INVESTIGATION INTO THE PROTECTIVE EFFECTS OF HELMETS ON USERS OF POWERED TWO-WHEELERS

by

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1. INTRODUCTION

In the Federal Republic of Germany, highway traffic, among other things, is characterized by a vigorous increase in the numbers of powered two-wheelers and till 1982 a growing number of fatal and injury accidents in this group of road users. For that reason, the Federal Highway Research Institute (BASt), as accident research center, has made the problems associated with passive safety features for users of powered two-wheelers a focal point of its programs of research and set up a number of research projects. In the following, only the results of helmet studies are reported. The work was undertaken to answer especially the questions raised in respect of the effectiveness of helmets as protective devices. The problem was approached by studying and plotting head injuries sustained in real accidents by helmeted and unhelmeted motorcyclists and by studying the loads sustained by the head by means of accident reconstructions. The objective of the research was also to study possibilities of optimizing head protection by means of helmet improvements.

2. SITUATION OF USERS OF POWERED TWO WHEELERS IN THE FEDERAL REPUBLIC OF GERMANY

The situation of users of powered two-wheelers in the Federal Republic of Germany is described in the following with respect to the development of numbers of two-wheelers in the various power classes, the development of accidents and that of the rate of helmet wearing.

In 1983, the number of registered powered two-wheelers was 2,96 millions. About 30 p.c. of these were motorcycles and motor scooters. The development of the numbers of these vehicles is shown in fig. 1 (see app.).

The statistics given show a four-fold increase in the numbers of vehicles in this category in the decade from 1972 to 1982. The figure for 1983 amounting to a total of 884,000 vehicles, however, indicate that the exponential trend of development is levelling off.

The numbers of fatal powered two-wheeler accidents for the years 1980 - 1982 are shown in fig. 2 (see app.). The trends with respect to light-powered two-wheelers (moped/mokick, mofa) and motorcycles (motorcycles in various power classes and scooters) vary. Whereas there is a downward trend in the development of fatal accidents in the light motorcycle class, the trend is towards rising numbers of fatalities in the higher power class. These absolute figures can be assessed against the background of the development of the overall number of powered two-wheelers above. However, if the various types of powered two-wheelers are compared, the variation of annual mileage figures, which may be considerable, will also have to be taken into account. Considering the overall number of powered two-wheelers, it is worth noticing that 57 p.c. of the riders killed are found among the group of motorcyclists representing 30 p.c. of all powered two-wheelers (the trend in 1983 in the number of fatalities in the motorcycle class is downward (7.2.p.c.)).

In the Federal Republic of Germany, the compulsory helmet usage law was introduced in 1976 for motorcycles and scooters and the class of light motorcycles (50 cc) and in 1978 extended to mopeds/mokicks (top speed 40 km/h, 50 cc) as well. Mofas (top speed of 25 km/h, 50 cc) are still the only vehicles not coming under the compulsory helmet usage law. The helmet usage rates for the motorcyclists and passengers coming under the law and those excepted from it are shown in fig. 3 (see app.).

With respect to those subject to the law, helmet wearing went up during the period of transitional provisions (1979 - 1980) and stayed around 95 p.c. since this period ended, both for riders and passengers. In contrast to that, the helmet usage rate in the mofa class was found to have remained just a little above 20 p.c.

3. ACCIDENT RESEARCH WITH RESPECT TO POWERED TWO-WHEELERS

The research projects mentioned at the beginning of this report, set up by BASt in order to optimize the protective effects of helmets, which is the topic of concern to us here, were carried out by means of three accident analyses and one laboratory study:

- In-depth investigation (OTTE/Hanover Medical University
- Effectiveness of passive safety features (analysis of two-wheeler accidents) SCHUELER/Heidelberg Institute of Forensic Medicine
- Advantages and drawbacks of passive protection devices (analysis of two-wheeler accidents) BEIER/Munich Institute of forensic Medicine
- Protective helmets for users of powered two-wheelers (laboratory studies) JESSL/Battelle Institute, Frankfort

Some of the research methods applied are summarized in the following table (Table 1).

