly suitable, as there detailed individual information concerning injuries, vehicle deformations and points of impact of injured traffic participants are documented accurately. In addition the velocities of the vehicles had, when the pedestrian or the cyclist was hit, been reconstructed on the basis of the accurate documentation of the traces of the accidents of deceleration processes, collision sites and final positions of the persons.

2 Basis of the Study

The investigations at the sites of accidents are a research project of the Bundesanstalt für Straßenwesen, which has been conducted in cooperation with the Forschungsvereinigung der Deutschen Automobilindustrie FAT since 1999 jointly in Hannover and Dresden (Otte 2003[3]). A scientific research team consisting of technicians and physicians equipped with special emergency vehicles drives to the sites of accidents, documents the damages to the vehicles, the injuries and the accident traces. The injured person is inspected in the hospital, where the initial treatment was performed. The accidents are reported by the police in case of traffic accidents with personal injury on the basis of a special sampling process (the accident that has been reported last). Per year in every investigation region approximately 1 000 traffic accidents are documented and per accident 1 000 to 2 000 individual data are collected in a special database (Bühning 2008[4]). Since GIDAS (German In-Depth Accident Study) has been launched app. 19 000 traffic accidents have been documented, involving approximately 34 000 vehicles, of these 22 000 motorcars with 47 000 persons in total. The proportion of pedestrians and bicyclists corresponds to the general accident statistics of the investigated areas of Hannover and Dresden, Germany, and can be applied representatively to all of Germany after statistically weighting the data sets. The injuries were coded in accordance with the Abbreviated Injury Scale AIS (AAAM 1998[5]).

For this study comparing pedestrians and bicyclists the accident data were evaluated based on the following criteria:

Solely head-on collisions of motorcars were regarded, solely standard front forms have been taken into account, accordingly so-called vans and SUVs had been excluded. Only collisions had been selected in which the pedestrian and/or bicyclists entered the scene at more or less right angles in relation to the direction of motion of the motorcar (clock system 2.00 to 4.00 o’clock and 8.00 to 10.00 o’clock). To enable a comparison also solely persons taller than 150 cm were regarded. In doing so the high influence of the kinematic projection process of the person at the vehicle front is taken into account, as the body size has a dominant influence on the projected length and thus very different places of impact on the vehicle result. Ultimately n=402 pedestrians as well as n=940 bicyclists remained for a detailed analysis.

3 Comparison of accident situation framework of pedestrians and bicyclists

For displaying the comparability of the two populations of pedestrians and bicyclists initially accident reference value, so-called epidemiologic data were compared. It turned out that the distribution of vehicle mass was nearly identical for both populations. Approximately 45% of the vehicles had a crash weight of 1 000 to 1 300 kg, approximately 30% weighted less than 1 000 kg, approximately 20% had a weight between 1 300 kg and 1.600 kg and only approximately 4% were heavier than 1 600 kg. The age distribution of the vehicles was also nearly identical for both groups of traffic participants. New vehicles are rarely found in current accident events, usually the vehicles are older. Collisions with vehicles of less than 3 years of age occurred in the accident events at only approximately 10%.

The impact directions in the clock system are also nearly identical for pedestrians and bicyclists. Collisions at right angles (9.00 and 3.00 o’clock respectively) prevail. For bicyclists entering from directions of 2.00 o’clock collisions occurred at 25.9% more frequently than for pedestrians at 11.6% (Figure 1).

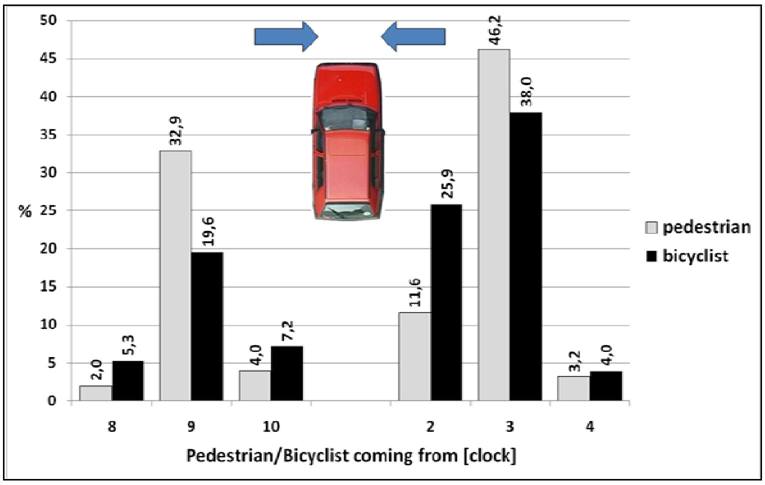

Figure 1 Direction of Vulnerable Road Users Peds/Bikes in Car collisions representativity

