Injury Severity and Causation Factors of Motorcyclists in Traffic Accidents in comparing Drivers of Motorcycle and All Kinds of Motorized Two-wheelers

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ABSTRACT

This study describes the injury frequency and injuries in detail for motorcycle drivers on German roads involved in traffic accidents and comparing the analysis with the whole group of all kinds of motorized two-wheelers. The study is based on documented accidents by GIDAS (German In-Depth-Accident Study). The current situation on injury frequencies on different body areas and the severity of such injuries are well documented and compared to previous time frames. Also the characteristics of the accident causes are analyzed on the basis of a special coding system ACAS (Accident Causation Analysis System) showing human factors responsible for the accident occurrence. For the present study 2.864 motorized two wheeler riders compared to 1.406 motorcycle drivers are used as representative distribution for the German situation, based on a statistical random selection of accident documentations and weighting procedure. Two-thirds of all motorized two-wheeler suffered from minor injuries MAIS 1 and 10% received severe injuries MAIS 3+. The trend of the last decades is shown a positive decrease of numbers in fatalities and severely injured riders. The smallest proportion of severe injuries MAIS 3+ can be observed for moped25 riders with 3.3%. The group of heavy motorcycles has a portion of 16.3% severely injured riders. Nearly 50% of the riders used protective clothes while 98% wear helmets. The impact location and load levels are discussed regarding an optimization of the safety level on the motorcycle and demands to the rider on protective equipment. Over 70% of the riders had contributed to the emergence of the accident with a human failure and in less than 2% of the cases a technical defect of the motorcycle was a contributing factor for causing the accident. Over 10% of the motorcycle riders had caused an accident due to an influence from the traffic environment or weather. This study will show that also demands to the drivers of motorcycles are needed to get further reduction in accident events.

INTRODUCTION AND OBJECTIVES

Road users without a protective outer shell are called "Vulnerable Road User". This includes pedestrians, cyclists and motorized two-wheeler users (powered two wheelers PTW). The latter are categorized by the German and the EU vehicle classification regulation into „Kleinkrafträder“ (EU-class L1e, <45 km/h, <50 ccm) and motorcycles (L3e, L4e >50 ccm, >45 km/h). The so called „Kleinkrafträder“ include cycles (<50 ccm, <45 km/h), Mopeds and Mofas (<25 km/h) and Light Mofas (<30 ccm, <0.5 KW, <20 km/h). The motorcycles can be divided into motorcycles (>50 ccm, > 45 km/h), light motorcycles (<125 ccm, <11 KW) and heavy so called “standard” motorcycles (>125 ccm, >11 KW).

Due to the different types of PTW and their different use driving and motion behavior on public roads are different. There are also different requirements for limits of speed arising from the motor vehicle authorities within these groups. The protection existing for users of these PTW is not fundamentally different, as there are helmets and protective clothing available. However the usage behavior is different riders of motorcycles almost generally use full face helmets protecting the whole head and often use protective clothing to protect the whole body also with special protectors. For scooters and mopeds however rarely a full face helmet is used, but more often half-shell helmets and open-face helmets. Protective clothes is also found in different frequencies depending on the type of PTW and special protectors inside the clothing are found almost exclusively among the riders of motorcycles (however also in rather low frequency of use).

The accidents which occur are often a reflection of driving performance, handling and traffic participation, while riders of PTW involved in accidents are found in almost all age groups. While crashed motorcyclists are quite often characterized by more mature ages, light motorcycles and scooters are mainly used by the younger generation. Age plays a part in the causes of accidents but also the results of suffering injuries as the biomechanical load limits of the elderly compared to the younger people are significantly reduced. The injury severity however is particularly influenced by the different masses of the colliding accident partners and thus by the loads transmitted to the body by the collision. Therefore the severity of the accident and the resulting injuries are different in the various groups of PTW.

It is currently estimated that there are about 30 million motorized two-wheelers in Europe, and a market for Europe is currently indicated to about 2.5 million two-wheelers annually (ACEM, 2007). Here, a heavy increase was observed in the years after 2005 (with only 2.0 million units). The trend of mopeds (<50 ccm) and scooters is now declining to about 1 million annually, in contrast the registrations of motorcycles (> 50 ccm) however is increasing by +3% to 1.5 million. Particularly in Asia motorized two-wheelers add to the overall picture of traffic. In India, for example, 69% of all motorized vehicles are motorized two-wheelers and 27% of all road deaths are among the group of riders of motorized two-wheelers. In Thailand it is estimated that 70-90% of road deaths and about 60% in Malaysia are from the group of riders of motorized two-wheelers. In many so-called "low and middle income countries" PTW are among the increasing means of transport. Consequently, it is not surprising that also many people of this road user group die in traffic of those countries. This is not the case in western countries, although there also many people are injured or killed every year by using these types of PTW. In the European Union about 40,000 people are killed in traffic each year (ETSC, 2008) of which in 2006 6,200 riders of PTW in the EU 25 countries lost their lives. These represent 16% of all traffic fatalities, while they only represent 2% of the total mileage driven. The risk to be killed is classified 18 times higher than with car drivers. It has been postulated that Norway, Switzerland, Denmark and Finland are the least dangerous countries for motorized two-wheelers, while the central and eastern Europe are represented as the most dangerous regions.

PTW users are particularly vulnerable as a result of the higher driving speeds collisions with heavier vehicles such as cars and trucks lead to high energy transmission. The use of protection such as helmet and protective clothing is common in many countries, but it is registered that in view of different temperatures from north to south the usage frequency varies. Similarly, half-shell and open-face helmets are used more frequently in southern countries. In Germany in 2012 99% of the drivers of PTW were wearing a helmet, only 53% wore additional protective clothing, 21% wore full protective clothing (BAST, 2013). It can be explained by the relatively high usage rate of protection gear that the injury situation on the road for motorcyclists now compared to previous years turns out positively. In 2009 651 killed motorcyclists were counted in Germany, about 18% less than 4 years ago (DeStatis, 2010). The number of killed PTW was not decreased over the last further years, moped users on the other hand, remained also constant (at about 100 fatalities per year), which also applies to the number of injured.

As technical causes, given the high technical quality of vehicle engineering and road design, hardly come into appearance for the occurrence of accidents and also as vehicles are continuously optimized in terms of safety, human causes may be stated as the main source for the occurrence of accidents. Especially to reduce the number of injuries and fatalities even further in the future the reduction of the absolute number of accidents is also required. Past studies revealed that the motorcyclist involved is obviously less culpable for the accident than the drivers of cars or trucks with which he collided. The neglecting of the right of way of the PTW by other road users is currently one of the most common causes of accidents (IFZ, 2004). According to the Association of insurance companies in situations where the motorcyclist was injured the car drivers often were to be blamed for the occurrence of the accident (Sporner, 1989).

The present study will clarify the extent to which the accident and injury situation has changed for the group of riders of PTW and which measures to increase safety must be sought in the future. For this it is effective to use the continuously carried out on-scene accident research in Hannover and Dresden (GIDAS) for analyzing the accident-structure. The study aims to analyze the structural characteristics of the different types of road users based on detailed documented traffic accidents and thereby identify injury priorities and mechanisms in connection with the used protective equipment such as a helmet and protective clothing. Furthermore accident causation factors and characteristics therefore should be identified.

BASIS OF THE STUDY

As part of GIDAS about 2,000 traffic accidents involving personal injury are documented annually by scientific teams in Hanover and Dresden since 1999. The reconstruction of the driving and collision velocities as well as the detailed documentation of the sustained injuries is recognized through the comprehensive collection of information (Otte, 2003 and Brühning, 2005). By means of a new coding system of accident causation factors (ACAS Accident Causation Analysis System) accident-relevant situations can be worked out and prophylactic measures can be defined (Otte, 2009 and Pund, 2006). The injuries are recorded based on the AIS (AAAM, 1998) and injury severities using the usual definition according to MAIS (maximum single-AIS on all registered injuries) are compared to the technical framework. For the determination of the collision and driving speeds, the traces of the accident scene are documented in a scaled drawing using 3D laser technology and the crash collision analysis is conducted by the simulation software PC-Crash (Otte, 2005). Based on the documentation of traffic accidents by statistically representative sampling methods and by an annually renewed matching of the data, the accident data in GIDAS can be regarded as representative for Germany (Pfeiffer, 2006).

The analysis of the statistically weighted data set was made as descriptive statistics. Therefore unknown parameters in the data set were not included, so that hereby the presented tables and graphs may display different numbers of "n".