ACCIDENT ANALYSES			LABORATORY STUDIES
OTTE/HANOVER	SCHUELER/HEIDELBERG	BEIER/MUNICH	JESSL/FRANKFORT
- IN-DEPTH STUDY OF ACCIDENTS DIRECTLY AFTER THEY HAD OCCURRED	- DATA COLLECTION BASED ON POLICE ACCIDENT RECORDS AND QUESTION-NAIRES	- DATA COLLECTION BASED ON POLICE ACCIDENT RECORDS	- IMPACT STUDIES (DUMMY TESTS WITH/ WITHOUT HELMET)
- ASSESSMENT AND DESCRIPTION OF DAMAGE TO HELMETS	- ASSESSMENT AND DESCRIPTION OF DAMAGE TO HELMETS	- ASSESSMENT AND DESCRIPTION OF DAMAGE TO HELMETS	- WIND TUNNEL MEASURE-MENTS TO DETERMINE THE EFFECTS OF WIND FORCES ON HELMETS
- RATING OF INJURIES (AIS)	- RATING OF INJURIES (MAIS)	- RATING OF INJURIES ACCORD-ING TO AIS	- WIND TUNNEL MEASURE-MENTS TO DETERMINE SOUND LEVELS IN HELMETS
- RECONSTRUCTION OF ACCIDENTS	- RECONSTRUCTION OF ACCIDENTS	- RECONSTRUCTION OF ACCIDENTS	- MEASUREMENTS OF THE VISUAL FIELD
- DOCUMENTATION OF ACCIDENT CONSEQUENCES	- QUESTIONING THOSE INVOLVED IN THE ACCIDENTS	- DETERMINATION OF USAGE RATES WITH RESPECT TO PRO-TECTIVE CLOTHING	
- QUESTIONING THOSE INVOLVED IN THE ACCIDENTS			

TABLE 1: RESEARCH METHODS

The studies conducted by OTTE are based on 224 powered two-wheeler accidents (1973 - 1981) involving 272 users (141 of them helmeted), analysed in the greater Hanover area.

The investigation of SCHUELER is based on a spectrum of 130 road accidents (1980) involving 142 users of powered two-wheelers (83 of them helmeted),which occurred in the Heidelberg Area.

The studies performed by BEIER are based on a total of 309 users of powered two-wheelers (257 of them helmeted) involved in 247 accidents. The study area includes the city of Munich and the administrative counties ("Landkreise") surrounding it.

3.1 Project results

3.1.1 Identification of main contact areas on helmets

In order that the protective effects of helmets may be improved it was necessary to know where helmets are affected in real accidents. For that reason, relevant contact areas were studied. The contact areas of helmets determined by OTTE and SCHUELER, based on their accident studies, are shown in fig. 4 and 5 (see app.).

The subdivisions of helmets resulting from the two studies are not the same. For that reason, a direct comparison of the relevant contact areas is not possible. However, the studies reveal that contact areas are seldom found at the top of the shell. The detailed subdivision carried out by SCHUELER enabled the determination of areas surrounding the ears and the area at the base of the helmet. The front area of the helmet turned out to be affected less often than had been assumed.

3.1.2 Head injuries

The effect of the use of protective helmets on injury severity is shown in the study performed by OTTE (fig. 6) (see app.).

No head injuries according to AIS-O were identified on 57 p.c. of riders who had been helmeted but on 32 p.c. only of unhelmeted users. At the same time, the percentage of injuries in the AIS classes 1 - 3 indicate an unfavorable trend in the case of unhelmeted riders. A comparative rating of the other AIS classes is problematical owing to the small number of relevant cases (AIS 4 = 7 cases, AIS 5 = 7 cases, AIS 6 = 9 cases) and is therefore refrained from here.

The findings of SCHUELER, shown in fig. 7 (see app.), indicate that the head injuries rated according to MAIS had been decisive for the overall injury severity in the case of 18 p.c. of helmeted riders. In the case of unhelmeted users of powered two-wheelers, head injuries were decisive for the relevant MAIS classification in 47 p.c. of these cases. The disproportionate high percentage of unhelmeted users in the MAIS classes greater than 2 also were mainly sustained by unhelmeted users of powered two-wheelers. However, in this case too, the small number of cases in the MAIS class $\geq$ 3 needs to be taken into account.

Table 2 shows the frequency of specific head injuries and the frequency of fractures/dislocations of the cervical vertebrae and the atlanto-occipital joint based on the 264 cases of seriously injured (AIS $\geq$ 2) motorcyclists and fatalities (200 helmeted, 64 unhelmeted) studied by BEIER.