The distribution of the collision speeds of the motorcars differs significantly between pedestrians and bicyclists. Whereas 35% of the accidents with pedestrians occurred at collision speeds of up to 20 km/h, this applied to 70% of the bicycle accidents. Thus the collisions with bicyclists occurred at significantly lower impact speeds, only 1.2% of the cases occurred at velocities of > 50 km/h (5% for pedestrians) (Figure 2).

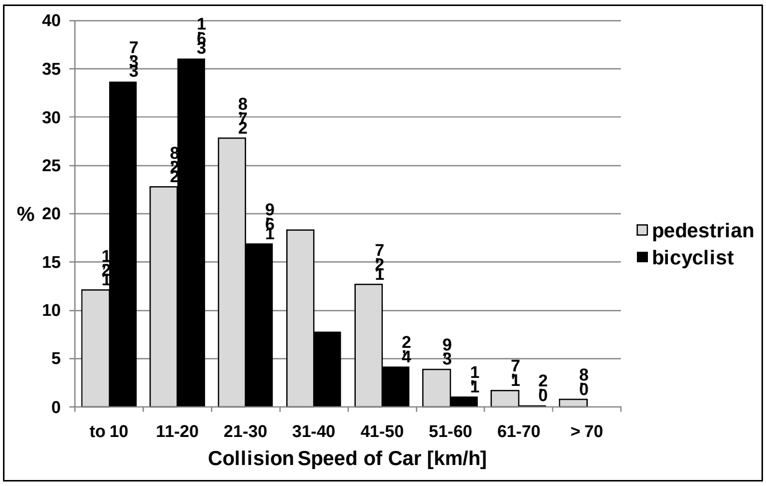

Figure 2 Collision Speed of Cars in frontal impacts with Vulnerable Road Users Peds/Bikes

The age distribution of pedestrians and bicyclists as casualties is nearly identical. Predominantly bicyclists between 18 and 64 years (57.6% pedestrians / 70.3% bicyclists) were involved in accidents, pedestrians in the elderly group +65 are nearly doubled versus cyclists of such age (**Figure 3**).

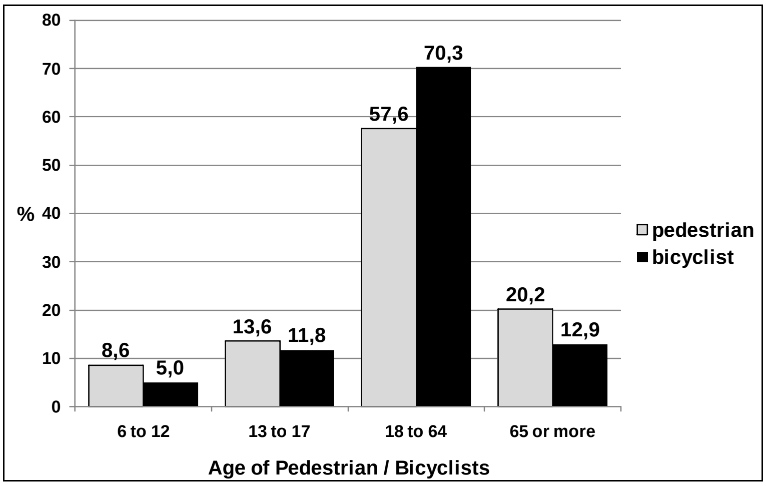

Figure 3 Age Distribution of Vulnerable Road Users Peds/Bikes

The injury severity of the pedestrians is significantly higher than for bicyclists. Thus 80.5% of the bicyclists were injured slightly MAIS1, in comparison to only 57.8% of the pedestrians. Injured persons in accordance with MAIS 2 occurred more rarely for bicyclists at 16.2% than for pedestrians at 29.3%. Only 2% of the bicyclists were severely injured (MAIS 3+) in comparison to 10% of the pedestrians (Figure 4). Bicyclists suffered fewer head injuries than pedestrians (62.8% and 39.5%).