To display the current accident and injury situations of road users the official statistics of traffic accidents in a country is to be look at. In order to implement measures to increase road safety for motorcyclists, it is necessary to carry out further detailed surveys that are done in a comprehensive and detailed analysis, including reconstruction of the accident on the example of the Accident Research Unit Hanover. The on scene accident research provides detailed information about vehicle damage for the two-wheeler as well as for the collision partners cars and trucks. Access to the injured is allowed and thus the detailed knowledge of injuries, including consideration of X-rays and insight into the medical documentation is available, hence the impact and injury kinematics of the riders of two-wheelers as well as the mechanics of injury can be determined. Essential characteristics of an evaluation of the trauma development are the technical accident circumstances such as impact speed and relative speed between the vehicles involved. These can be reconstructed with the use of traces on the roadway and the points of rest of vehicles and people involved using mechanical principles. Interviews of accident participants also provide information about the accident development, situational actions of the drivers involved and failures in the driving task. Such a comprehensive accident research is continuously conducted in Germany as part of the GIDAS project (German In-Depth Accident Study) by the Federal Highway Research Institute and the Research Association for Automotive Technology FAT since 1999. Two teams, one each in the regions of Hannover and Dresden annually document 2000 traffic accidents involving personal injury (Brühning, 2005) based on a statistical sampling method (Pfeiffer, 2006).

DATA STRUCTURE OF THE STUDY

For the present study GIDAS data from the years 1999-2011 (n=24,013) were analyzed and from this accidents with motorized two-wheelers (n=3,474) were selected. After excluding cases with unknown information such as cases without riders, and cases in which important parameters were unknown such as injury information, head injury, wearing of safety helmet, a total of 2,864 riders of powered two-wheelers including 1,406 motorcyclists remained for the analysis (Figure 1). These 2 groups are compared within this study. On the one hand this study will display the injury situation of motorcyclists compared to the group of all PTW, on the other hand aspects of passive safety (injury and injury severity and their distributions) and active safety (causation and avoidance strategies) will be analyzed as a snapshot of the current accident situation. For the latter a subsample of the years 2008-2012 was chosen as for this data a special classification of accident causes (ACAS Accident Causation Analysis System) was started in the investigation at Hannover Medical School. This is a special coding system of human, vehicle and environmental causation factors collected from interviews and accident descriptions (Otte, 2009).

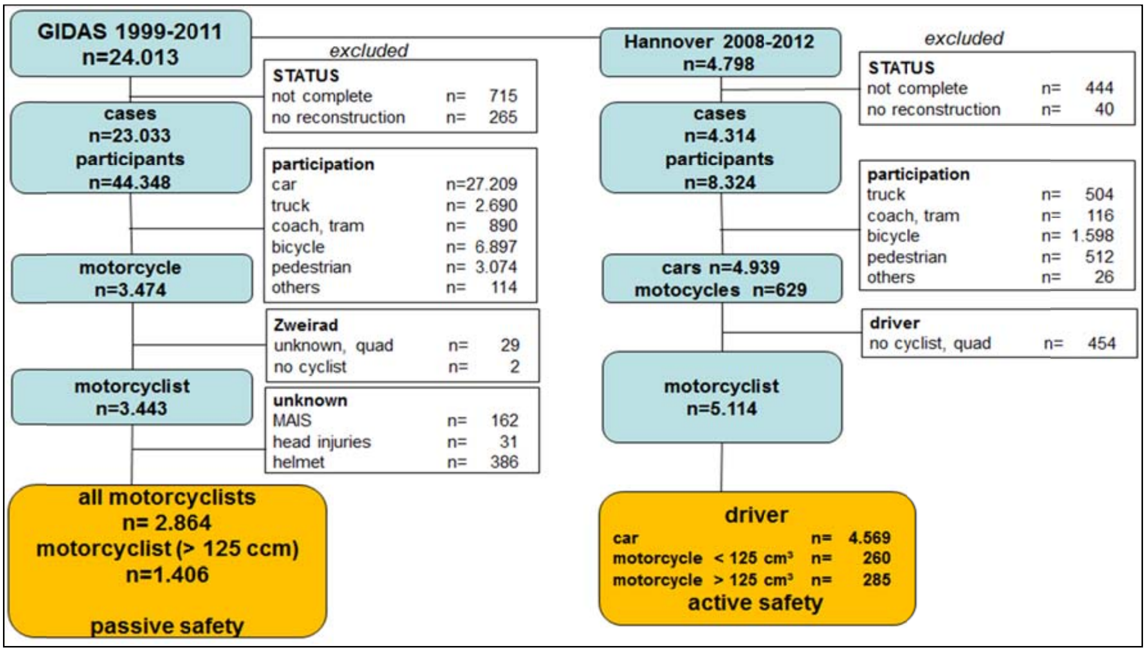


Figure 1 Sample Frame of the Study for GIDAS Database (left: passive safety, right: active safety)

INJURY SITUATION OF MOTORCYCLISTS

The analysis is conducted for the different types of motorized two wheelers PTW according to the categories valid in Germany. There are 4 major categories summarized in the group of "all motorized two-wheelers":

1. "Mofa": maximum speed of 25 km/h , in this study referred to as **moped25**
2. "Mokick": engine displacement of up to 50 ccm and a maximum speed of 45 km/h, in this study referred to as **moped**
3. "Kleinkraftrad": with an engine displacement of up to 125 ccm in this study referred to as **light motorcycle**
4. "Motorrad": with an engine displacement of over 125 ccm, in this study referred to as **(heavy) motorcycle and compared to the group of all PTW**

The injuries are classified by the Abbreviated Injury Scale (AIS) in 6 degrees of severity AIS 0 uninjured, AIS 1 minor, AIS 2 moderate and AIS 3 severe up to AIS 6 (AIS 3+) (AAAM, 1998) (Otte, 1995). 57.3% of all motorcyclists suffered from minor injuries MAIS 1, 25.6% had an injury severity of MAIS 2 and 11.9% of motorcyclist suffered from serious injuries of MAIS 3+. Only a comparison with other road users allows an assessment to what extent the proportion of the severely injured is of importance for the whole accident situation. For this purpose, belted car occupants were considered (data source GIDAS 2013, accidents of 2000-2012, n = 21,668), for which a proportion of the severely injured occupants MAIS 3+ results in 1.8%.This shows that motorcycling has a 6.6-times higher risk to suffering serious injuries.

Figure 2 shows that the proportion of the severely injured riders varies for different types of motorized two-wheelers. Thus, the smallest proportion of severe injuries MAIS 3+ can be observed for moped25 riders with 3.3%. The groups of mopeds have a proportion of 7.5%, the group of light motorcycles has a proportion of 8.8% and the group of heavy motorcycles has a portion of 16.3% severely injured riders.

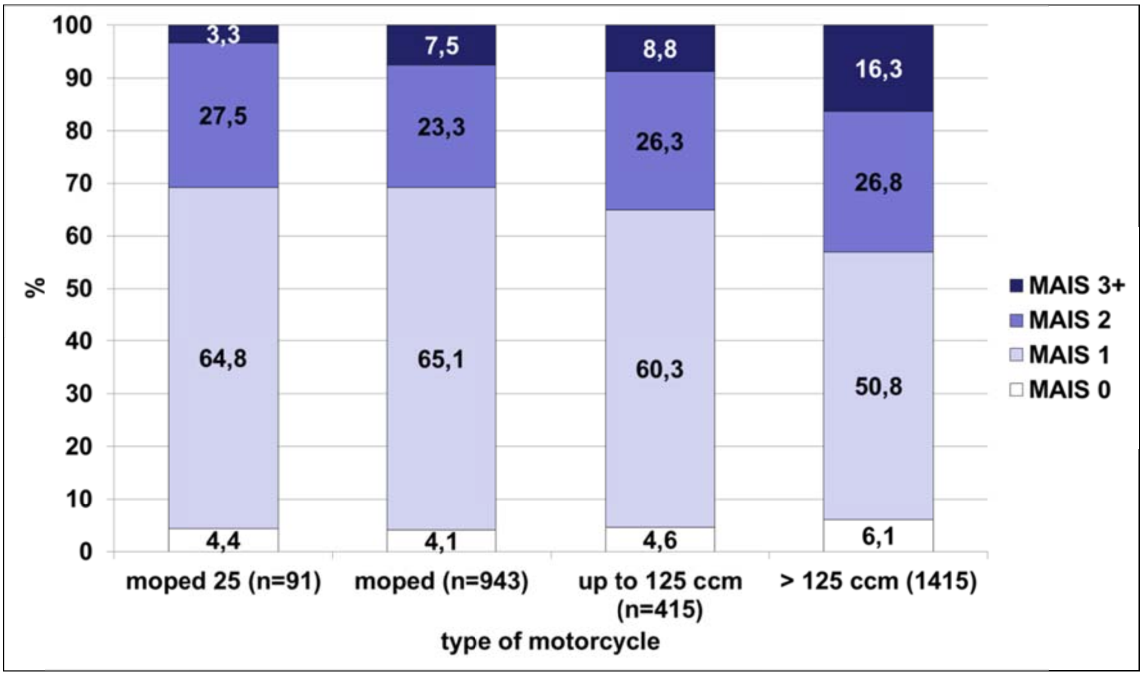


Figure 2 Maximum injury severity grades for motorcyclists of different two-wheeler-groups (100% each group)

The relevant parameter for the injury severity apparently is the impact speed which is resulted by the relative velocity between the colliding vehicles in which the collision angle comes into account. 80% of the relative speeds for the motorcyclists are below 60 km/h. Compared to this 80% of the relative speeds of the total group of powered two-wheelers are found to be at 50 km/h which means that motorcycle accidents are obviously characterized by a higher speed of the motorcycle itself.