Skull fractures, representing a proportion of 4 - 7 p.c. among the seriously and fatally injured helmeted motorcyclists are considerably less frequent than among unhelmeted motorcyclists (proportion of about 30 p.c.). Even assuming a greater degree of uncertainly associated with the findings for unhelmeted motorcyclists owing to the small number of cases, it still stands to reason to assume that unhelmeted motorcyclists are likely to sustain skull fractures four times as frequently as seriously injured motorcyclists who had been helmeted. Fractures and dislocations of the cervical vertebrae and of the atlanto-occipital joint are rare with helmeted motorcyclists (about 1 - 3 p.c.). In the case of unhelmeted motorcyclists such injuries were sustained in 9 - 10 p.c. of the cases. Table 2 shows that brain trauma (SHT) of between the first and third degree was found on a total of 38 p.c. of unhelmeted riders studied. The decisive finding that the helmet is a major

	WITH HELMET	WITHOUT HELMET
TOTAL NUMBER OF CASES	200	64
FRACTURES/DISLOCATIONS		
VAULT OF THE SKULL	4 %	31 %
FACIAL SKULL	7 %	29 %
BASE OF THE SKULL	6 %	28 %
ATLANTO-OCC.-JOINT	1 %	9 %
CERVICAL VERTEBRAE	3 %	10 %
CRANIAL-BRAIN TRAUMA		
DEGREE 1 AIS 2	28 %	18 %
DEGREES 2-3 AIS 3-6	10 %	35 %

TABLE 2 - FREQUENCY OF SPECIFIC HEAD AND CERVICAL SPINE INJURIES (BEIER)

abatment factor with respect to the risk of sustaining severe injuries is confirmed by the trend from serious brain traumas to lighter ones. The more serious brain injuries were found on unhelmeted motorcyclists in 35 p.c. and on helmeted riders in 10 p.c. of the cases studied.

3.1.3 Laboratory results

Laboratory results can be grouped into:

- the results of measurements of the forces associated with a specific impact situation (head against rigid plate),
- the results of measurements of the forces and sounds affecting a helmeted head at various riding speeds.

With respect to impact tests, two results are of importance. The effect of the movement of the whole mass of the body of a motorcyclist in an impact against a more or less rigid obstacle (in the case of the accidents, for instance, against the A-post of a passenger car) is clearly shown in fig. 8. If, in the case of the 5 % female dummy, peak deceleration values of 1200 m/s^2 are measured, these values rise to more than 2100 m/s^2 in the case of the 95 % male dummy. This energy potential has to be considered in the design of the energy absorbing padding of helmets. However, thus far, the reduction of this potential has not been entirely successful.

The smaller, but still remaining difference between the helmeted and unhelmeted 5 % female and the 50 % or 95 % male dummy confirms this fact.

The effect of speed deceleration values, averaged about three milli-seconds, is shown in fig. 9 (see app.).

The protective effect of the helmets looked into is demonstrated by the comparisons with the unhelmeted dummy. The only exception is the helmet whose shell had been broken up in the crash.

3.1.4 Special problems: loss of helmets

The potential protective effect of helmets can be of full benefit to riders only if helmets do not get lost in accidents. Loss of helmets in any phase of an accident can be caused by technical defects (e.g. breakage of the strap or buckle, breakage of strap anchorage, etc.) or wrong rider usage (chin strap not or improperly secured, etc.). There is a remarkably high number of cases in which the helmet was lost owing to the above-mentioned defects and faults of usage.

The studies performed by OTTE revealed that 13.5 p.c. of helmeted motorcyclists had lost their helmets in the crash. The majority ($>$ 10 p.c.) came off after the primary head impact.

The studies of SCHUELER are based on a sample of motorcyclists, including 82 helmeted riders. Thirteen of them (16 p.c.) had lost their helmet in the crash. In two cases the helmets had been at least partially effective as risk abatement factors.

In the study performed by BEIER, 19 motorcyclists (7.4 p.c.) out of 257 helmeted riders lost their helmets during the trajectory phase in the crash. During the remaining phases of the crash, the risk abatement effect of these helmets thus was lost. Cases in which helmets came off as a result of head impacts are counted among the group of helmeted riders because helmets at least had afforded partial protective effects in such cases.

The large number of helmets lost remain a fact worthy of attention, even taking into account the different points of view of the authors named. This fact needs to be considered in the design of helmet locking on fastening systems but should also be considered as a reason for planning and launching education campaigns demonstrating desirable modes of behavior with respect to the usage of helmets.

