ANALYSIS OF THE PASSIVE SAFETY OF MOTORCYCLES USING ACCIDENT INVESTIGATIONS AND CRASH TESTS

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ABSTRACT

Based on information in DEKRA accident reconstruction expertises, 302 motorcycle accidents were analysed which occurred within the period 1989 to 1996 in Germany. Among them were 46 accidents involving motor scooters. The accident analysis results (e.g. distribution of accident types, motorcycle movement before crash, movement of the riders after the crash) are described and commented upon to supplement and update findings already published earlier in relation to actual accident occurrences involving motorcycles. In particular, there is a discussion of collision configurations and collision velocities together with the injuries of the rider (injured body parts, causes of the injuries). In addition, the collision configurations and collision velocities in accidents involving cars and motorcycles are compared with the crash test configurations described in ISO/DIS 13232.

In accordance with ISO/DIS 13232, four crash tests were carried out in which motorcycles collided with the side of cars. In two tests the car was stationary before the collision; in two other tests a collision of two moving vehicles was simulated. A Hybrid III pedestrian dummy (50 th percentile male) was used as the motorcycle rider.

In conclusion, against the background of actual accident occurrences and the test results, the current position with regard to the passive safety of motorcycles is described and pointers given toward possibilities for improvement.

INTRODUCTION

The current regulations of the Federal Republic of Germany define **motorized two-wheelers** as follows.

Kleinkraftrad: Mopeds and motor-assisted bicycles with an engine capacity not exceeding 50 cc and a maximum design speed not exceeding 50 km/h, bearing an identification mark, as well as „mopeds“ and bicycles fitted with an auxiliary motor as defined by the former German Democratic Republic regulations, with up to 50 cc and up to 60 km/h.

Mofa 25: Bicycles fitted with an auxiliary motor (including „Leichtmofas“) with an engine capacity not exceeding 50 cc and a maximum design speed not exceeding 25 km/h, bearing an identification mark.

Leichtkraftrad: Motorcycles/motor scooters with over 50 to 125 cc piston capacity and a power not exceeding 11 kW (as well as „Kleinkrafträder“ with up to 50 cc and exceeding 40 km/h, provided that they were registered prior to 31 December 1983).

Kraftrad: Motorcycles with an engine capacity exceeding 80 cc.

Kraftroller: Motor scooters with an engine capacity with over 80 cc.

Motorrad: Two-wheeled **motorcycles** bearing an official registration number (**„Leichtkraftrad“, „Kraftrad“** and **„Kraftroller“**).

German terms will be used partially with regard to explicit definitions in the following. **Figure 1** contains a long-term overview of the development of the relative frequency for the motorcyclists killed and severely injured in accidents inside and outside urban areas in the former German countries within the period 1956-1996. In **Figure 2** are the corresponding figures of registered motorcycles („Krafträder“ and „Kraftroller“) in the same period.

After beginning with a high level in the 50s, when the motorcycle has been a mass-transportation vehicle in Germany, the figures of killed and severely injured motorcyclists dropped by the middle of the 60s, remained constant until the beginning of the 70s and rose again clearly afterwards. New highest levels were reached in the years 1982/83: 959 killed outside urban areas (1982), 14 420 severely injured inside urban areas (1983) and 8 875 severely injured outside urban areas (1983). The number of motorcyclists killed inside urban areas did not follow this trend: 543 killed were registered in the year 1975 and 512 killed in 1983.

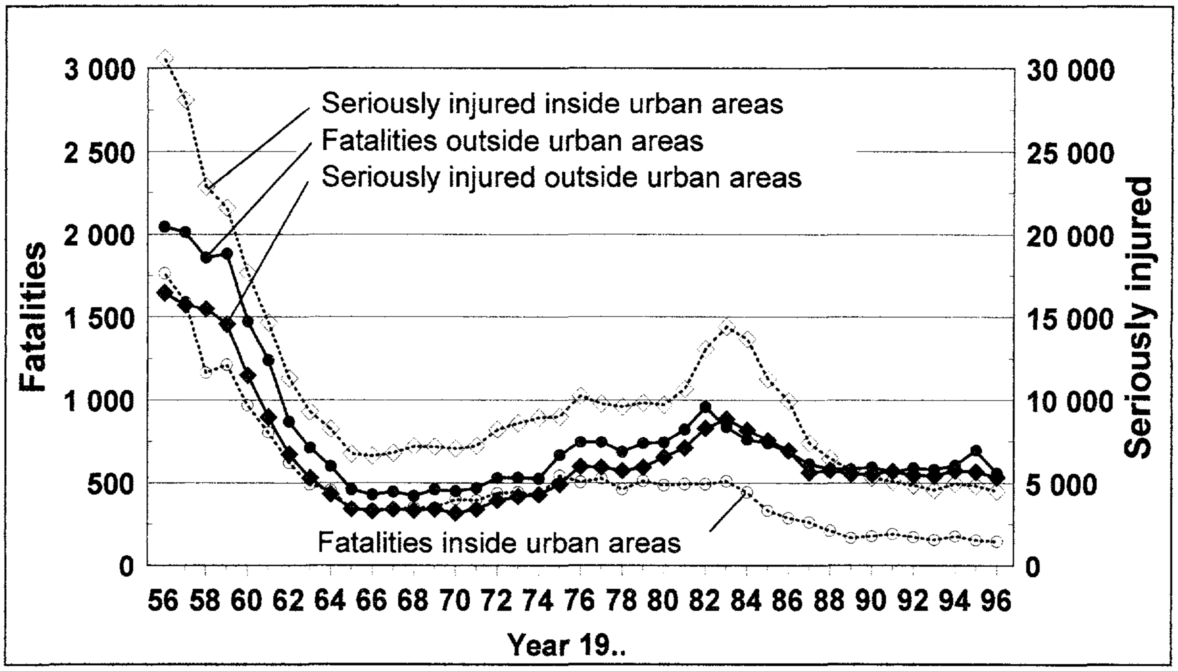


Figure 1. Absolute frequency of fatally injured or severely injured motorcycle riders in the former German countries within the period 1956 to 1996 (source: German Federal Ministry of Statistics)

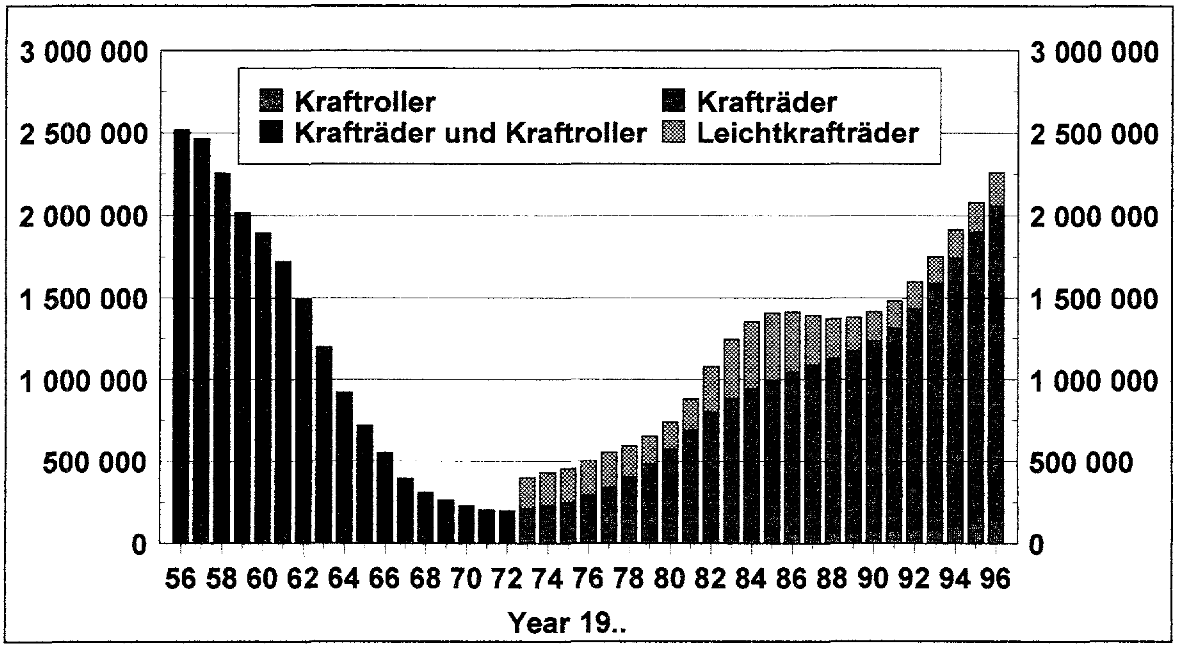


Figure 2. Absolute frequency of registered motorcycles („Krafträder" and „Kraftroller") in the former German countries within the period 1956 to 1996 (source: German Federal Ministry of Statistics)

The figures of killed and severely injured motorcyclists dropped again clearly until the end of the 80s. The development of the figures for motorcyclists killed inside and outside urban areas was approximately equal. In contrast, the number of severely injured decreased much more inside urban areas than outside. In the 90s the number of killed and severely injured motorcyclists remained virtually constant.