A higher injury severity can also be detected at higher engine displacement. Thus 15.8% of the riders of motorcycles with an engine displacement over 750 ccm were severely injured MAIS 3 +, whereas only 7.7% of the moped riders (up to 50 ccm) and 8.9% of riders with PTW in the 51 to 125 ccm displacement class. However the analysis shows that the curb weight of the vehicle has no influence on the injury severity.

That the riders of bigger motorcycles have a higher incidence of severe injuries can also be seen when analyzing different classes of engine power of the PTWs. While 15% of the riders of PTWs with an engine power of 50-75 kW are severely injured this share rises to 25% for riders of PTWs with an engine power greater than 75 kW. Consequently the proportion of severe injuries is also influenced by the power to weight ratio (mass/kW) of the vehicle (Figure 3). This is visible especially for light-weight motorcycles with high power (0-3 kg/kW) where the share of severely injured (MAIS 3+) riders is about twice as high as for the other power weight classes.

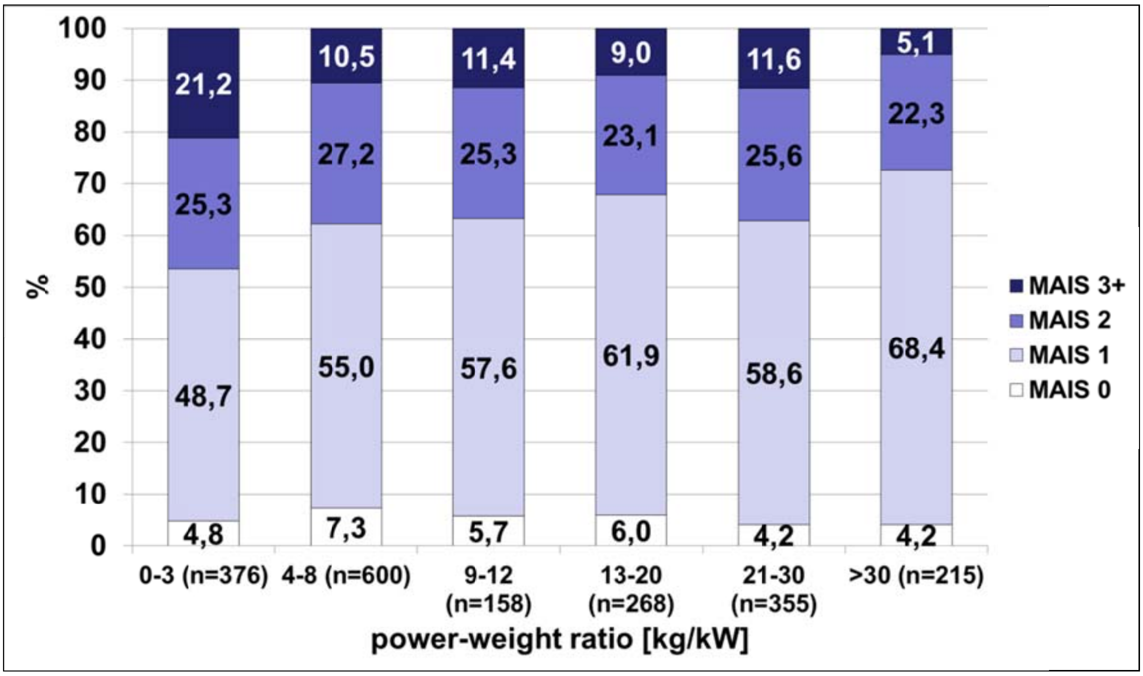


Figure 3 Maximum injury severity grade and power to weight ratio (100% each group)

An influence of injury severity for different age groups of motorcyclists, however, is not visible. From the sample of cases a weak trend towards higher injury severity may be seen for over 60 year olds a certainty however cannot be given due to the small number of people in the sample.

ACCIDENT TYPES

The classification of accident situations can be done on the basis of a classification system using 7 accident types which is also used in official accident statistics (GDV, 1998). Here the conflict situation which led to the accident immediately before collision is considered. It turns out that riders of PTW are mostly involved in accidents which occurred due to a conflict between a turning in or crossing road user without priority and a vehicle with priority at crossings with 26.5%. Accidents involving pedestrians (cutting across the roadway) are rare at only 2.4%, as well as accidents with stationary traffic at 5.2%. The proportion of severely injured riders is relatively constant for almost all types of accidents (10-15%), yet a high proportion of moderate injuries MAIS 2 can be seen in driving accidents and “turning off accidents” due to a conflict between a turning off road user and a road user coming from the same direction or the opposite direction.

Form from the conflict situations (accident types) between the parties different collision constellations result between motorcycle and opponent, which are scientifically classified by collision types. Here 7 collision types were established based on a former study of the authors (Otte, 1998) which are scientifically widely recognized and often found in literature.

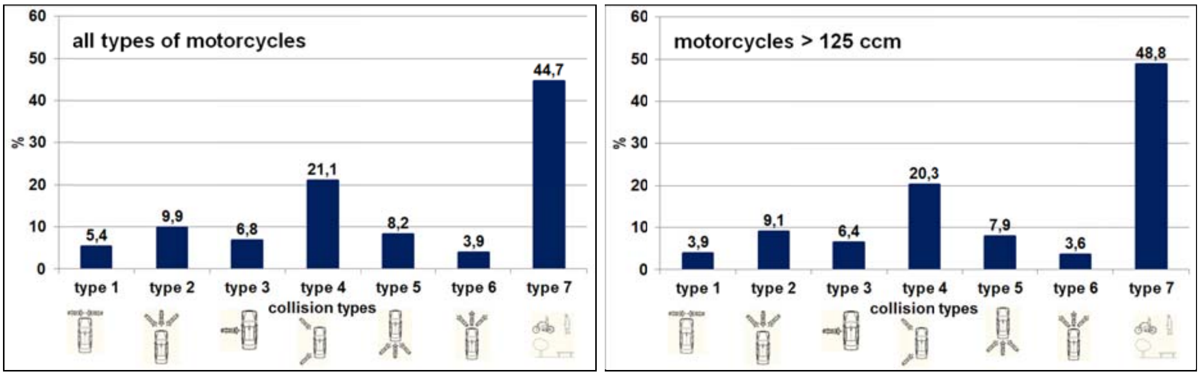


Figure 4 Collision configurations (types) of all motorcycles (n=2,848) and motorcycles > 125 ccm (n=1,406), 100% all persons in each diagram

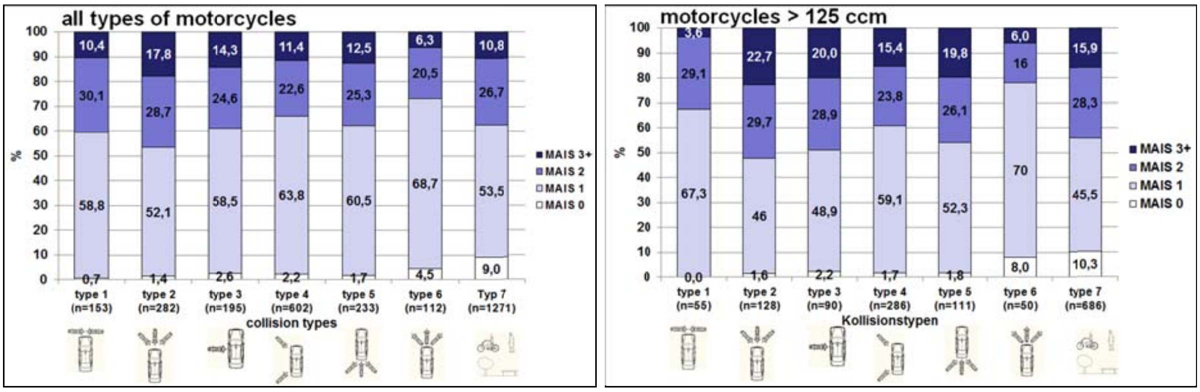


Figure 5 Collision configurations (types) of all motorcycles (n=2,848) and motorcycles > 125 ccm (n=1,406) and maximum injury severity grade of motorcyclist (100% each group of collision types)

For PTW in general, the oblique collision frontally into the side of a vehicle (type 4 with 21.1%) and the single vehicle accident with impact with objects (type 7 with 44.7%) are the most common collision types (see Figure 5). Also for motorcyclists (> 125 ccm) these two collision configurations are most common (20.3% respective 48.8%). The most severe types of collisions turn out to be the types 2,3,4,5 and 7. The most severe collisions are found in type 2 where the PTW collides into the front of the collision opponent at an oblique angle as well as the impact of the PTW practically perpendicular into the side of the car in the area of the compartment. These provide a particular exposure to head injuries, often associated with trauma to the entire body

INFLUENCE OF A SAFETY HELMET ON THE SEVERITY OF INJURY

To determine the effectiveness of a safety helmet in the accident situation of riders of PTW, 2 groups were formed, riders with safety helmet (n = 2,725) and riders without helmet (n = 139) – see Figure 6. The ratio of the number of cases shows the high usage rate of safety helmets, which in Germany is found to be at 99% according to studies of the Federal Highway Research Institute (BAST, 2009). When considering the injury severity by AIS, a significantly lower proportion of severe head injuries AIS 3+ is found with riders that had used the helmet (3.4%) versus riders that had not used the helmet (4.3%). Also, the injury severity of AIS 2 (moderate) shows up much less with helmet use with 9%, compared to 11.5% of cases without a helmet. Even AIS 1 injuries are less frequent at 7.6% with the protective helmet compared to 11.5% without the helmet.