3.2 Discussion of Results; Future Perspectives

Attempts at identifying the contact areas on helmets by means of head impact studies revealed that the areas surrounding the ears and the area at the base of helmets need to be paid greater attention to than has been done in the past. From the design point of view, the energy absorption capacity of these areas (by optimizing the padding) and the stiffness of the shell on both sides (by improving the design of the shell) could still be improved. In these attempts at optimization, it needs to be considered that the anchoring points of the vizor and the fastening or securing devices of the chin strap do not turn into break-away points with the consequence of shell break-up in crashes.

Despite the wearing of helmets, head injuries will still occur in future. Nevertheless, the energy absorption capacity of the padding needs to be improved, for it is known that the capacity of energy absorption, in specific cases, can be exhausted by the maximum deformations (elastic and plastic) sustained. The remaining impact energy then will fully affect the head of the accident victim and still can cause serious injuries. As a consequence, efforts should be concentrated on designing paddings affording a wider range of energy absorption, and improving the protective effects of helmets at higher impact velocities without simultaneously altering their protective effects at low speeds. The large number of lost helmets further call for improvements in the fields of safe fastening or buckling and adjustment facilities in respect of the chin straps. Apart from the mechanical strength of these devices, the fit of helmets (e.g., by appropriate adjustments) calls for attention.

4. REFERENCES

Aldman, B., The Protective Effect of Crash Helmets, IVth International IRCOBI Conference on the Biomechanics of Trauma, Göteborg, 1979

Beier, G., Schuller, E., Spann, W.: Vor- und Nachteilige Wirkungen passiver Schutzeinrichtungen für motorisierte Zweiradfahrer, FP 7806/3, BASt, unpublished

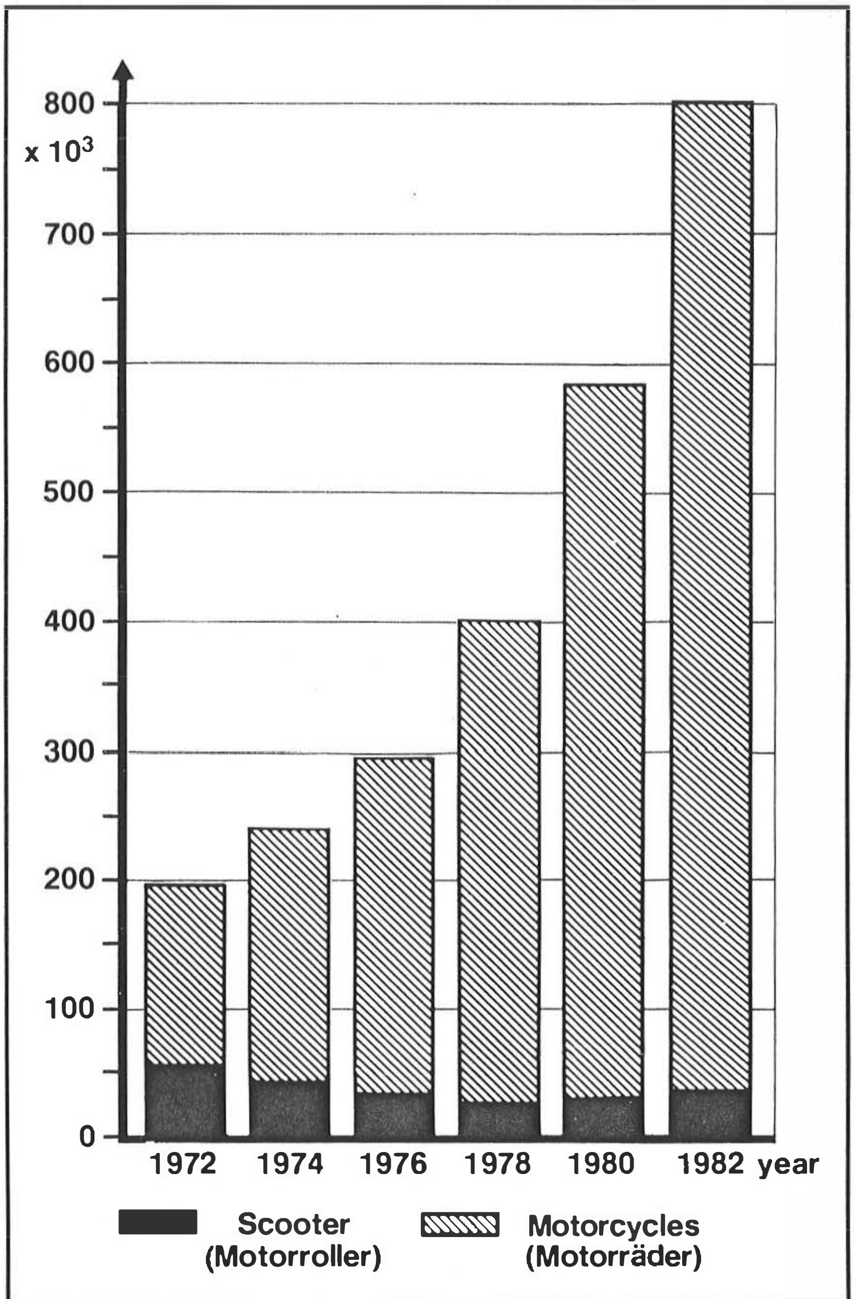
Hurt , H.H.: Status Report of Accident Investigation Data "Motorcycle Accident Cause Factors and Indentification of Countermeasures", DOT HS-5-001160, 1979