In comparison with the number of registered vehicles it can be observed, that the drop of killed and severely injured from 1982/83 until 1989/90 is reflected partially in the change in the number of registered „Leichtkrafträder“. Because „Leichtkrafträder“ are used predominantly by beginners and inside urban areas, the clear decrease of severely injured inside urban areas can be put down to the fall in the number of registered vehicles of this type. It is also remarkable that the clear increase of motorcycles beginning in the mid-80s does not follow a parallel increase of severely injured and killed motorcyclists.

Great increase rates were registered on the German market regarding the number of sold Motorroller, **Figure 3**. Very popular are hereby Motorroller with 50 cc piston capacity and 50 km/h maximum speed (as „Kleinkrafträder“ not represented in Figure 2). From the 186 000 „Motorroller“ sold in Germany in 1995, 166 000 belonged in the category 50-cc-„Roller“. As well attractive are „Motorroller“ with 125 cc piston capacity („Leichtkraftrad“), whose maximum engine power is 11 kW and a speed not allowed to exceed 80 km/h. These vehicles are permitted to be driven with a driving licence for passenger cars which was issued before April 1, 1980.

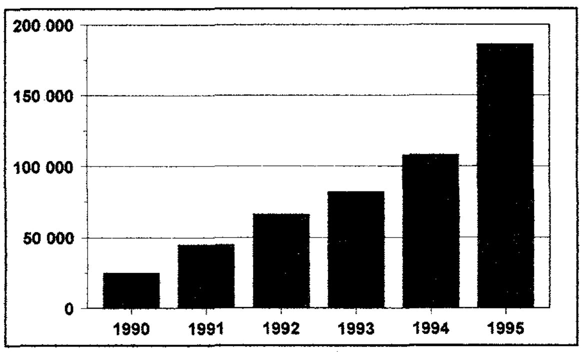


Figure 3. Motor scooters sold on the German market in the 90s (source: Verband der Fahrrad- und Motorrad-Industrie IVM)

Among the important changes in the legal regulations in Germany with regard to the traffic safety of motorized two-wheelers are:

August 1, 1980: Fine for riders of motorized two-wheelers (except „Mofas“) who drive without using a helmet.

October 1, 1985: Compulsory wearing of a helmet and a fine for „Mofa“ riders riding without a helmet.

April 1, 1986: Introduction of a graded motorcycle licence for motorcyclists.

October 1, 1988: Compulsory use of a dipped headlight for motorcyclists even during daytime.

Great significance is attached to the compulsory use of a helmet and to the graded motorcycle licence which, in spite of an increasing number of motorcycles, have helped to prevent a parallel increase in the number of motorcyclists killed and severely injured in accidents. In this context one must also take into account the improvements in protective clothing (helmet and suit).

Assessments of the technical evolution of the motorcycle itself show that active safety has been improved through further development of the chassis, tyres and the antilock brake system. The potential benefit of these measurements lies in the avoidance of accidents. However, technical improvements of the motorcycle in the field of passive safety, designed to lessen the effects of an accident (like the airbag in cars), can barely be registered at production motorcycles (LANGWIEDER et al., 1987, GRANDEL and BERG, 1994).

Considering that the active safety of motorcycles already displays a very high standard of evolution - similar to the protective clothing of the motorcyclists designed to ease the injuries - the passive safety of motorcycles is increasingly becoming the focus of interest. This should be seen in front of the goal of lowering the number of deaths in accidents from 45 000 in 1997 to 25 000 in 2010 within the European Community (SAFETY MONITOR, 1997). To reach this goal within the existing standards of vehicle safety, all potentials for further traffic system improvements must be examined and exploited if there is to be any prospect of success. The passive safety of the motorcycle has to be considered here in an appropriate way.

RESULTS OF AN ANALYSES OF 302 MOTORCYCLE ACCIDENTS IN GERMANY

By evaluation of accident-analytical DEKRA expertises 302 accidents, involving a total of 315 motorized two-wheelers with 358 riders, which occurred between 1989 and 1996 in Germany, were analysed (VON BRÜHL, 1994, MALL, 1995, DOBIASCH, 1997, BREHMER, 1998). Expertises of these type are written by DEKRA experts to resolve single accidents in traffic. These expertises can be used by the department of accident research for further scientific studies.

The distribution of the accident location of the 302 DEKRA cases is shown in **Figure 4** in comparison with the accident location of the 55 275 registered accidents with motorized two-wheelers revealed in the federal statistics for 1995. While the accidents occurring inside urban areas (68.4 %) are predominant in the federal statistics, those which occurred outside urban areas dominate the DEKRA cases with 56 %.

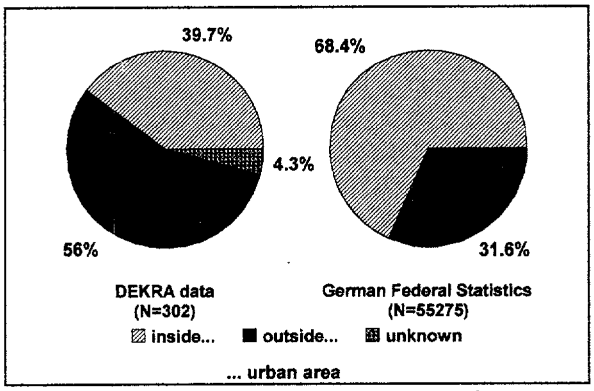


Figure 4. Location of the 302 accidents of motorized two-wheelers (years 1989 to 1996) in the DEKRA database compared with all such accidents in Germany (federal statistics, year 1995)

In **Figure 5** is a comparison of the injury severity between the accidents evaluated by DEKRA and the federal statistics. The DEKRA material contains more accidents with riders killed inside and outside urban areas than in the federal statistics. Corresponding to this the federal statistics contain more accidents inside and outside urban areas with slightly injured riders. Therefore the DEKRA cases are tending to be more severe.

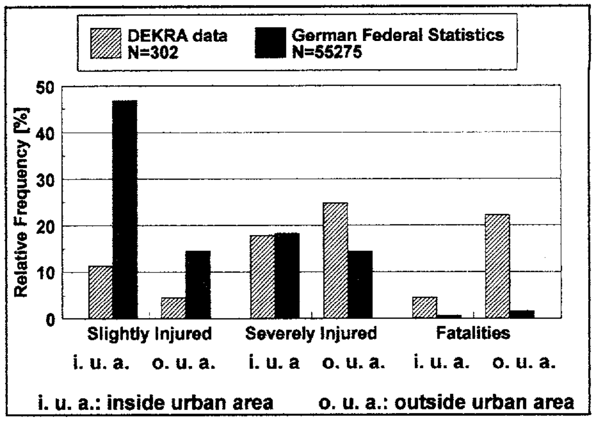


Figure 5. Severity distribution of the 302 accidents of motorized two-wheelers in the DEKRA database compared with all such accidents in Germany (federal statistics, year 1995)

Figure 6 contains further information about the types of motorized two-wheelers involved in the DEKRA cases. The classification of 297 out of 315 motorized two-wheelers was known. The „Sport-Motorräder" were the most frequent among the „Krafträder", followed by „Tourer", „Sport-Tourer", „Enduro" and „Chopper". The lighter vehicles with less than 80 cc piston capacity predominated in the „Roller" category. „Mofas" were seldom.