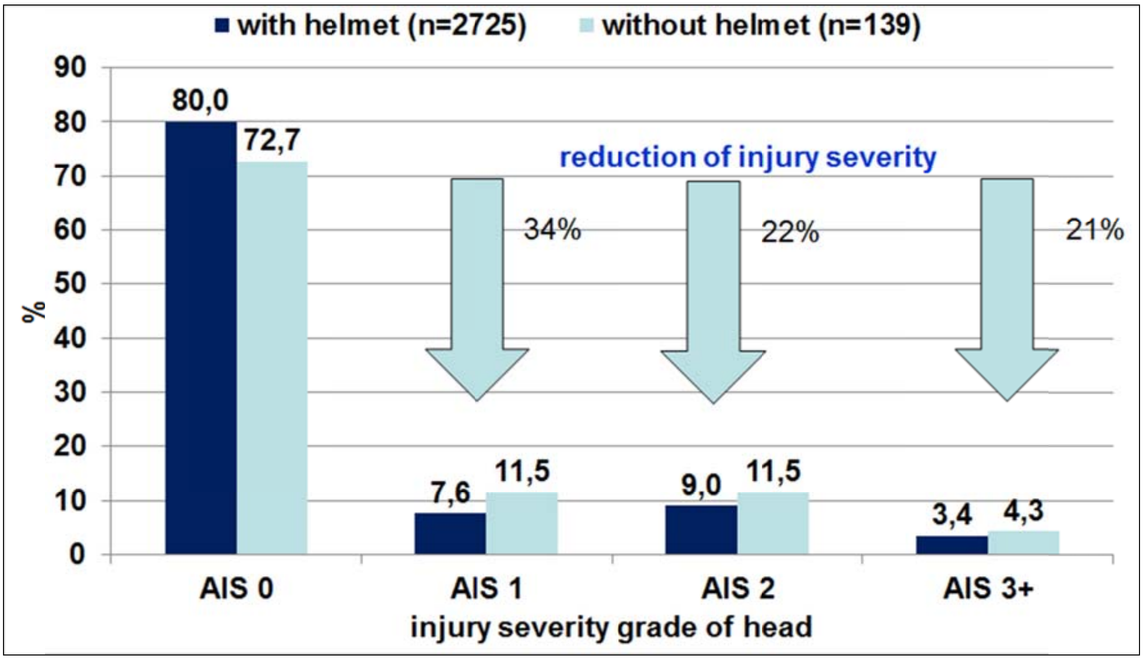


Figure 6 Injury severity grade head with and without use of helmet (100% each group of persons – with and without helmet)

Thus, the protective effect of the helmet is clearly visible, which leads to the effect that there is a higher proportion of uninjured riders with helmet (80%) than without helmet (72.7%). This is particularly evident, when considering the overall injury severity MAIS of all riders with a helmet where serious injuries often occur at the total body, while the head is not or less seriously injured due to the helmet. This is particularly important for patients hospitalized as poly traumatized victims (per definition more than 3 injured body regions with AIS 3+ each), so that with the absence of severe head injuries, the chances of survival can be improved with a helmet.

The following reduction of injury severity with the use of a helmet can be deduced from the study:

AIS 1 minus 34%
AIS 2 minus 22%
AIS 3+ minus 21%

This high level of protection provided by a motorcycle helmet can also be found when considering the injury-frequency of different body regions (Figure 7). Motorcyclists (PTW > 125 ccm) only had head injuries in 19.9% of the cases, while the injuries to other body regions were more frequently observed.

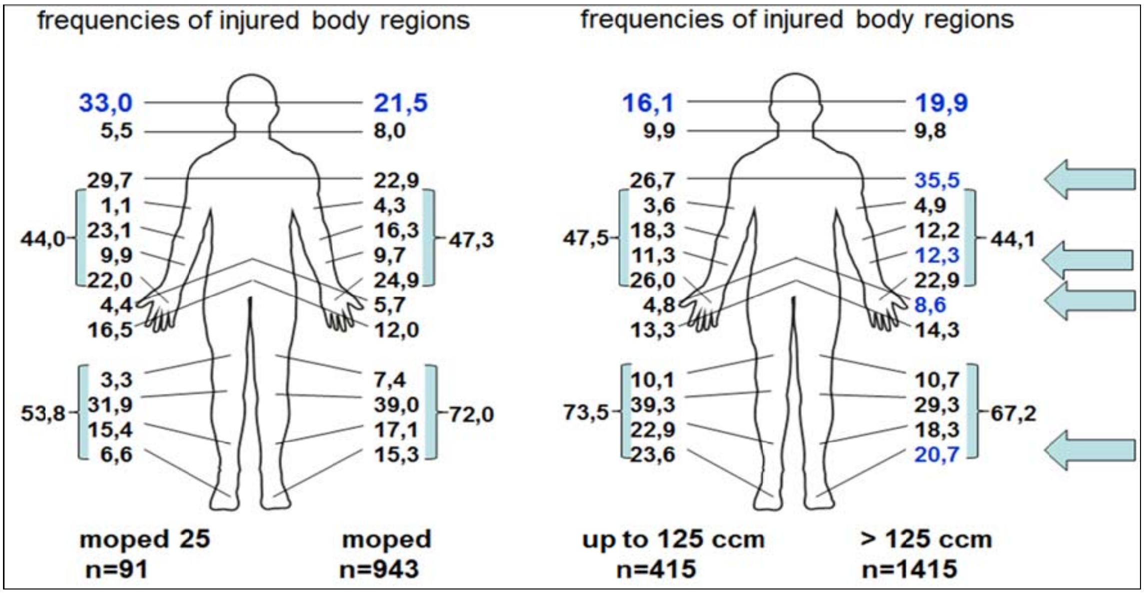
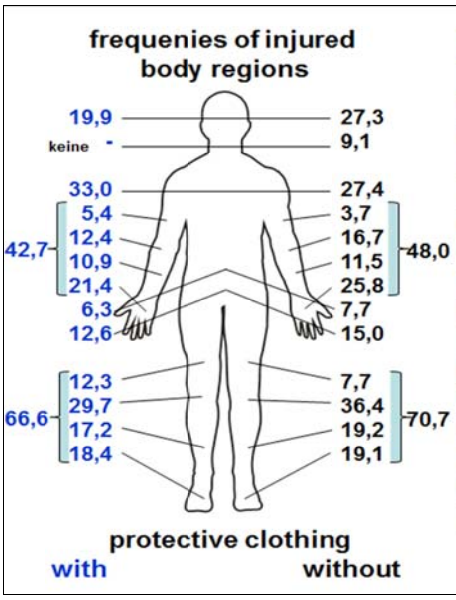


Figure 7 frequencies of injured body regions of motorcyclists for different types of motorcycles (100% all persons each group)

Arm injuries were present at 44.1% of the injured motorcyclists (> 125 ccm) and leg injuries were present at 67.2% of motorcyclists. Particularly common are also chest injuries with 35.5%. Especially thoracic injuries have the higher percentages with riders of motorcycles (> 125 ccm) than with riders of other types of PTW. Here obviously the combination of the used protection, such as protective clothing and with special impact energy absorption zones seems to be the reason for the differences between the different types of PTW (Otte, 1987). In contrast with the exception of the helmet which is used by nearly all riders of PTW, protective clothing is rarely found within the other types of PTW (Otte, 1991).



injured body regions only

	with protective clothing			without protective clothing		
	AIS 1	AIS 2	AIS 3+	AIS 1	AIS 2	AIS 3+
head	37,6%	46,4%	16,0%	42,1%	42,1%	15,8%
neck	-	-	-	81,2%	8,8%	10,0%
thorax	58,6%	24,7%	16,7%	65,7%	22,5%	11,8%
upper extr. total	75,8%	20,9%	3,3%	81,8%	16,4%	1,8%
upper arm	47,8%	42,0%	10,1%	56,9%	43,1%	-
elbow	99,4%	0,6%	-	99,2%	0,8%	-
lower arm	42,9%	49,3%	7,9%	58,6%	34,8%	6,6%
hand,-joint	87,9%	12,1%	-	86,8%	13,0%	0,2%
abdomen	55,8%	25,0%	19,2%	67,4%	24,2%	8,4%
pelvis	75,3%	16,7%	8,0%	86,0%	11,5%	2,5%
lower extr. total	70,8%	16,8%	12,4%	78,4%	14,0%	7,6%
upper leg	41,5%	6,5%	52,0%	50,3%	4,2%	45,5%
knee	86,2%	13,4%	0,3%	90,4%	9,2%	0,4%
lower eg	59,9%	29,7%	10,4%	66,9%	22,7%	10,4%
foot, ankle joint	69,9%	27,8%	2,3%	77,9%	20,6%	1,5%
	100%			100%		

Figure 8 Frequencies of injured body areas with and without protective clothing related to the injury severity grades AIS (100 % all injured body areas)

In the scope of this study an attempt was made to determine the effectiveness of the use of protective clothes (Figure 8). For this purpose, riders were considered with and without protective clothes. An analysis based on all persons included in the study (100%) was conducted analyzing at which body regions the rider was wearing protective clothes and which injury severity grade according to AIS were found there by percentage frequency. Unfortunately no clear result regarding the effectiveness could be seen here.