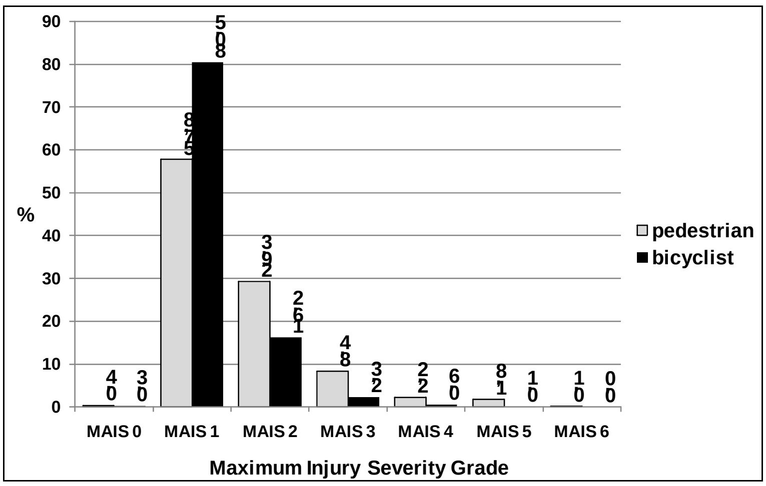

Figure 4 Maximum Injury Severity Grade (MAIS) of Vulnerable Road Users Peds/Bikes

60% of the pedestrians injured at the head suffered from injuries AIS 1 (bicyclists 77%), 6.8% (2.7% bicyclists) suffered from severe head injuries (AIS 3+) (Figure 5). Injuries to the neck occurred nearly at the same frequency for both populations at approximately only 6.5%. They are predominantly injury severities AIS 1 so-called "Whiplash-Injuries", which at 95% occurs more frequently for bicyclists than for pedestrians (65%). Bone and ligament injuries of the cervical spine AIS 2+ are at 4,8% rare for bicyclists, but occur frequently for pedestrians at 34%. Regarding the remaining body parts, looking from the neck to the legs, show a nearly identical injury frequency for both groups. Besides injuries to the neck at approximately 6.5%, there were thorax injuries at approximately 25%, injuries of the legs at approximately 47.5% and of the abdomen at approximately 6%, of the pelvis at approximately 15% and the legs at approximately 73% for pedestrians and bicyclists. Only the legs constituted a higher risk of severe injuries for pedestrians (AIS 3+ 10.2% pedestrians, 2% bicyclists).