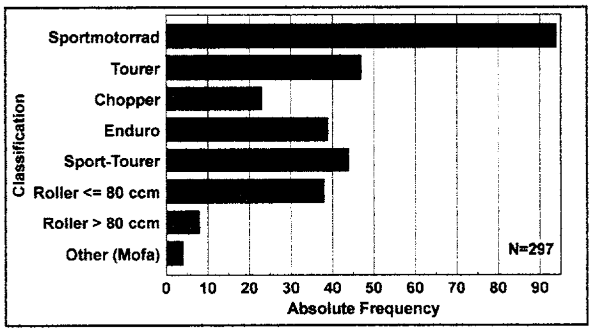


Figure 6. Distribution of the motorized-two-wheeler types in the DEKRA database

The following evaluations refer only to „Krafträder" and „Roller" (with no differentiation according to piston capacity). For these vehicles **Figure 7** shows the distribution of accident types of the corresponding 292 accidents. According to this, „Krafträder" and „Roller" are most frequently involved in accidents caused by turning into a road or crossing a road. Second frequently, both „Krafträder" and „Roller" were involved in accidents between vehicles moving along a carriageway and third frequently in accidents caused by turning off the road.

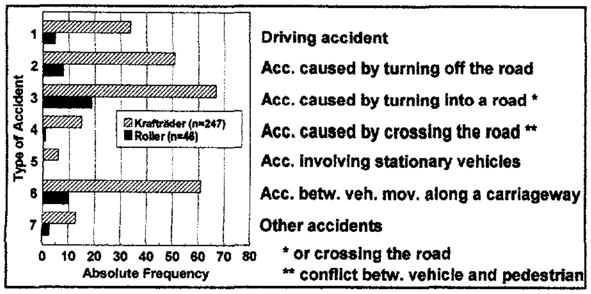


Figure 7. Distribution of the accident types of „Krafträder" and „Roller" in the DEKRA database

Figure 8 shows the absolute frequencies of the road category on which the „Krafträder" and „Roller" were moved at the time of the accident. Accidents on the „Autobahn" were very rare. The „Krafträder" mostly crashed on „Landesstraßen„ and „Bundesstraßen" while the „Roller" mostly crashed on „Ortsstraßen".

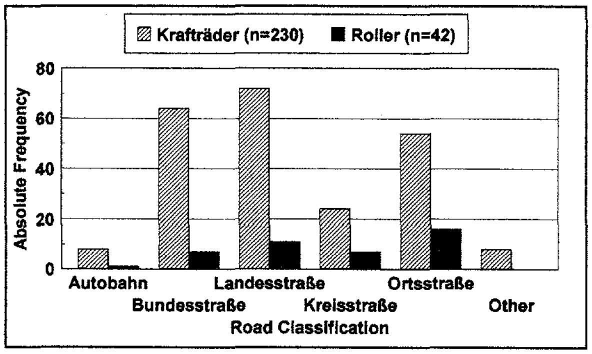


Figure 8. Road classification of accidents involving „Krafträder" and „Roller" from the DEKRA database

The most frequent opponent of the „Krafträder" in the DEKRA cases was in 137 cases (63 %) a car and in 14 cases (6 %) a truck. Regarding the „Roller" accidents, the car was again the most frequent opponent, with 31 cases. A corresponding evaluation of accidents with two participants featuring motorized two-wheelers and personal injury, as revealed in the federal statistics for the year 1995, shows a car as an opponent in 79 % of cases and a truck in 6 %.

The „Motorräder" in the DEKRA cases were most frequently used by only one motorcyclist. Only 13 % of the „Krafträder" and at least 15 % of the „Roller" were being used by two riders at the time of the accident.

Figure 9 describes the movement of the „Krafträder" and „Roller" immediately before the accident. Most vehicles collided upright. Approximately 20 % of the „Krafträder" and 18 % of the „Roller" collided with the opponent while sliding on the side. Around 10 % of the „Krafträder" collided moving in slant.

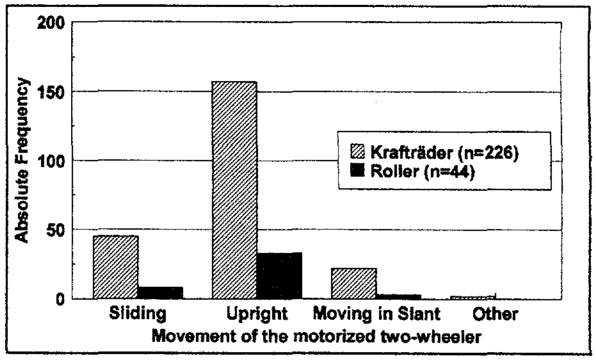


Figure 9. Classification of the movement of „Krafträder" and „Roller" immediately before the crash (DEKRA database)

The injury severity of 324 riders was known. The corresponding distribution of the killed, severely injured, slightly injured and uninjured riders is documented in **Figure 10**. The number of killed and severely injured riders on the „Roller ≤ 80 cc" was equal while the number of slightly injured came close. Among the other types of motorized two-wheeler (except „Mofas"), the severely injured riders predominated.

From the frequencies shown in Figure 10 it is easy to determine the proportions of killed, severely injured and slightly injured riders corresponding to the two-wheeler types, **Figure 11**. These proportions reflect the corresponding risks. The passive safety of „Tourer", „Chopper" and „Enduro" appears to be best because of the lowest proportion of killed riders. Because of their high proportion of killed riders the „Mofas", „Roller > 80 cc" and „Sportmotorräder" do not appear to be favourable in terms of passive safety.

An in-depth assessment of the injury severity must also take into consideration the collision speed, **Figure 12.** The mean collision speed of every two-wheeler type with fatalities among the riders lies, as expected, above the mean collision speed in the accidents with severely injured riders. In analogy, the mean collision speed in accidents with slightly injured riders is lower than in those with severely injured riders. The mean collision speed in accidents with killed riders is highest among the „Sportmotorräder", „Tourer" and „Chopper" at around 80 km/h.