It is remarkable however that the identified percentages for AIS 1 injuries without the use of protective clothes are higher for almost all body regions. This could be an indication of the existing effectiveness of protective clothing for riders of PTW.

DEVELOPMENT OF SAFETY FOR MOTORCYCLISTS AND PTW BASED ON THE INJURY OUTCOME IN TRAFFIC ACCIDENTS

The safety level can be detected in looking to the injury severity in traffic accidents at different time positions. Here GIDAS can be used for such overview regarding the fact that in-depth-investigation carried out at the Medical University Hannover since 1985 by using the same methodology of accident sampling. It can be seen in Figures 9 and 10 that the proportion of severe injury grades MAIS 3+ are reduced with the factor of nearly 3 from the years 1985-93 to 2003-11 for users of PTW. There could be seen a reduction of severely injured motorcyclists of nearly 50% over the time period of more than 20 years.

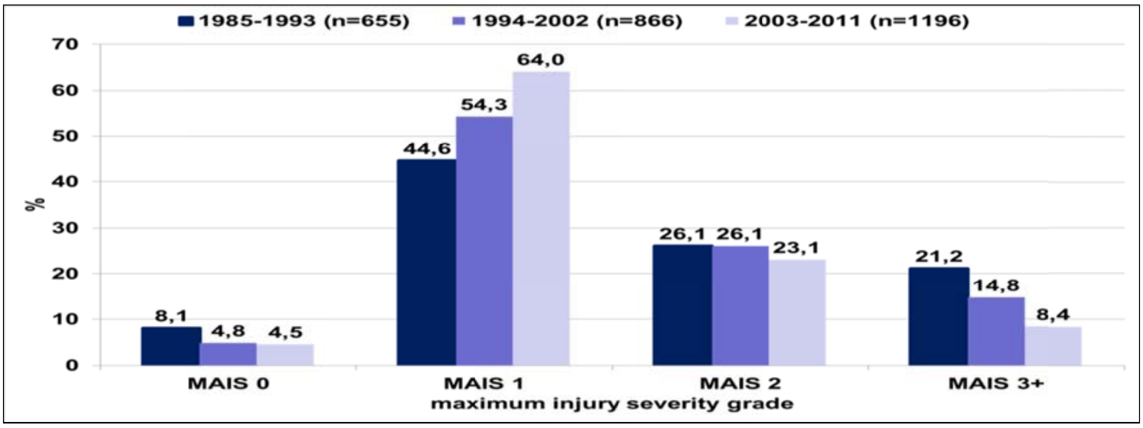


Figure 9 Frequency of injury severity grades MAIS of all motorcyclists related to different year groups (100% all persons each year period)

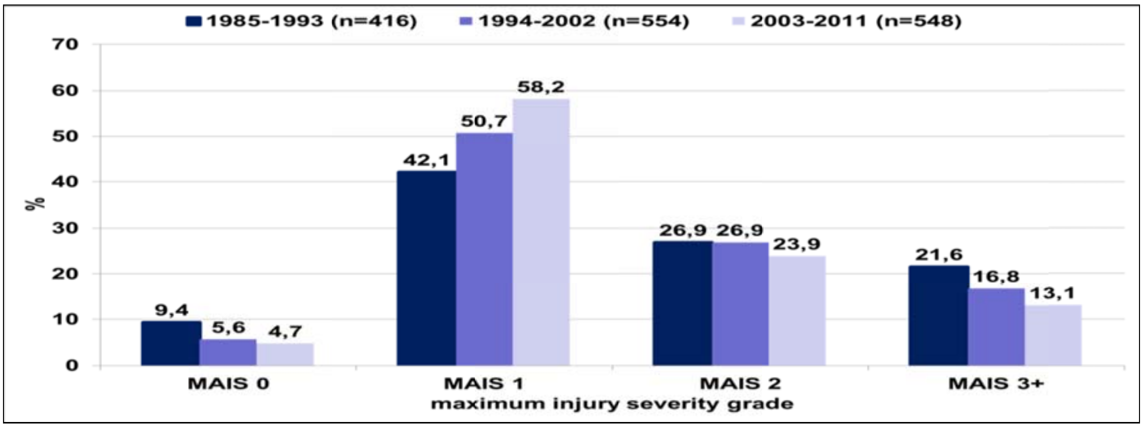


Figure 10 Frequency of injury severity grades MAIS of all motorcyclists on motorcycles with > 125 ccm only related to different year groups (100% all persons each year period)

CAUSES OF TRAFFIC ACCIDENTS INVOLVED POWERED TWO-WHEEL-DRIVERS

A look into the German national statistics shows that road users depending of the age do not cause accidents at the same rate. This is revealed when comparing the amount of accidents causers of an age group with the amount of road users at that age group which did not caused an accident (Figure 11).

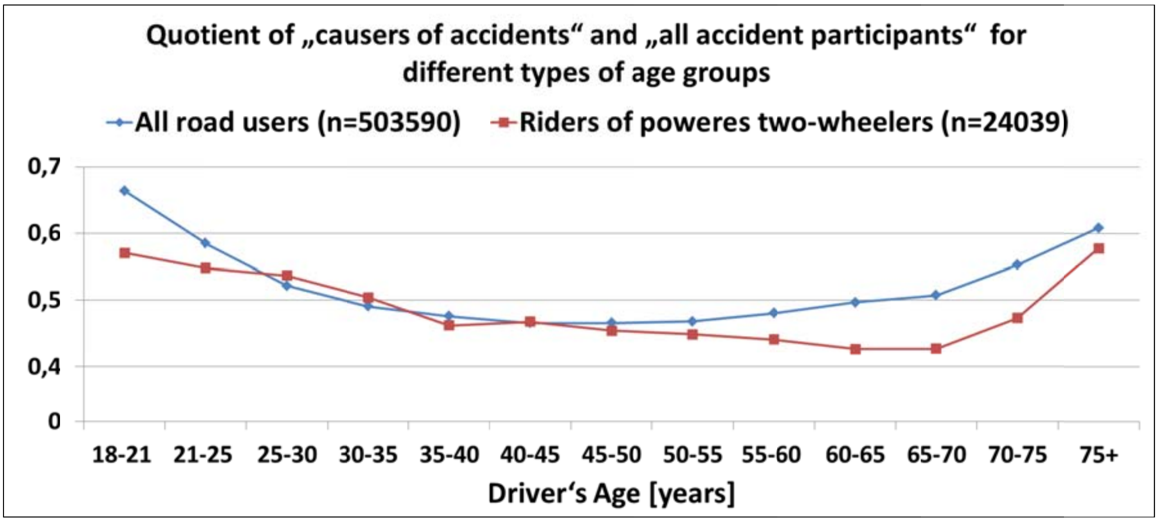


Figure 11: German national statistics 2010: Quotient of causers of accidents and all accident participants for different age groups, comparing riders of PTW with all road users.

The graph shows the quotient of accident causers to all accident participants comparing riders of PTW to all road users. Thus for example young road users (aged 18-21) in 66% of the cases the main causation leads to the driver of the PTW when involved in an accident. For the group of all road users the risk of causing an accident decreases with the age and with gaining more experience over the years to about 47% for road users aged between 40 and 60. However this risk begins to rise for road users over 60 years of age to a point where the group of the over 75 year old again have a risk of causing the accident which with over 60% has nearly reached that of young novice road users. Interestingly this graph has a visible deviation for the riders of PTW: On one hand the young riders of PTW are less likely to be the causer of an accident (57%) than young road users not using a PTW (66%). On the other hand elderly riders of PTW of ages between 60 and 70 when in an accident only have a risk of 43% to be the causer of that accident while other road users at that age when in an accident in 50% of the cases have caused the accident. So elderly motorcycle riders seem to be more cautious in traffic and cause less often accidents than other types of road users at that age. It is assumed that more mentally and physically fit seniors use PTW.