Jessl, P., et al.: Schutzhelme für motorisierte Zweiradfahrer, Band 1, BASt, Forschungsberichte Unfallforschung, Nr. 91, 1983

Löfsund, P.: Motorcykelsäkerhet, VTI Rapport 253, 1983

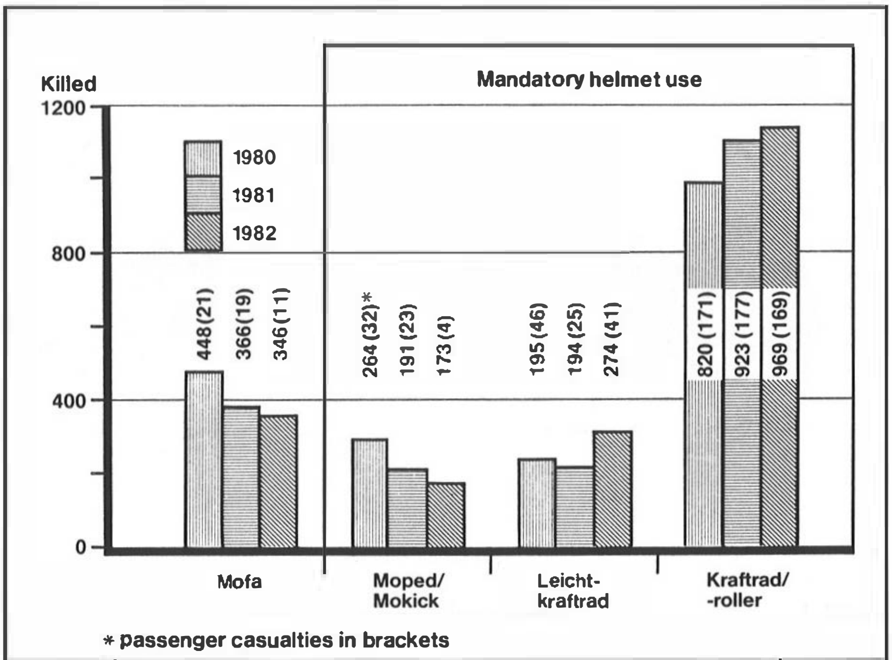
Otte, D., Suren, E.G.: Rekonstruktion von Zweiradunfällen aus Erhebungen am Unfallort, FP 7806/2, BASt, unpublished

Schüler, F., Mattern, R., Helbling, M.: Optimierung des passiven Unfallschutzes für motorisierte Zweiradfahrer, FP 7806/6, BASt, unpublished