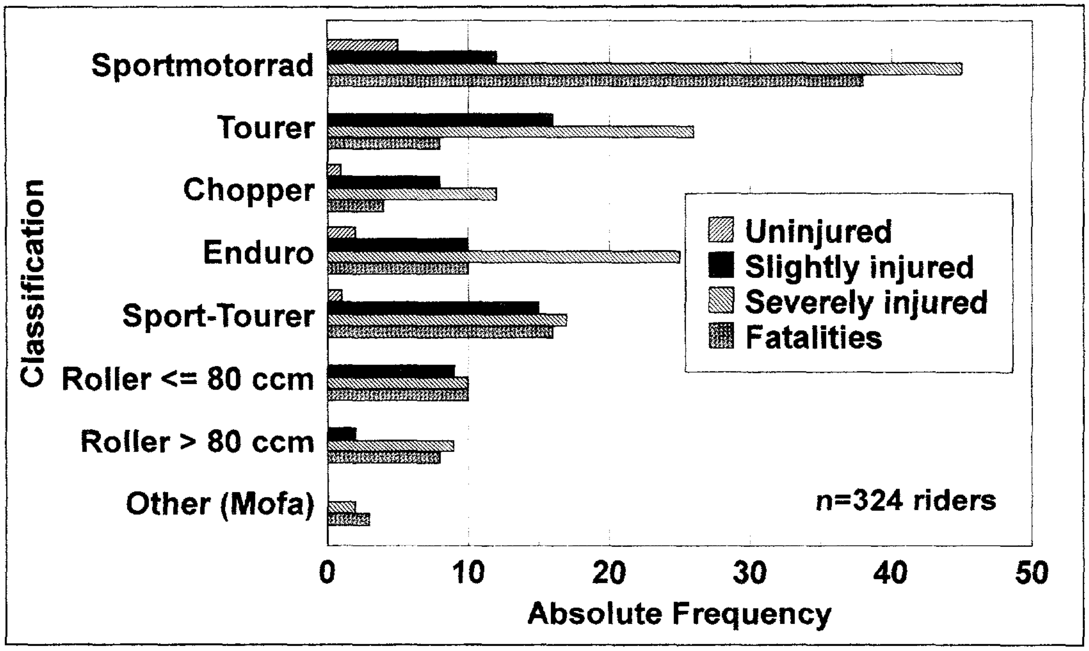


Figure 10. Injury severity in relation to the type of motorized two-wheeler

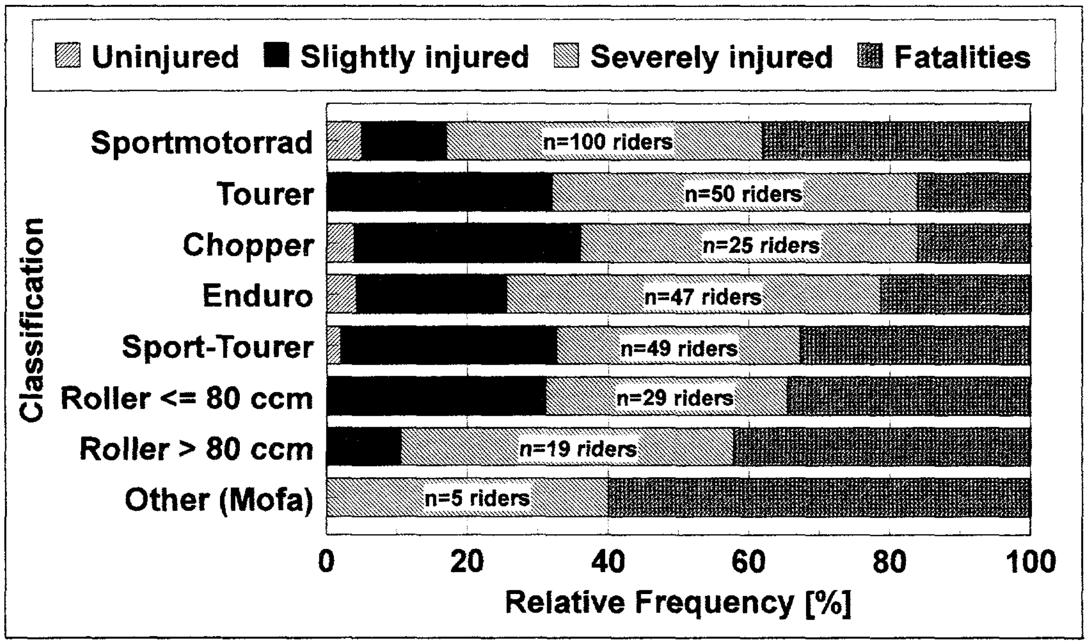


Figure 11. Proportion of killed, severely injured or slightly injured riders of the different types of motorized two-wheeler

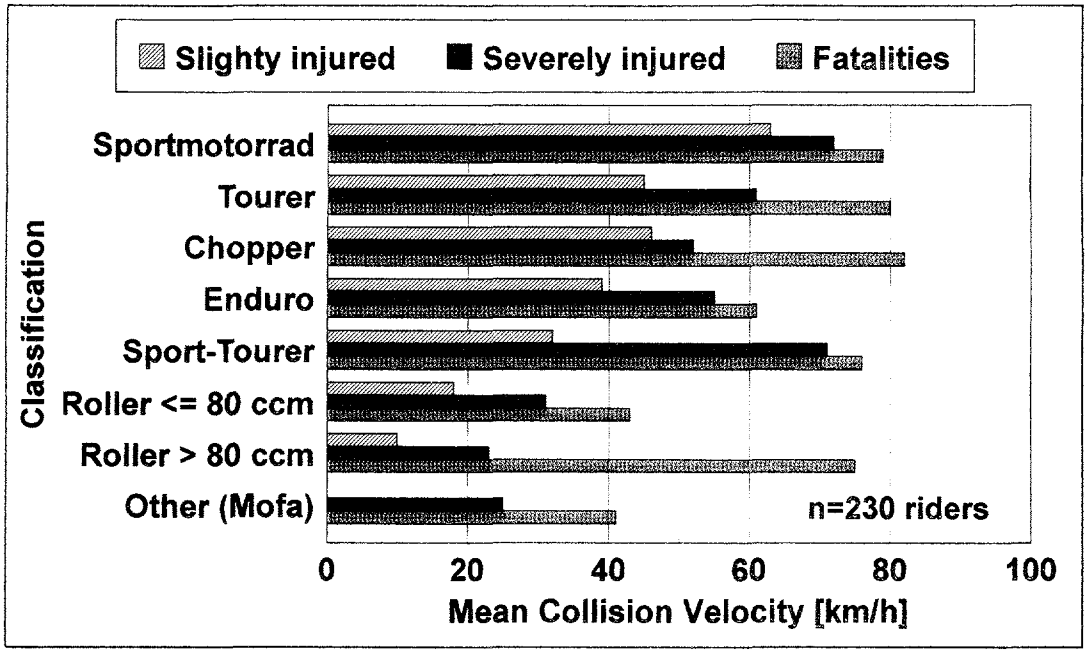


Figure 12. Mean collision velocity and injury severity in relation to the type of motorized two-wheeler

The mean collision speed for „Sport-Tourer" with fatalities among the riders was 76 km/h and for „Roller > 80 cc" 75 km/h. The killed riders on „Enduros" had a mean collision speed of 61 km/h.

With a mean collision speed of 43 km/h the killed riders of the „Roller ≤ 80 cc" category were moving significantly slower than the riders of the „Krafträder" and „Roller > 80 cc". The mean collision speed was lowest for „Mofa" fatalities, at 41 km/h. On the one hand this corresponds with the lower engine power of these motorized two-wheelers, but on the other hand indicates illegal power-raising manipulations on the „Mofas".

Different parameters are decisive in improving the passive safety of the different types of motorized two-wheeler. With regard to crash tests and the figures represented in Figure 12, the conclusion is clear that significantly clearly lower collision speeds are relevant for the „Roller ≤ 80 cc" riders than for the „Motorräder" riders.

In this context it must be remembered that the passive safety of two-wheeler riders also depends on their protective clothing and that the injury severity for the same mechanical loadings is influenced by the age and constitution of the riders.

Also relevant for the rider's injury type and severity is how they moved after the start of the collision and what they collided with in the further course of the accident.

Figure 13 contributes further results from the DEKRA survey. A collision between the riders of „Kraftrad" and „Roller" with the opponent was registered in most cases. Second frequently, the „Kraftrad" riders slid on the road and the „Roller" riders reached their final positions within a free flight. Third frequently, the „Roller" riders slid on the road. Fourth frequently, the „Kraftrad" riders had an impact with an obstacle (mostly on the roadside). This was rare for the „Roller" riders. Also rare was for a „Kraftrad" or „Roller" rider to be run over by the opponent.

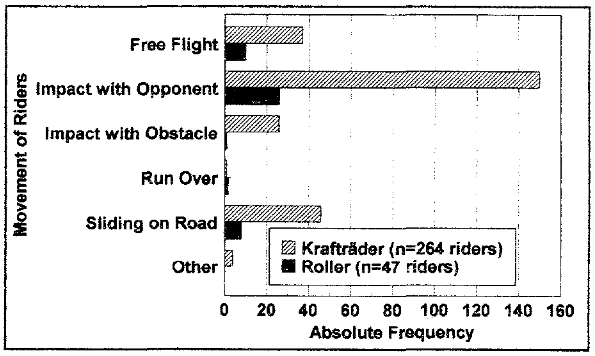


Figure 13. Movement of the riders of the motorized two-wheelers immediately after the crash

The cause of the rider injuries as established was in most cases the impact with the opponent, **Figure 14**. Only the „Krafträder" riders injured themselves on the tank or the footrests of their own vehicle. The handle bar of the „Krafträder" and „Roller" was also an item which caused injuries. Injuries caused by the road surface could frequently be registered on the „Krafträder" riders and as well on the „Roller" riders.