For the prevention of accidents with VRU above all the knowledge of the causes of the accidents is of special importance. Thus the need for in-depth accident causation data in accident research led to the development of a special tool for the collection and coding of such data called ACAS (Accident Causation Analysis System), which was developed based on the GIDAS methodology and presented at international conferences in 2006 and 2009 (Pund, 2006 and Otte, 2009). In ACAS causation factors of traffic accidents which contributed to the emergence of the accident are collected for each accident participant. According to the ACAS methodology the factors are divided in to three different groups: Human factors (group 1), factors from the vehicle technology (group 2) and factors from the driving environment and/or from the infrastructure (group 3). Figure 12 displays the distribution of causation factors on the three groups, comparing causes of motorcycle riders (light and heavy motorcycles depending on the engine displacement) with the causes of car drivers.

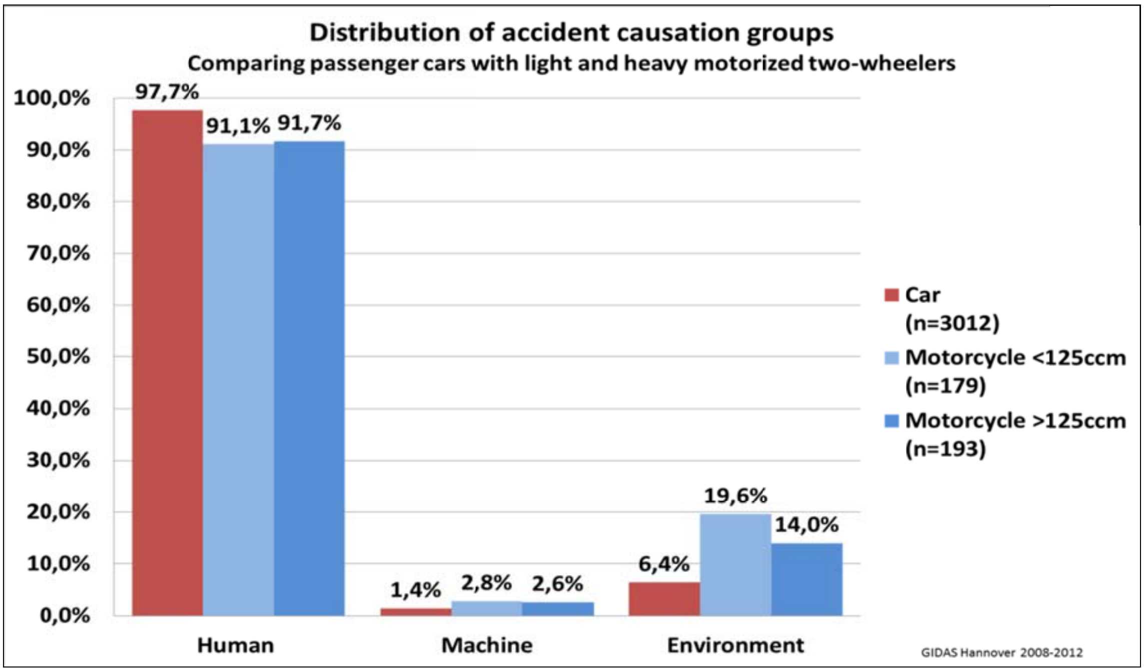


Figure 12: Distribution of accident causation factors on the three groups of the ACAS system, comparing heavy (>125ccm) and light motorcycles (<125ccm) with cars (100% each vehicle type).

For all types of road users the vast majority of causation factors are related to human failures (over 90%) thus the focus of this analysis is on this group of causes. Technical failures of the vehicle in general rarely contribute to the emergence of accident with fewer than 3% of the cases. The fact that here motorcycles have higher rates of causes in this group was not further analyzed but can be explained by the effect of a vehicle failure (e.g. blown tire) which may lead to an accident more frequently with motorcycles than with cars. A higher influence on the accident causes and a more significant difference between cars and motorcycles can be seen in the group of factors from the environment. While only 6.4% of the accidents caused by cars had a contributing factor from the environment some 14% respectively over 19% of the accidents caused by motorcycles had a contributing factor from the environment. The reason here is that riders of PTW are even more dependent on the continuous traction between tires and road. However environmental conditions like rain or a poor condition of the road surface have a strong influence on the traction. As seen in Figure 12 human factors yield over 90% of the causes of traffic accidents. The core of the ACAS system therefore is based on the analysis of these human factors, which is achieved by describing the human participation factors - and failures of these - in a chronological sequence from the perception to a concrete action/operation.

Composition of 4-digit-code on accident-causation-factors. In road traffic accidents causes for all fields of interaction can be expected: (1) Human causes, (2) causes from the range of the technology of the vehicle and (3) causes from the range of the infrastructure and/or the environment (so called 3 different groups), given the first number of the causation code, accordingly with all human causation factors in group 1. Each of the three fields of interaction is subdivided into specific categories of causation factors, as seen exemplarily for group 1 in Figure 13. These categories are described by the 2nd number of the causation code. Each category is further subdivided into characteristic influence criteria (3rd number of the code), which represent the most frequent factors, which led to an accident. Only in the human causation factor group 1 each influence criteria can be further specified by specific indicators (4th number of the code). In the group of the vehicle technical defects of accident influences can be stated.

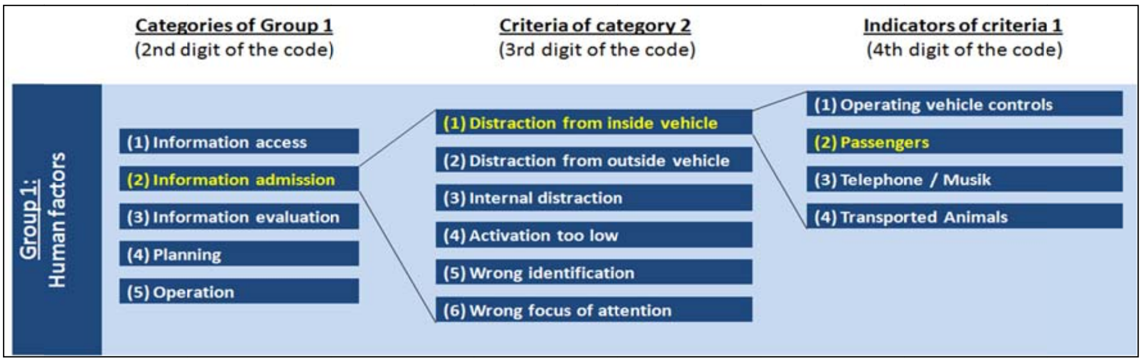


Figure 13: Composition of the ACAS-code – here exemplarily for the Group 1 (human factors)

Example: If someone were distracted by a conversation with a passenger, and thus did not recognize important traffic information, the code of this cause would be:

1 – 2 – 01 – 3 **Code**

Explanation: The accident cause is from the group of human causation factors (first number = 1); Not recognizing something is a failure in the category of the information admission (second number = 2); The influence criterion here is a distraction from inside the vehicle (third number of the code = 1); The distraction in the vehicle occurred due to a passenger (fourth number of the code = 3)

For the present study the frequency-distribution of human causation factors on the five categories was analyzed again comparing the situation of riders of light (<125 ccm) and heavy (>125 ccm) motorcycles with the situation of car drivers (Figure 14).

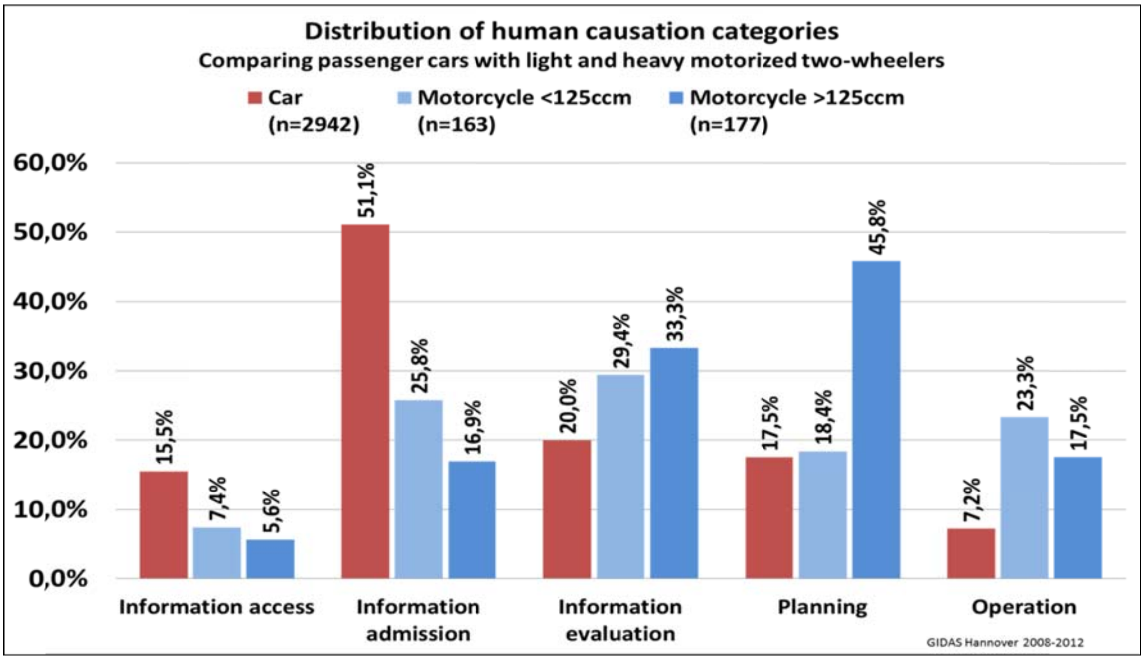


Figure 14: Frequency distribution of human causation factors on the 5 categories of human failures. Comparison of heavy (>125ccm) and light motorcycles (<125ccm) with cars (100% each vehicle type)

When looking at the **first category (Information access)** it becomes obvious that car drivers (15.5%) more frequently had a problem with the information access than the riders of powered two-wheelers (7.4% respectively 5.6%). The analysis of the codes of this category revealed that failures of car drivers are mostly related to factors like hidden Information (e.g. crash opponent) by buildings, vegetation or other vehicles on the one hand and information masking and subsequently poor visibility e.g. due to heavy rain on the other hand. Both effects are less common with riders of PTW as they generally have a higher seating position and thus a better overview and less frequently ride during bad weather.