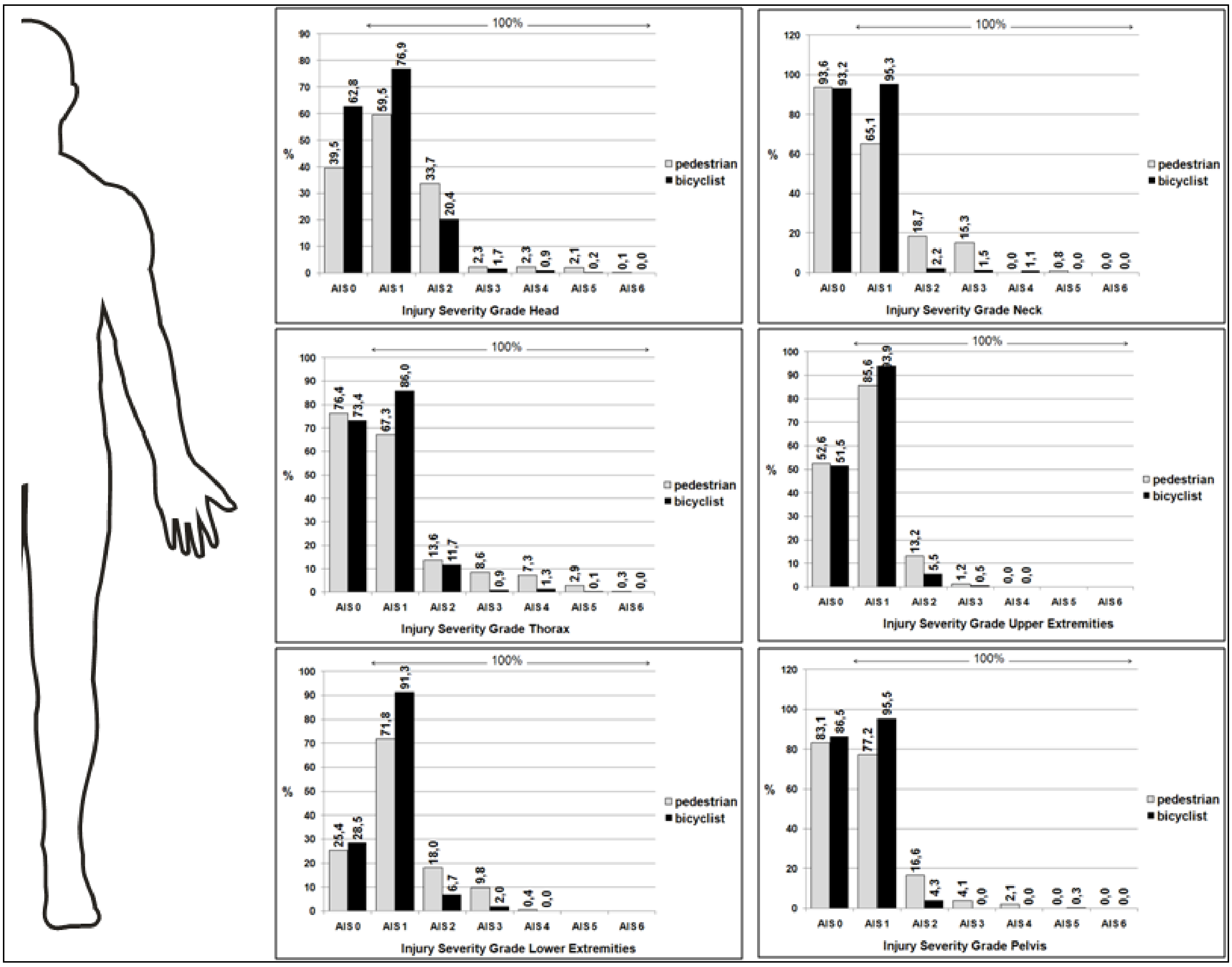

Figure 5 Injury Severity Grades (AIS) of Body Regions of Vulnerable Road Users Peds/Bikes

4 Spectra of the points of impact of the head at the vehicle

In the course of a detailed analysis the team measured at the scene the vehicles and documented the places of the impact of the head in XYZ-coordination system. The measurements are plotted in a diagram together with a picture of a standardized vehicle shape (Figure 6). The result shows an influence of the impact velocity. With higher speed the impacts were found more to the upper bonnet and windscreen region. The predominant places where impacts occurred in the rear half of the hood of the vehicle at a distance of more than 50 cm away from the front edge up to the windscreen in distances of up to 150 cm from the front end. This can be explained because the impact velocity is the prevalent influencing factor for the kinematics of the body following in a wrap-up around the vehicle shape. As the accident events are very frequently marked by impact velocities of up to 40 km/h, this explains the impact pattern very often in that speed range below the windscreen area. It is remarkable that for velocities of > 40 km/h the area of the windscreen is hit very frequently. This applies to pedestrians as well as to bicyclists in the same manner. For pedestrians nearly most impact conditions related with severe injuries AIS 3+ are located in the windscreen area, bicyclists also suffered from head impacts more distributed to bonnet area concerning their own relative movement possibilities.