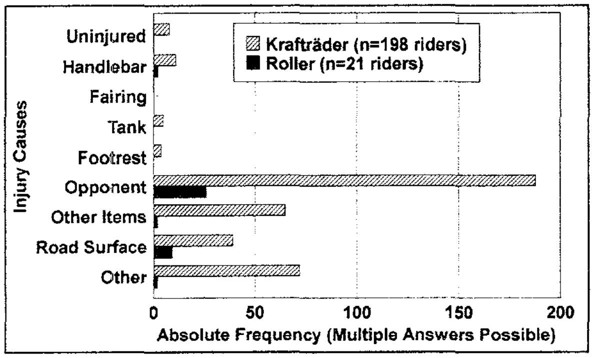


Figure 14. Injury causes of the riders of the motorized two-wheelers

An overview of the injured body parts is documented in the distribution shown in **Figure 15**. The „Krafträder" and „Roller" riders were mainly injured on the head. The riders are at considerable risk despite the use of a helmet.

With regard to „Roller" riders, the knee is also at considerable risk, followed by the lower and upper leg. Furthermore the „Roller" riders were also injured on the neck, foot/ankle, abdomen, back, pelvis/hip and lower arm. Injuries to the face, shoulder, upper arm, elbow and chest were not registered on „Roller" riders.

Of importance for „Krafträder" riders are injuries to the knee, hand/wrist, chest, neck, lower leg and foot/ankle. In any event, 6 „Krafträder" riders survived the accident without injury.

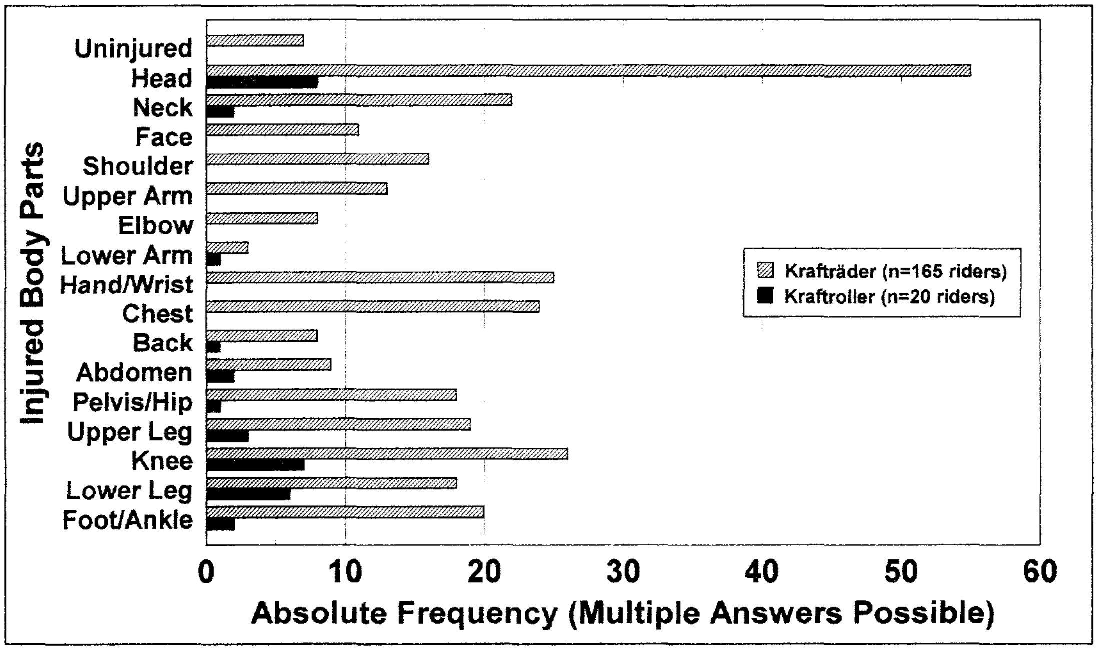


Figure 15. Injured body parts of the riders of the motorized two-wheelers

COLLISION SITUATIONS OF THE MOTORCYCLE ACCIDENTS IN THE DEKRA DATABASE COMPARED WITH ISO/DIS 13232

The standard ISO/DIS 13232 was the first world-wide created uniform requirements for standarized comparable crash tests in order to analyse the passive safety of motorized two-wheelers (VAN DRIESSCHE, 1994). This standard, developed by ISO/TC22/SC22/WG22, appeared in 1996 and is already taken into account by several producers of motorcycles and „Roller".

501 motorcycle accidents from the USA (Los Angeles) and Germany (Hannover) were analysed in order to define the test matrix. 25 impact constellations were defined depending on the impact point on the car (figure 1), the impact point on the motorcycle (figure 2) and the impact angle (figure 3), **Figure 16**. Of these 25 constella-

tions, the six constellations 114, 143, 225, 412, 413 and 414 were selected for carrying out full-scale tests, **Figure 17**. For the remaining constellations the standard is suggesting numerical crash simulation.

The accident survey was studied with a subset of the motorcycle accidents from the DEKRA database (only accidents featuring a motorcycle/car collision) in accordance with the standard ISO/DIS 13232. The relative frequencies of the impact constellations from the DEKRA cases are shown in comparison with the relative frequencies as per ISO/DIS 13232, **Figure 18**.

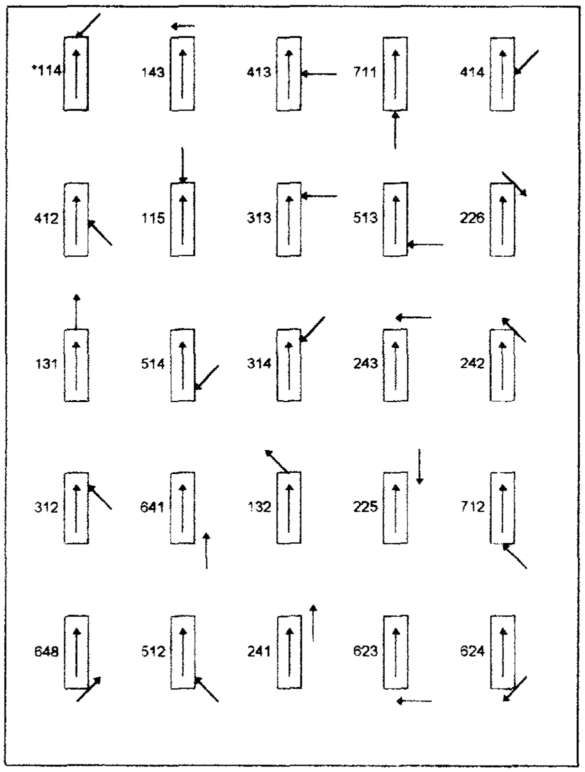


Figure 16 Motorcycle/car impact configurations defined in ISO/DIS 13232

In both data sources, ISO/DIS 13232 and DEKRA, the impact constellation 114 (oblique frontal impact of the motorcycle against the front of the car) is the most frequent, with 12.3 % and 13.0 % respectively. Impact constellation 143 (right-angled impact of the car front against the side of the motorcycle) is second most frequent according to ISO/DIS 13232 with 10.5 %, but only 3.3 % in the DEKRA material. According to ISO/DIS 13232 the impact constellation 413 (right-angled frontal impact of the motorcycle against the side of the car) is third most frequent with 10.0 %, similar to the DEKRA cases where it ranks second with 10.8 %. Impact constellation 226 (oblique impact of the car front against the motorcycle side) is represented with the same percentage (10.8 %) in the DEKRA cases, whereas in ISO/DIS 13232 this constellation is only of subordinate importance with 4 %.

In view of modest case numbers the impact constellations were not separated into „Krafträder" and „Roller". Against the background of possible differences between accident occurrences in Germany and in the USA - especially for severe accidents - the obvious priorities obtained from the data published in ISO/DIS 13232 should be further discussed.

The impact constellations suggested according to ISO/DIS 13232 for costly full-scale tests do not correspond in all cases with the rank order resulting from the evaluation of the material (suggested comparison of the rank order of the impact constellations 711 and 225 in Figure 16). Constellation 711 (impact with the motorcycle front against the back of the car) is third most frequent in the ISO/DIS 13232 data, but is not used for full-scale tests. Constellation 225 (glancing collision in opposite traffic) is used in full-scale crash tests although it ranks only 19th in ISO/DIS 13232.