In **category 2 (Information admission)** again car drivers more frequently have problems than the riders of PTW. In over 50% of the cases car drivers had a failure of acquiring the relevant information which contributed to the emergence of the accident (PTW only 25.8% respectively 16.9%). A further analysis revealed that drivers of cars are more often distracted and have a wrong focus of attention than the riders of PTW. This seems quite plausible as riders of PTW have less sources of distraction like passengers or in car electronics.

The **third category (Information evaluation)** consists of failures concerning misjudgments and misinterpretations. Riders of PTWs (29.4% respectively 33.3%) more often have failures in this category than car drivers (20%). Looking into these causation factors reveals that the high frequency among the PTWs is often related to a misjudgment of the own vehicle (in about 20% of the cases). Typical factors here are a misjudgment of the vehicle behavior (dynamics and stability) as well as a misjudgment of the own speed. Major differences between light and heavy Motorcycles are not evident in this group.

Failures from the **category 4 (Planning of an action)** are twice as likely with the riders of PTWs as with car drivers. Interestingly, here the level of the light motorcycles (<125 ccm) is about that of the cars (both approx. 18%). The increased proportion of planning errors (over 45%) is solely related to the riders of heavy motorcycles and here only due to the subcategory of "intentional traffic violations" (in over 40% of the cases). The analysis of the distribution of the intentional violations of heavy motorcycles (> 125 cc) shows that this is mainly a matter of excessive speed (in over 2/3rds of the cases of intentional violations). *See the case example*.

> *Case example: The 29 year old rider of a heavy motorcycle (Suzuki GSX-R750) was driving at high speed along a major city road with three lanes in his direction. As the traffic light in front of him changed to red he started to brake, lost control over his motorcycle, fell over and slid against the pole of the traffic lights. The driver was severely injured (MAIS 3) and taken to hospital. A reconstruction of the accident revealed that the rider was travelling at about 120 km/h where the speed limit was 50 km/h.*

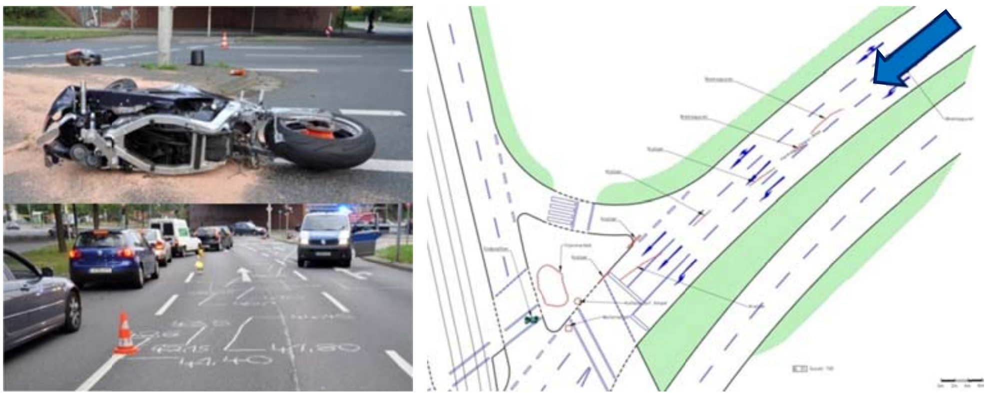


Figure 15: Case example

Failures from **category 5 (Operation)** are significantly more frequent with riders of PTWs (23.3% respectively 17.5%) than with car drivers (only 7.2%). Both types "mix up- or operation errors" as well "reaction errors" are common with PTW riders. The handling of PTWs in general is more difficult than that of cars. Especially when it comes to braking with PTWs this can be a cause of an accident: While it is difficult to cause an accident due to wrong braking with cars this is still well possible with motorcycles as an over braking and blocking of the front wheel mostly results in a crash. These cases can are still common in real life accidents while ABS for PTWs is not as widespread as for cars.

To answer the question whether the types of human causes have an influence on the injury situation, the causation factors of riders of PTWs were correlated with the injury severity. Therefore in a first step the injury severity distribution for different types of human causation categories was analyzed for all types of PTWs (Figure 16). Accidents caused due to an information admission failure (e.g. the rider misses to see a relevant road user due to a wrong focus of attention) have visibly caused higher shares of moderate injuries (MAIS 2) to the rider with 36.2% and of severe injuries (MAIS 3+) with 11.6% than the accidents caused due to other human failures. A possible explanation here is that with accidents caused by Information admission failures the relevant information often possibly was not seen at all or very late which leaves no or very little time for a possible avoidance maneuver like braking. On the other hand accidents based on an information admission failure imply that the relevant information was seen in time, but was just misinterpreted/falsely estimated which may have left time to begin an avoidance maneuver.

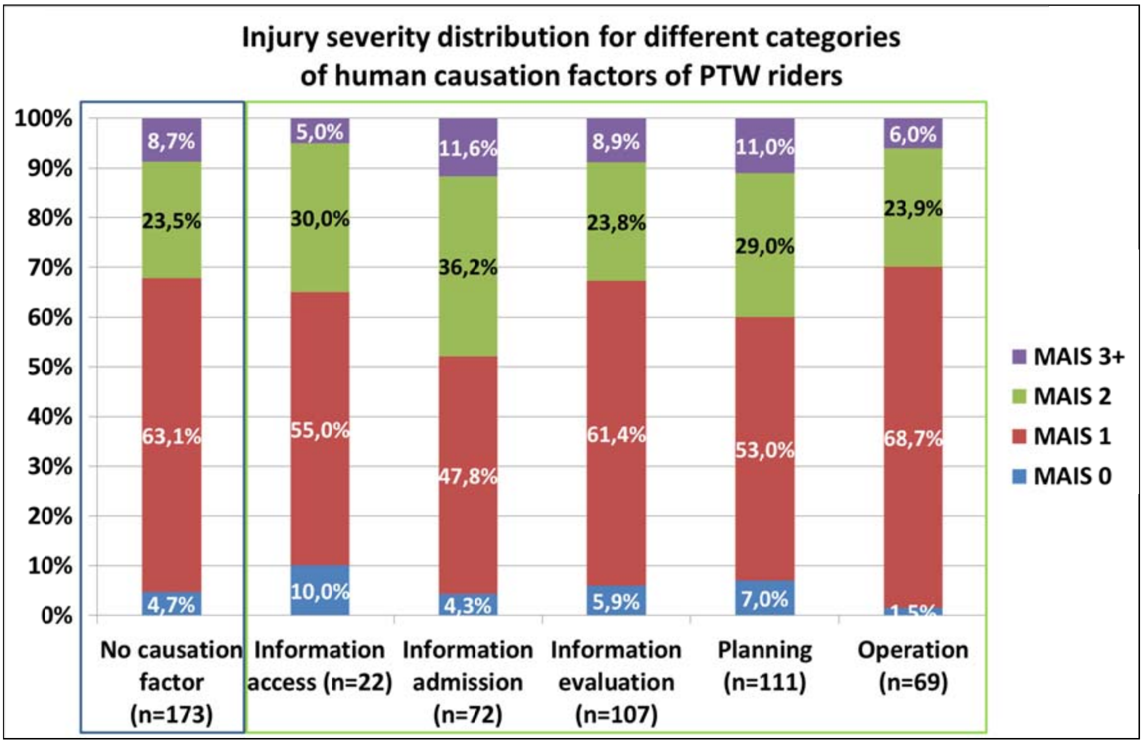


Figure 16: Injury severity distribution for different types of human causation categories from riders of PTWs (100% each category of causation factor)

When looking at the group of riders of motorcycles with an engine displacement of over 125 ccm (Figure 17) the correlation between the accident causes and the injury severity shows a very similar qualitative characteristic. While accidents caused by an information admission failure again have high rates of moderate injuries (MAIS 2) with 50% and of severe injuries (MAIS 3+) with over 10%, no significant differences between the other causation categories can be identified due to the low number of cases. As expected the shares of severe injuries are visibly higher with riders of motorcycles than with riders of all types of PTWs.