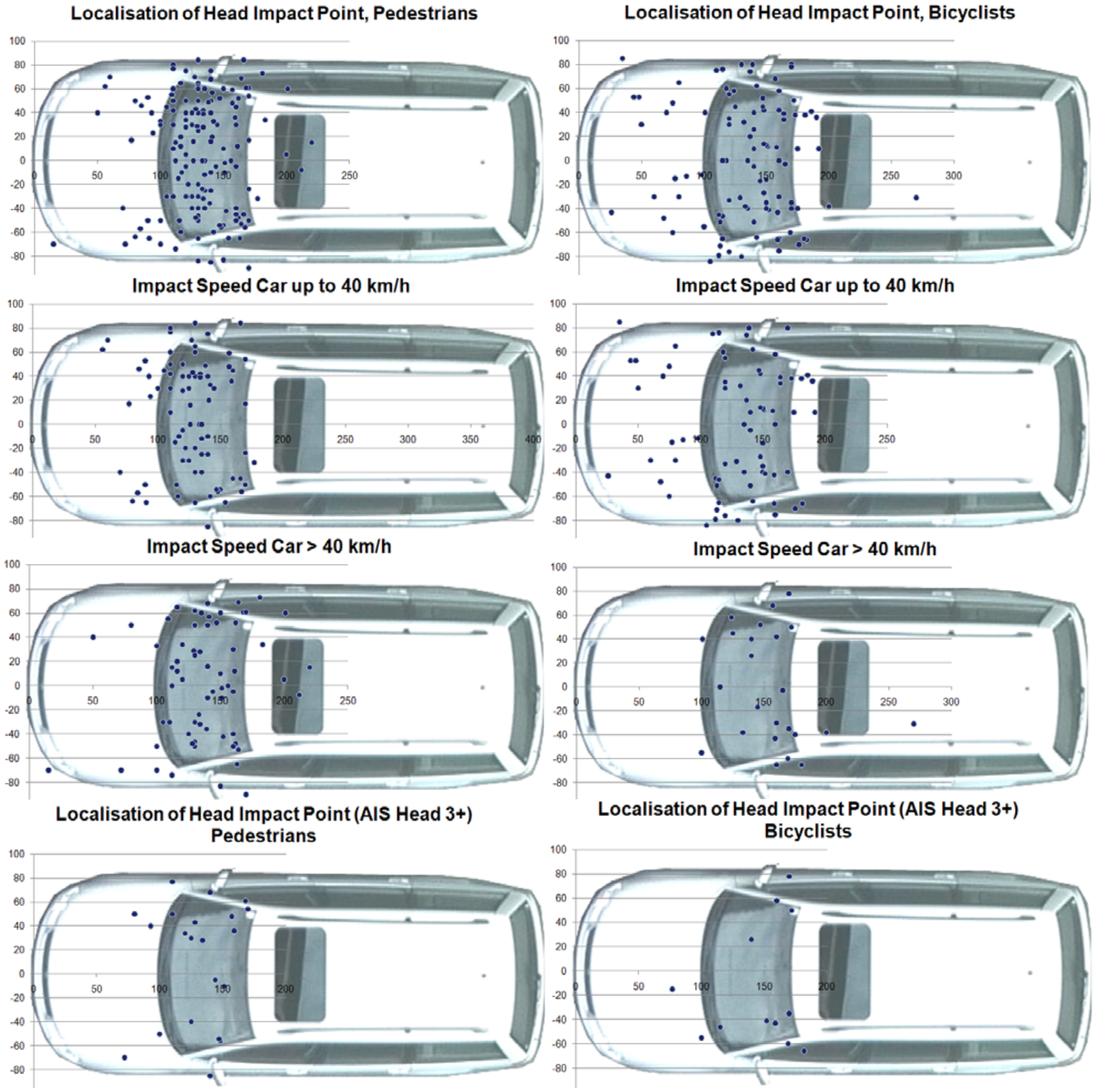

Figure 6 Localization of Head Impact of **Pedestrians** (n=151)

To be able to determine the points of impact and sources of injuries, for which the pedestrians suffered most severe head injuries, only cases of AIS Head 3 and more were regarded. For that a mathematical calculation of the 3-dimensional measuring points of all head impacts with coded windscreen impact of a person was carried out. The results are transferred into a scaled picture of a standardized windscreen reproduction (Figure 7).