The collision speeds defined in ISO/DIS 13232 must also be discussed. These measure 0 m/s, 6.7 m/s (about 24 km/h) and 9.8 m/s (about 35 km/h) for cars and 0 m/s and 13.4 m/s (about 48 km/h) for the motorcycle. Wherever two moving vehicles collide in a full-scale crash test, the motorcycle is always twice as fast as the car. This may depend on the speeds representable on the available crash facilities and is therefore justified with the demands of experimental practice. In comparison with the DEKRA data already available, 48 km/h appears to be too low for the motorcycle accidents and too high for the „Roller" accidents.

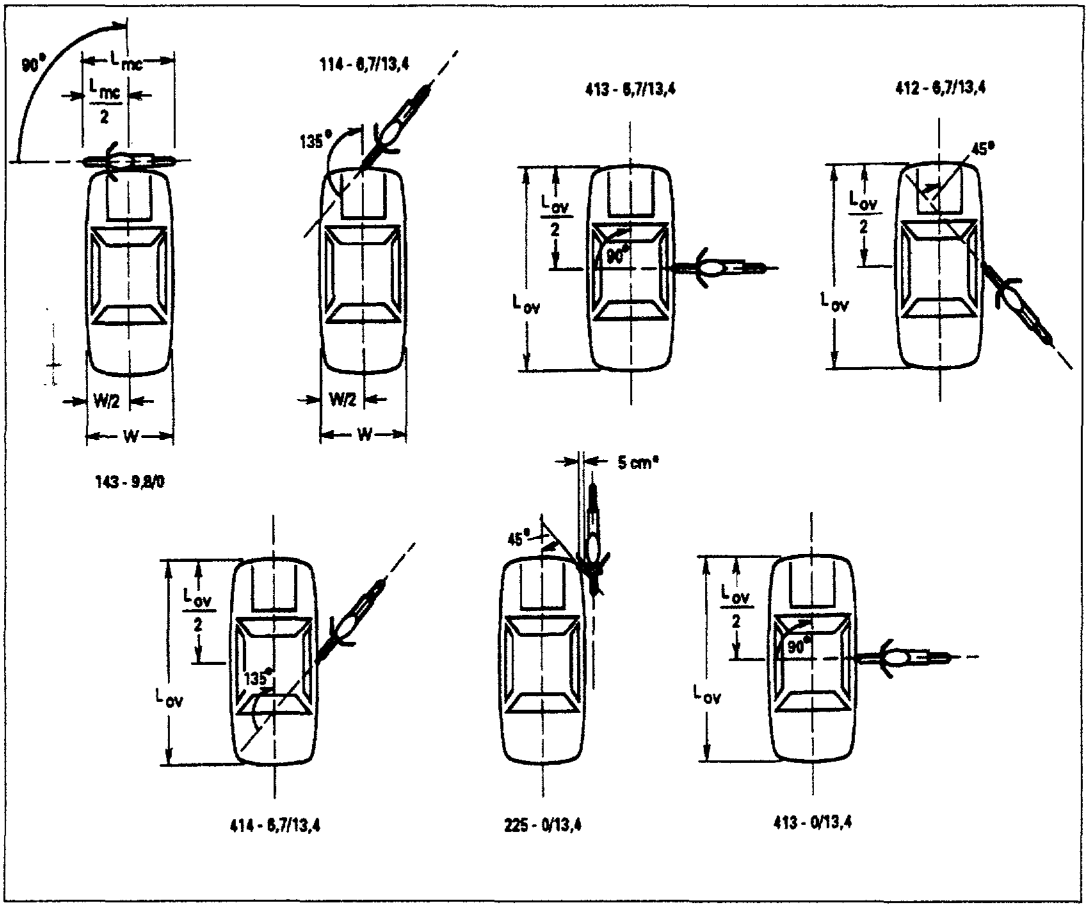


Figure 17. Motorized two-wheeler/passenger car impact configurations defined for use in full-scale crash tests in ISO/DIS 13232

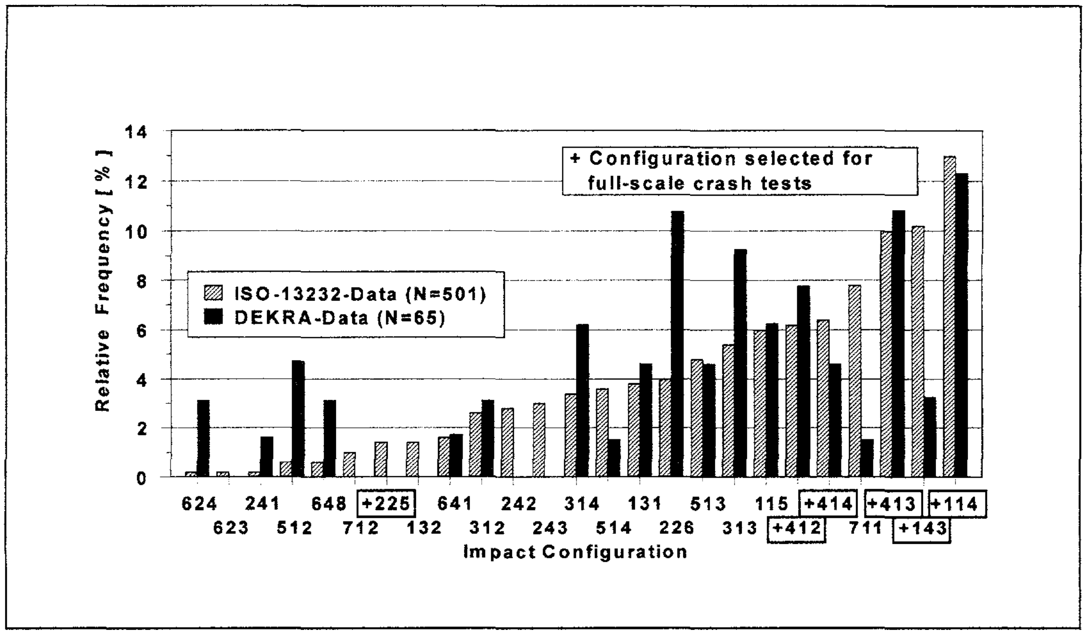


Figure 18. Relative frequencies of the motorized two-wheeler/passenger car impact configurations in the ISO/DIS-13232 database and in the DEKRA database

FULL-SCALE TESTS IN ACCORDANCE WITH ISO/DIS 13232

The DEKRA accident research department carried out four tests during the qualification period of the DEKRA crash centre for running instrumented full-scale crash tests as per ISO/DIS 13232. This was commissioned by vehicle producers with the object of making results available for publication. The impact constellations 414 and 413 were reproduced in these tests. In two tests the motorcycle collided with a stationary car and in two more tests a moving car was hit by a motorcycle.

Figure 19 gives an overview of the four full-scale crash tests which were carried out. It contains the collision speed of the vehicles and the impact configurations with their corresponding code numbers as per ISO/DIS 13232, as well as information concerning the head impact and the movement path of the rider.

Crash-numbers	Con-figuration	Head-Impact / Motion-course
SH 95.32 MuZ Skorpion Tour	414 24 48	No head-impact at the car. Glances over tailgate
SH 95.33 Honda CB 450 N	(414) 0 47	Head-impact at the roof edge. Glances over side
SH 96.20 MuZ Skorpion Tour	414 24 47	Head-impact at the side. Glances over side
SH 96.21 Suzuki GSX 400 E	413 0 48	Head-impact at the side-window. Dive into cabin

Figure 19. Overview of the four full-scale motorcycle/passenger car crash tests carried out at the DEKRA crash centre in accordance to ISO/DIS 13232

The motorcycles were selected according to the sitting position and the size of the motorcycle. These parameters must be more or less identical in all tests in order to allow an interpretation of the test results. All four motorcycles were of the „Tourer“ type. On this type the sitting position of the rider is relatively upright. The cars used as opponents were VW Golf I and Golf II. The rider was represented by a Hybrid III dummy (50th percentile male, standing doll). A rider dummy as suggested by ISO/DIS 13232 could not be used for reasons such as deadline and costs.

Figure 20 shows as an example the collision of two moving vehicles, whereby a MuZ Skorpion Tour impacted at 48 km/h against the B-pillar of a VW Golf I which was moving at 24 km/h. The movements of the rider were determined by evaluating the film. The loadings of the upper leg were available as a measurement. **Figure 21** shows the movement paths and the dummy loadings on head, chest and upper leg in an impact of a Honda CB 450 N motorcycle at 47 km/h with a stationary VW Golf I. The tests shown in Figure 20 and 21 correspond to configuration 414 as per ISO/DIS 13232.