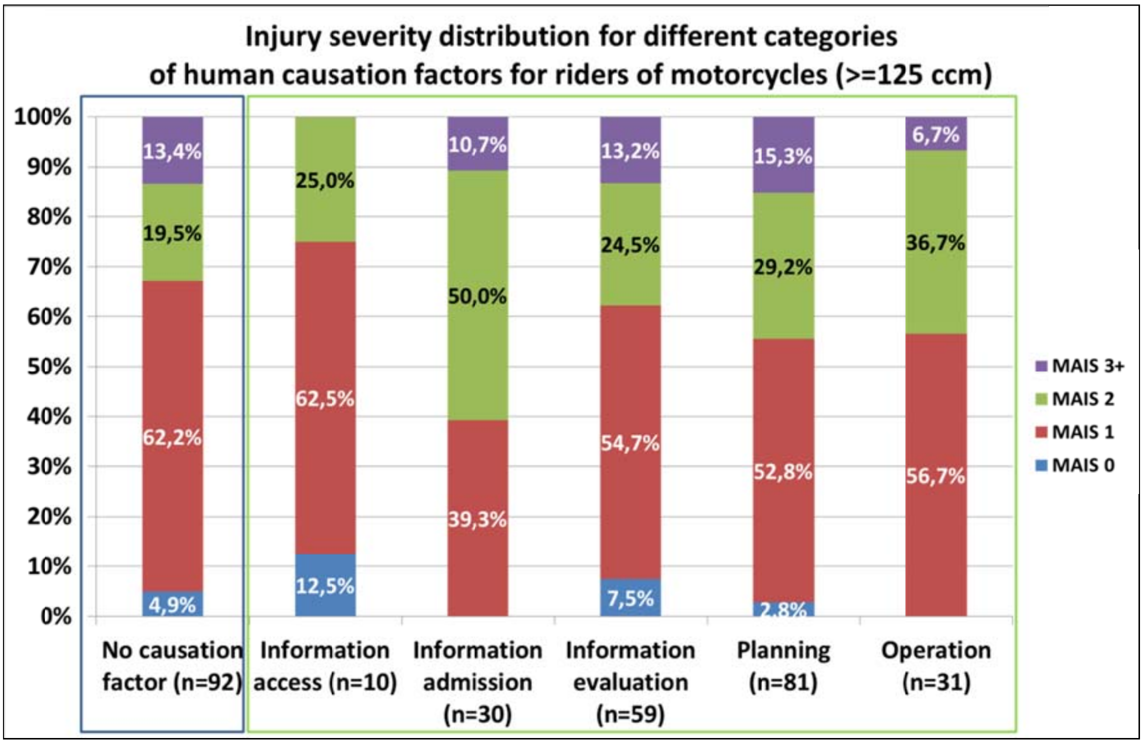


Figure 17: Injury severity distribution for different types of human causation categories from riders of motorcycles with an engine displacement of over 125 ccm (100% each category of causation factor)

SIGNIFICANCE OF SEVERAL ACCIDENT PARAMETERS FOR INJURY SEVERITY

An ordinal logistic regression was performed to examine the influence of both the causes of accidents as well as other parameters (Table 1). In addition to the causes of accidents the type of powered two-wheeler, crash weight, age, relative velocity and the annual mileage were included.

Effect	DF	Wald Chi-Square	Pr > ChiSq
Relative velocity	1	50.9341	<.0001
Age	1	8.8486	0.0029
Crash weight	1	3.9641	0.0465
Annual mileage	8	7.4723	0.4866
Information access	1	4.5625	0.0327
Information admission	1	6.2102	0.0127
Information evaluation	1	0.0822	0.7743
Planning	1	0.0369	0.8477
Operation	1	0.3300	0.5657
Type of powered two-wheeler	1	4.9166	0.0266

Table 1 Statistical analysis of effects of several accident parameters for the injury severity grade MAIS

Here, a separate category was created for "unknown" annual mileage to not exclude those cases in the analysis. The significant p-values are highlighted in yellow.

It turns out that in addition to age, relative speed, crash weight and type of powered two-wheeler the human causation categories “information access” and “information admission” have a significant impact on the injury severity, while the relative velocity has a highly significant impact.

DISCUSSION AND CONCLUSION

The study of accidents of powered two-wheelers in comparison to the group of motorcycles showed that the injury situation of both groups improved steadily over the past few years. Still, a share of 8.4% of severely injured and most severely injured (MAIS 3+) riders in the group all PTWs and correspondingly 13.1% in the group of motorcyclists is registered. With a high proportion of slightly injured (MAIS 1) of 60 to 65%, a high level of safety is achieved on the road. Wearing the motorcycle helmet here proves especially beneficial to the resulting injury frequency and injury severity of a person, as with motorcyclists only 19.9% suffered head injuries. Motorcyclists are well protected by the helmet; the study reveals an effectiveness of the helmet usage in relation to a reduction of head injuries AIS 1 to minus 34% and AIS 2 to minus 22% and severe head injuries AIS 3+ to minus 21%.

The study could also determine the protective effect of protective clothing, however not with the expected significance. Here influences of different materials, the different use of protective clothing for different body regions and the sometimes very low use of protective clothing result in an undetectable effect in the statistical sample.

Since the distributions of the relative velocities of the considered groups of motorcycles and other PTW not very much different from each other, the collision constellations define the outcome of injury in relation to the collision types only a little. The most serious consequences occur when the rider’s body collides relative to the chassis of the collision partner. Cars thus only represent a particular danger at accidents at crossings with the possibility of the rider to hit the passenger compartment, with trucks almost all collisions against front, side or rear are equally dangerous. Here the study revealed a high proportion of oblique collisions of two wheelers against the vehicle side with both cars and trucks (collision type 4 with about 21%). Particularly among motorcyclists this type as well as the perpendicular frontal crash against the side of the vehicle (type 3) showed a high proportion of severely injured MAIS 3+. Relatively common are single-vehicle crashes of motorcyclists with about 45%. This also includes those collisions where another two-wheeler or a pedestrian were involved. Severe injuries AIS 3+ are particularly often in association with a high risk of bone injuries of the cervical spine and the lower extremities. Leg injuries in future require special attention as they are often accompanied with long treatment durations and long-term consequences (Kalbe, 1981). One useful solution is seen here in the usage of protective clothing with protectors and the use of padded machines whose injury protection effectiveness in combination with the development of special leg protectors have been shown to be useful in previous publications (Otte, 2002).

To be able to further improve the injury situation of motorized two-wheeler in the future, accident analyzes in the scope of on-scene surveys are still important to gain detailed knowledge about injury patterns, the kinematics and injury mechanisms. In addition, however, it is especially important to avoid accidents at the beginning of the development. This can be achieved through adequate measures concerning the road layout, measures at the PTW and also measures concerning the attitude and behavior of drivers of PTW.

Attention must be turned towards the causes of the accidents and their relationships to human, machine and the environment to be able to postulate measures for the prevention of accidents in addition to the injury prevention.

The application of causation analysis tools ACAS (Accident Causation Analysis System) showed that riders of powered two-wheelers do have a characteristic distribution of cause factors when compared to drivers of cars. Even though there is a higher influence of environmental factors on the causes of accident from riders of PTW than on car drivers, the focus still lies on the human factors for both groups (over 91% for riders of PTW, 97.7% for car drivers). The human factors in ACAS are divided into 5 categories of possible failures. Here the analysis revealed that riders of PTWs had frequent failures in the Information evaluation which are often related to a misjudgment of the behavior or speed of the own vehicle (in about 20% of the cases). Furthermore riders of powered two wheelers have a high incidence of accident causes from the subcategory of intentional breach of rules. While riders of light motorcycles (< 125 ccm) are at the same level as car drivers with about 18% of causation factors, the riders have motorcycles (≥ 125 ccm) have an incidence of over 40% from this subcategory which is mostly related to excessive driving speed. Another source of accident causes which is specifically high with PTW when compared to cars are operation failures (23.3% for light motorcycles, 17.5% for motorcycles but only 7.2% for cars) as the handling of a PTW in general is more difficult than that of cars. As a result wrong braking or over braking with PTW does lead to accidents as ABS for PTW is not as widespread as for cars.

A correlation between the causation factors of riders of PTW with the injury severity revealed that the category of human failure had no significant influence on the injury severity distribution with one exception: Accidents caused by a failure of information admission (e.g. the rider misses to see a relevant road user due to a wrong focus of attention) of the rider of a PTW resulted in visibly higher shares of MAIS 2 had MAIS 3+ injuries than failures from the other categories.

It can be seen from the study that for PTW a high safety level can be established, the proportion of severe injury grades MAIS 3+ are reduced with the factor of nearly 3 from the years 1985-93 to 2003-11 for users of PTW. There could be seen a reduction of severely injured motorcyclists of nearly 50% over the time period of more than 20 years.

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