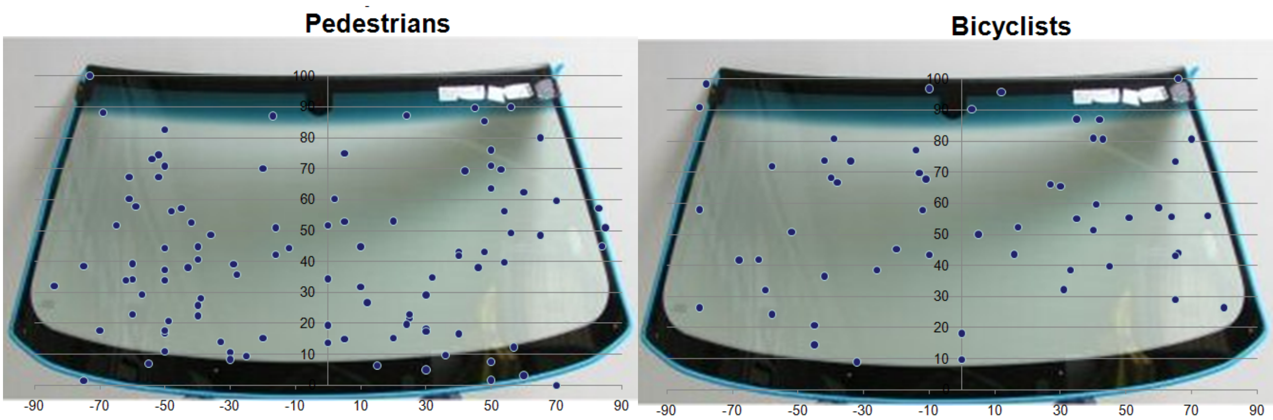

Figure 7 Localization of Head Impact Points on Windscreen, (n=57 Bicyclists, n=102 Pedestrians)

It is remarkable that nearly all places of head impact in occurred at a distance of more than 100 cm in X-direction. This refers mainly to the area of the windscreen. As a rule the velocities exceeded 40 km/h. The area of the windscreen becomes only important for collisions with pedestrians for speeds beyond 40 km/h, for collisions with bicycles injuries are caused at lower speeds, however.

5 Sources of injury of pedestrians and bicyclists in comparison

It was possible to match the documented injuries to the impact objects (Figure 8). The bumper was the most frequent cause of injuries at motorcars, 42.7% were injured by it. Besides the bumper the remaining front caused injuries in 30% of the cases and the hood in 24.5%. For bicycle accidents the bumper caused injuries in only 28.6% of the cases and the frontal surface of the motorcar also only in 22.5%. Injuries caused by the windscreen (30.7% pedestrians, 14.7% bicyclists) were remarkably frequent.

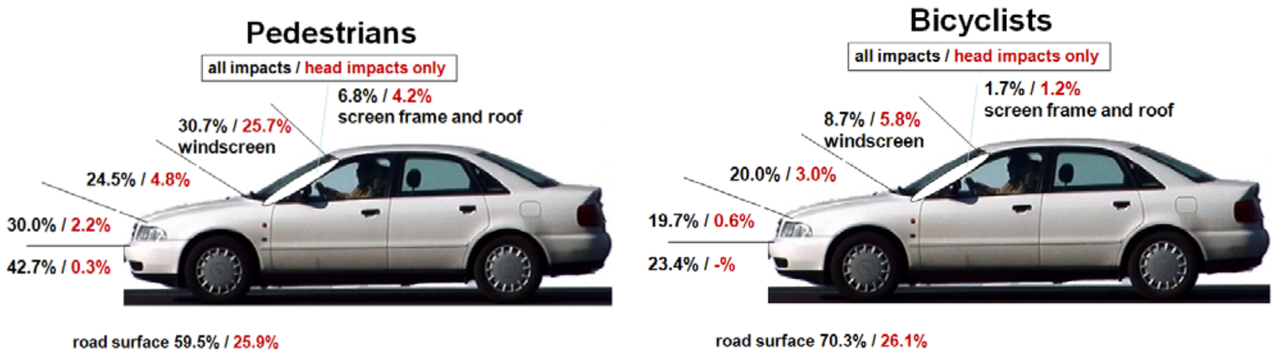

Figure 8 Injury Causing Parts of Impacts of Vulnerable Road Users Peds vs Bikes (100% all Persons)

The adjoining frames were named twice as often as a source of injury for pedestrians as for bicyclists (6.8% and 3.1%). In the figures of the percentages of injury severities the sources the injuries of the head were listed as well. Here the road is responsible for injuries of pedestrians just as for bicyclists at the same incidence rate of 26%, whereas bicyclists in total suffered less frequently from injuries caused by the road in comparison to pedestrians.