In the collision of the MuZ Skorpion Tour and the moving VW Golf I (Figure 20), the dummy first hit the roof edge of the Golf with its left shoulder at time t = 124 ms after the start of the collision with the motorcycle's front wheel. From the beginning of the collision until this moment the motorcycle had gone a distance of about 70 cm referred to its centre of gravity. The Golf had gone a distance of about 80 cm in the same time frame because of its own speed. After the shoulder impact, the dummy slid over the tailgate of the Golf. No impact occurred between the rider's helmeted head and the body of the car. The loadings measured on the upper leg are somewhat high, at - 4.6 kN (push) respectively. 7.5 kN (pull), but are still clearly lower than the protection criterion of 10 kN.

The evaluation of the dummy movement with the same impact angle against a standing vehicle, Figure 21, shows that the dummy's head hits the roof edge of the Golf at t = 126 ms after the start of the collision. The stillstanding Golf massively hinders the movement of the dummy so that no further phase-out path remains. As a consequence only a small part of the impact energy of the dummy is transformed into a sliding movement. Nevertheless the loadings measured on head and chest are lower than their biomechanical limits (HIC = 1 000, a_{3ms}-Head = 80 g, a_{3ms}-Chest = 60 g, SI = 60 g). The loading on the left upper leg, at -10.3 kN (push), lies in the region of the corresponding protection criterion of 10 kN.

Figure 22 shows another test with two moved vehicles which was carried out with a collision angle of 135°. A MuZ Skorpion Tour at a speed of 47 km/h impacted with its front wheel on a VW Golf II moving with 24 km/h in the area of the B-pillar. The impact occurred in this test on the right side of the car. This test corresponds to constellation 414 as per ISO/DIS 13232 because of the symmetry and can therefore be compared directly with the tests shown in Figure 20 and 21.

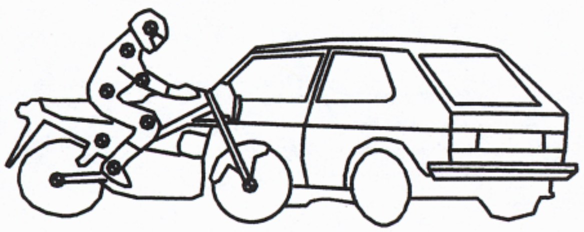
Despite the same impact constellation with moving vehicles as in Figure 20, however in the test shown in Figure 22 an impact occurred between the helmeted dummy head and the Golf II body below the right side window. This is due to the strong upward movement of the motorcycle. The Golf covers a distance of about 1 m within the time period between the start of the collision and the head impact at t = 158 ms. With reference to its centre of gravity the motorcycle covers a distance of only about 10 cm in movement direction in the same time period. Therefore the collision location is not cleared by the Golf as it is in test SH 95.32. As the back of the motorcycle rises, the dummy receives a corresponding force which causes him to rotate about his transverse axis so that he impacts the Golf head first. In both upper legs of the dummy increased pulling forces of 7.5 and 10.0 kN were measured. The measured head loadings, at HIC = 108 and $a_{3ms} = 33$ g, are way down in the undercritical area. In contradiction to this, the chest loadings of SI = 1 042 and $a_{3ms} = 90$ g lie above the corresponding protection criteria. This loading results from the impact of the dummy's chest on the fork bridge of the motorcycle. In the further course of movement beginning at t = 158 ms the dummy slides over the rear side panel.

The fourth test, **Figure 23**, corresponds to configuration 413 as per ISO/DIS 13232. The Suzuki GSX 400 E motorcycle collides at 48 km/h perpendicular with the B-pillar of a standing VW Golf II car. In comparison to the other three tests, differences between collision angles of 90° and 135° become clear. No slipping occurs in the perpendicular impact and the dummy head brakes through the side window of the Golf II at t = 126 ms. He penetrates the passenger cell to a depth of about 30 cm by t = 200 ms. In the further course of movement the dummy sinks to the ground on the impacted side of the Golf. The value HIC = 319 determined from the loadings on the dummy head in fact lies far below the protection criterion of 1 000. However, the 3ms-deceleration value of 84 g lies in the region of the corresponding limit of 80 g. The chest loading of 32 g and an SI-value of 174 lie far below the corresponding protection criteria.

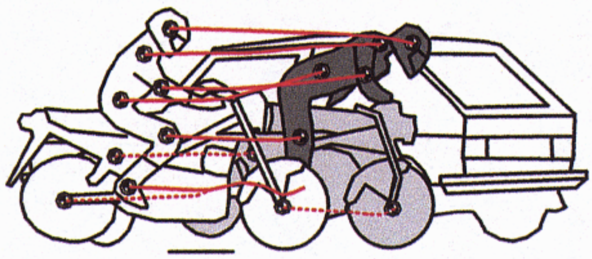
With knowledge of the movement paths and the measured dummy loadings of other similar tests, the results of which already have been published (BERG, 1988, GRANDEL and BERG, 1994, LANGWIEDER et al., 1987, GROSE, 1996), it is realistic to expect that on all four full-scale crash tests a motorcycle airbag installed in the area of the tank/steering head could have deployed in time. Therefore the movements of the riders could have been positively influenced and direct head and body impacts on the car body could have been intercepted. The forward-upward movement of the dummy supported by the airbag would have lifted the dummy head over the roof edge. So all in all, a more favourable movement path would have been initiated, leading to a flight with less injury risk or a glancing movement over the roof of the car in a real world accident.

Leg deflectors could also have contributed towards reducing the loadings on the upper and lower leg in all tests. Keeping the legs away from the handlebar of the motorcycle could also improve the effectiveness of the airbag. Thus the dummy's movement after the start of the collision could have been more flexible and in consequence less injury-prone.

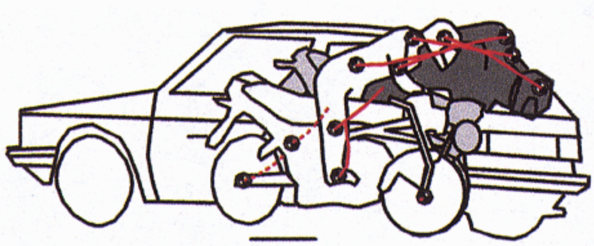
t = 0 ms (start of impact) SH95.32



t = 0 ... 124 ms (impact of dummy shoulder)



t = 124 ... 198 ms (dummy glances over tailgate)



Head: a_{3ms} = --- HIC = ---

Chest: a_{3ms} = --- SI = ---

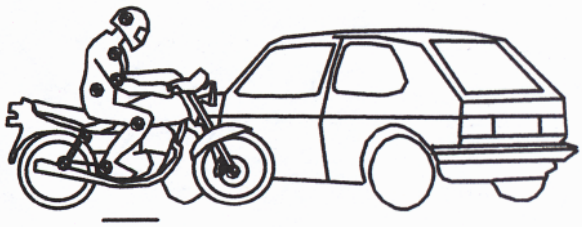
Pelvis: a_{3ms} = ---

Femur: F_{left} = -4.6 kN F_{right} = +7.5 kN

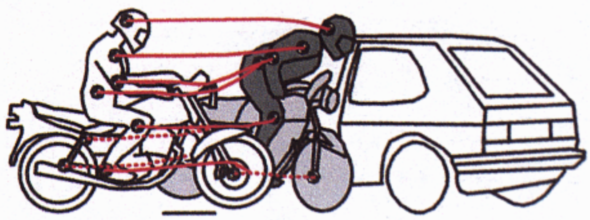
- nicht gemessen

Figure 20. Results of film evaluations of a full-scale crash test between moving motorcycle and moving passenger car and measured femur loadings of the dummy (Configuration 414 in ISO/DIS 13232)

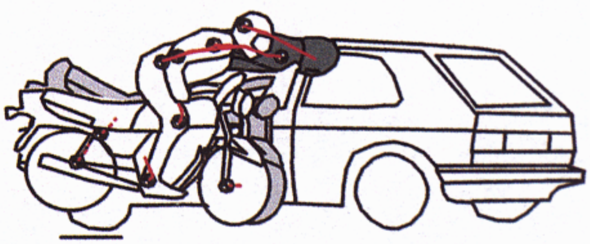
t = 0 ms (start of impact) SH95.33



t = 0 ... 126 ms (impact of dummy head)



t = 126 ... 201 ms (dummy glances over side)



Head: a_{3ms} = 57 g, HIC = 157

Chest: a_{3ms} = 14 g SI = 52

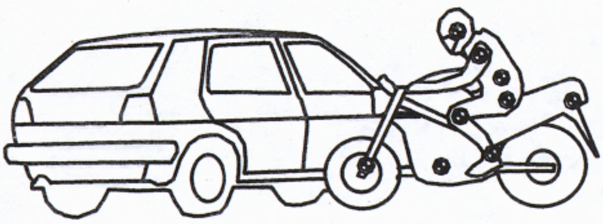
Pelvis: a_{3ms} = ---

Femur: F_{left} = -10.3 kN F_{right} = +2.1 kN

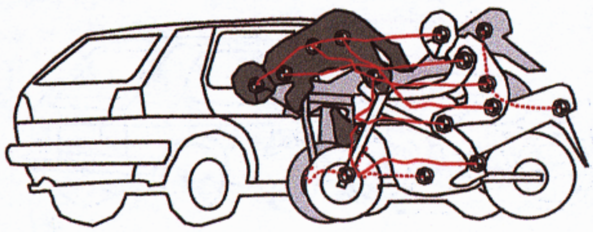
- nicht gemessen

Figure 21. Results of film evaluations of a full-scale crash test between moving motorcycle and stationary passenger car and measured head, chest and femur loadings of the dummy (Configuration 414 in ISO/DIS 13232)

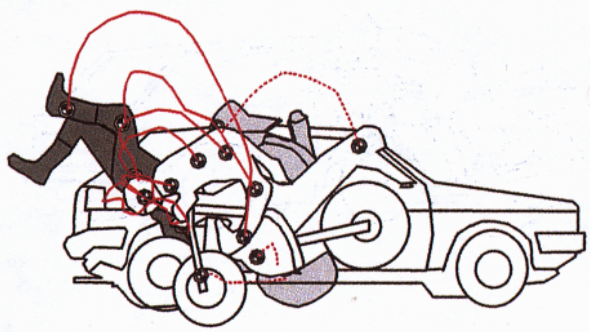
t = 0 ms (start of impact) **SH96.20**



t = 0 ... 158 ms (impact of dummy head)



t = 158 ... 653 ms (dummy glances over side)



Head: a_{3ms} = 33 g HIC = 108

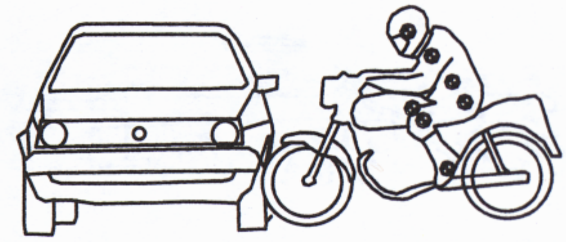
Chest: a_{3ms} = 90 g SI = 1042

Pelvis: a_{3ms} = 25 g

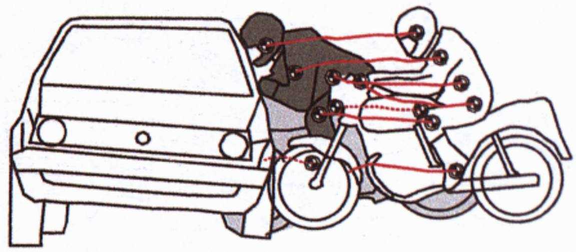
Femur: F_{left} = +4.9 kN F_{right} = +10.0 kN

Figure 22. Results of film evaluation of a full-scale crash test between moving motorcycle and moving passenger car and measured loadings of the dummy (Configuration 414 in ISO/DIS 13232)

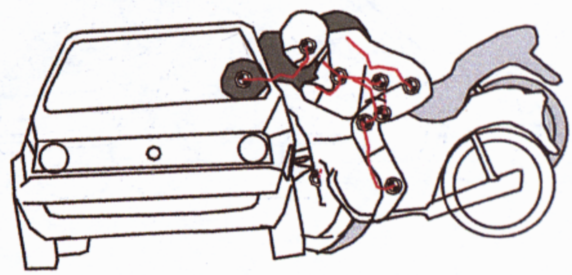
t = 0 ms (start of impact) **SH96.21**



t = 0 ... 86 ms (impact of dummy head)



t = 86 ... 200 ms (dummy dive into cabin)



Head: a_{3ms} = 84 g, HIC = 379

Chest: a_{3ms} = 32 g SI = 174

Pelvis: a_{3ms} = ---

Femur: F_{left} = +3.0 kN F_{right} = +4.6 kN

- nicht gemessen

Figure 23. Results of film evaluations of a full-scale crash test between moving motorcycle and stationary passenger car and measured head, chest and femur loadings of the dummy (Configuration 413 in ISO/DIS 13232)

CONCLUSIONS

1. The number of motorcycle riders killed and severely injured in accidents in Germany has remained almost constant in the 1990s to date. Simultaneously, in the category of motorcycles the number of registered „Krafträder" (piston capacity of over 80 cc) has increased further while the number of „Leichtkrafträder" (piston capacity 50 to 125 cc, engine power not exceeding 11 kW) has remained nearly constant. The number of „Roller" (especially those with a piston capacity ≤ 80 cc) has also increased.

2. Evaluation of 302 accidents of motorized two-wheelers from the stock of the DEKRA accident research department, which occurred within the period 1989-1996 in Germany, shows that now as in the past the head and the lower extremities (foot/ankle, lower leg, knee, upper leg) are at particular risk. The „Kraftrad" riders were also frequently injured on the face, shoulder and the upper extremities (hand/wrist, elbow, upper arm). This trend has not yet been confirmed with regard to „Roller" riders.

3. The standard ISO/DIS 13232 for the first time created world-wide uniform requirements for standarized and comparable crash tests, and these are already being taken into consideration in the development of new vehicles by some producers of motorcycles and „Roller". The impact constellations suggested in this standard should be further discussed against the background of real world accidents. For tests with a moving motorcycle, ISO/DIS 13232 always suggests a collision speed of 13.4 m/s (about 48 km/h). Evaluations carried out to date by the DEKRA accident research department in conjunction with the driving performance of the motorized two-wheelers indicate the use of higher speeds in crash tests for severe accidents with „Krafträder" and suggest that lower speeds are relevant for crash tests with „Roller".

4. Conducting crash tests with motorcycles with complete conformity with the standard ISO/DIS 13232 is difficult at present because of the high cost of motorcycle dummies. Therefore tests with a Hybrid III dummy (50th percentile male, standing doll) were carried out by the DEKRA accident research department for the qualification of the crash centre with a view to the impact constellations as per ISO/DIS 13232. The results of these tests indicate that crash tests featuring a frontal impact of the motorcycle with the side of the standing vehicle tend to lead to higher loadings on the dummy head than corresponding collisions with moving vehicles. The measured deceleration loadings on the helmeted dummy head still lay below the relevant protection criteria.

In one test where the motorcycle impacted a moving car, the measured deceleration loadings of the dummy's chest lay above the limit $SI = 1000$ and $a_{3ms} = 60$ g. Evaluation of the high-speed film showed that the reason was an impact of the dummy's chest against the fork bridge of the motorcycle.

In all tests performed the measured forces on the upper legs indicate an increased loading on these body parts.

On the one hand an airbag, which is being discussed in connection with terms such as concepts of a safety motorcycle and is already in use in prototype testing, could have had an impact-diminishing function by intercepting the head and the upper body. On the other hand a forward/upward movement of the dummy would have been initiated. This would have lifted the head over the area of danger and the dummy could have been diverted over the car. In conjunction with knee pads, the resulting movement of the dummy during the collision would have been more flexible and less injury-prone.

Hopefully the standard ISO/DIS 13232 can provide new impulses which will be useful in the further development of passive safety elements for suitable motorcycles, such as „Tourer" and „Enduro", up to their production launch.

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