6 Throw distances of pedestrians and bicyclists in comparison

In collisions with the front of vehicles the bodies are lifted by the hood and glide across the hood towards the windscreen; this applies to pedestrians as well as to bicyclists (Otte 2006[6]). The horizontal distance respectively the horizontal trajectory length of the place of the head impact from the front part as bumper is the so-called "throw distance". This value is influenced also by the impact velocity, the body size and the shape/design of the car. After the person has exchanged impulse energy with the vehicle and has assumed its velocity, the body separates from the vehicle and moves forward in the direction the car is moving due to the initiated movement (flying phase), hits the road surface and slides to its final position (sliding phase), thereby dissipating energy. It was often discussed if the injuries are suffered from during the primary vehicle impact or the secondary road impact (Otte 2001[7]).

It is obvious that the trajectory function shows a higher increase when the quadratic regression is depicted for pedestrians than for bicyclists (Figure 9). At a speed of 60 km/h a trajectory throw length of approximately 18 m occurs for pedestrians with a probability of 95%. For bicyclists a trajectory length of only 12 m is regarded probable. This is due to the proper motion of the bicycle and the possibly resulting increase of the transverse trajectory throw length at the expense of the longitudinal trajectory throw length.

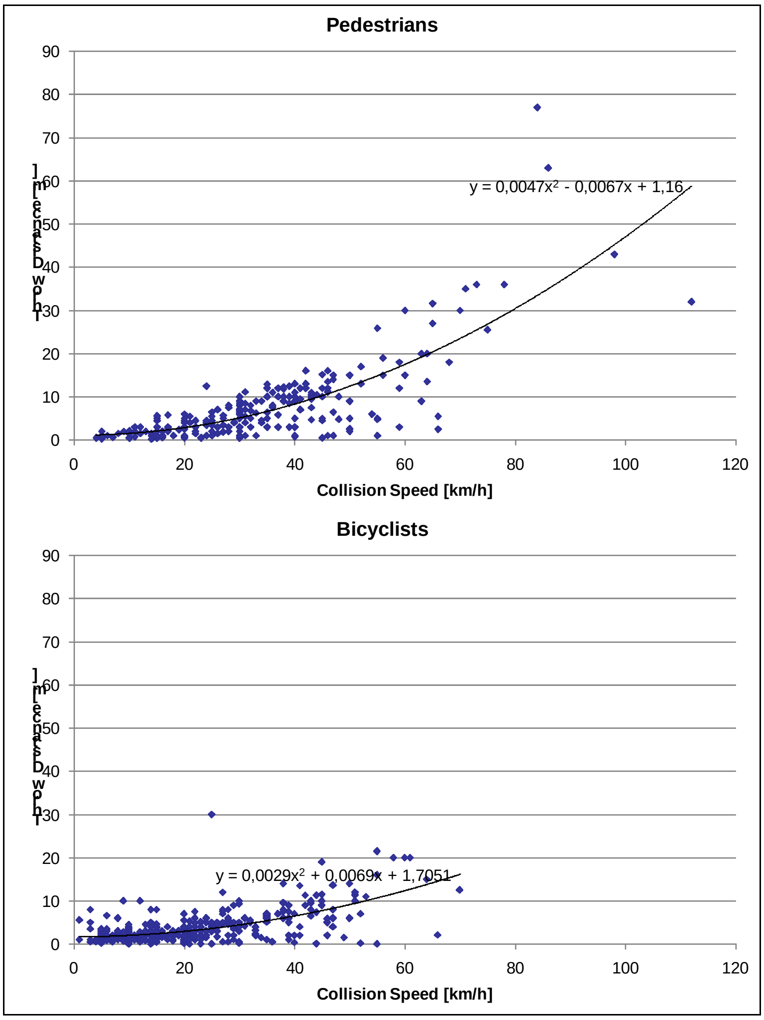

Figure 9 Localization of Head Impact Points on Windscreen, (n=57 Bicyclists, n=102 Pedestrians)

7 Conclusion

The accident analysis showed in comparing pedestrian and bicycle accidents that there is a comparability of these two types of accidents. However, there are also differences of the injury situation of the two groups of persons due to the different structure of the colliding mass systems 'pedestrian' and 'bicyclist with bicycle' and the proper motion of the bicycle, which also has to be taken into account.

Bicyclists are injured less frequently and less severely than pedestrians in particular at the head and legs. Bicyclists have a shorter trajectory throw length. They hit the windscreens of motorcars significantly less frequently; they do however suffer slightly more frequently from injuries due to an impact with the road.

New vehicles have to pass a number of tests to prove sufficient pedestrian protection (Directive 2003 / 102 /EG[2]), which has come into effect in October 2005 and been used in vehicle development since. From 2010 phase 2 of the EC-agreement applies. The tasks and question of the study was to what extent results for the injury situation based on data of pedestrian accidents also apply to bicyclists, who also are to be protected by this directive.

The results of the study gives answers for directives currently applied to vehicle design for pedestrian protection to a large extent, cover the requirements for the protection of bicyclists. The injury situation for pedestrians looks like nearly the same than for bicyclists. Except the head and legs of the bicyclists suffered lowered frequencies of injury and severity.

It remains to be stated, however, that for bicyclists the windscreen area with the lateral frame structures is responsible for severe and most severe head injuries. A testing procedure that includes these issues seems urgently required. The detailed analysis of the places of impact in the area of the windscreen justifies the definition of a testing position in the periphery of the windshield close to the lateral frame. To warrant the protection of the bicyclist the upper part of the windscreen should be taken into consideration.

ACKNOWLEDGMENTS

For the present study accident data from GIDAS (German In-Depth Accident Study) was used. GIDAS is the largest in-depth accident study in Germany. The data collected in the GIDAS project is very extensive, and serves as a basis of knowledge for different groups of interest. Due to a well defined sampling plan, representativeness with respect to the federal statistics is also guaranteed. Since mid 1999, the GIDAS project has collected on-scene accident cases in the areas of Hannover and Dresden. GIDAS collects data from accidents of all kinds and, due to the on-scene investigation and the full reconstruction of each accident, gives a comprehensive view on the individual accident sequences and its causation. The project is funded by the Federal Highway Research Institute (BASt) and the German Research Association for Automotive Technology (FAT), a department of the VDA (German Association of the Automotive Industry). Use of the data is restricted to the participants of the project. However, to allow interested parties the direct use of the GIDAS data, several models of participation exist.

Reference

[1] CARE 2008 European Road Accident Database
http://ec.europa.eu/transport/road_safety/observatory/statistics/care_en.htm

[2] Directive 2003 / 102 /EG
http://ec.europa.eu/enterprise/automotive/directives/vehicles/dir2003_102_ce.htm

[3] Otte, D.; Krettek, C.; Brunner, H.; Zwipp, H.: Scientific Approach and Methodology of a New In-Depth-Investigation Study in Germany so called GIDAS, ESV Conference, Japan, 2003

[4] Brühning, E., Otte, D., Pastor, C.; 30 Jahre wissenschaftliche Erhebungen am Unfallort für mehr Verkehrssicherheit, Zeitschrift für Verkehrssicherheit 51, 175-181, 2005

[5] Association for the Advancement Automotive Medicine: The Abbreviated Injury Scale - Revision 98, American Ass. f. Automotive Medicine., Morton Grove, Illinois (USA) 1998

[6] Otte, D.: Use of Throw Distances of Pedestrians and Bicyclists as Part of a Scientific Accident Reconstruction Method, *Vortrag und Proc., 2004 SAE World Congress, Detroit/USA, March 2004, SAE-Paper 2004-01-1216*

[7] Otte, D.: Analysis and load assessment of secondary impact on the road for grown-up pedestrians after car collisions, Proc., Ircobi, Isle of Man, UK, 2001