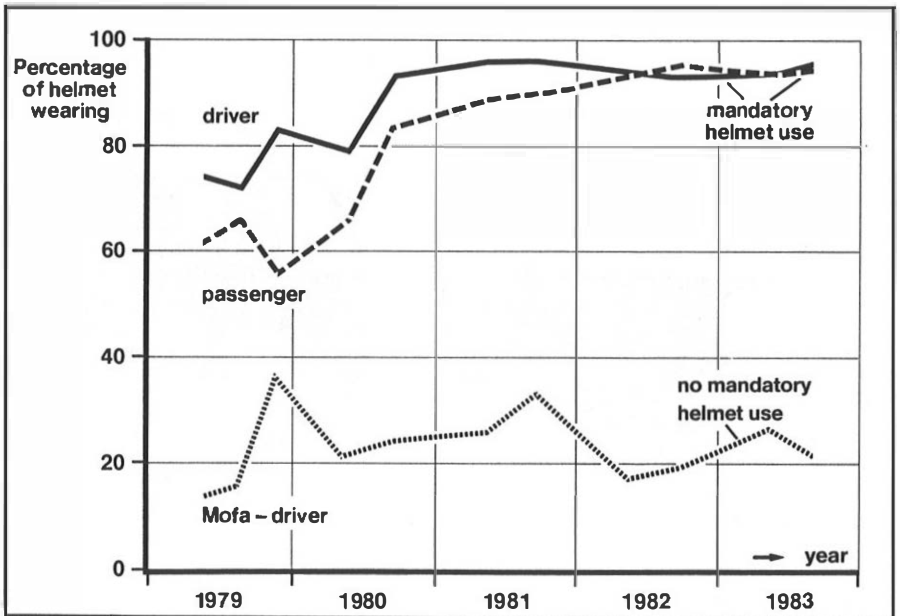
BASt	Numbers of motorcycles	U 3.2 s

Figure 1



BASt	Numbers of killed drivers and passengers of powered two – wheelers	U 3.2s

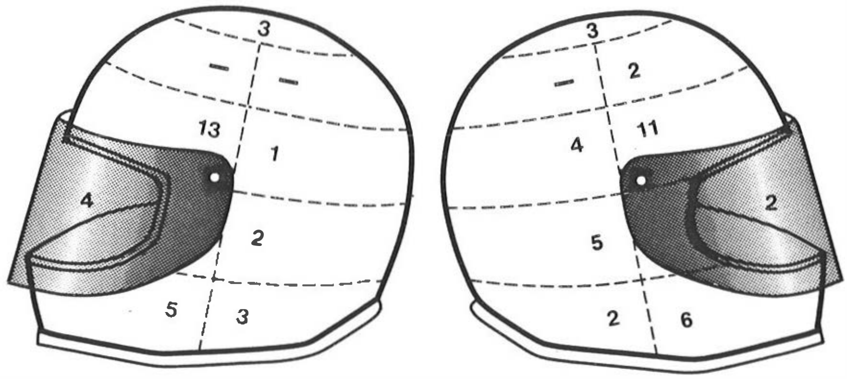
Figure 2



BASt	Helmet wearing of users of powered two-wheelers	U 3.2 s

Figure 3

141 helmets



left side

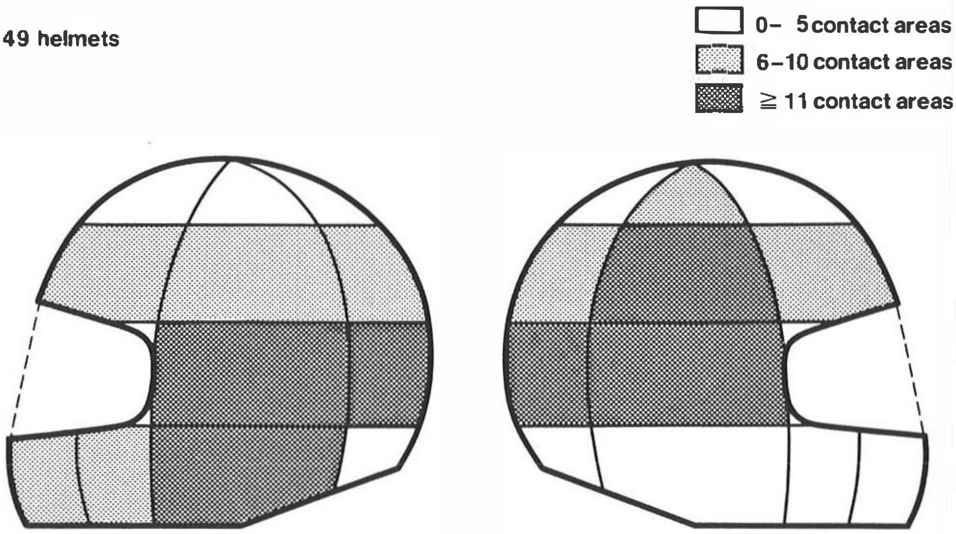
right side

source: Otte/Hannover

BASt	Relevant contact areas	U 3.2 s

Figure 4

49 helmets



Left side: 86 contact areas

Right side: 72 contact areas

source: Schüler/Heidelberg

BASt	Relevant contact areas	U 3.2 s

Figure 5

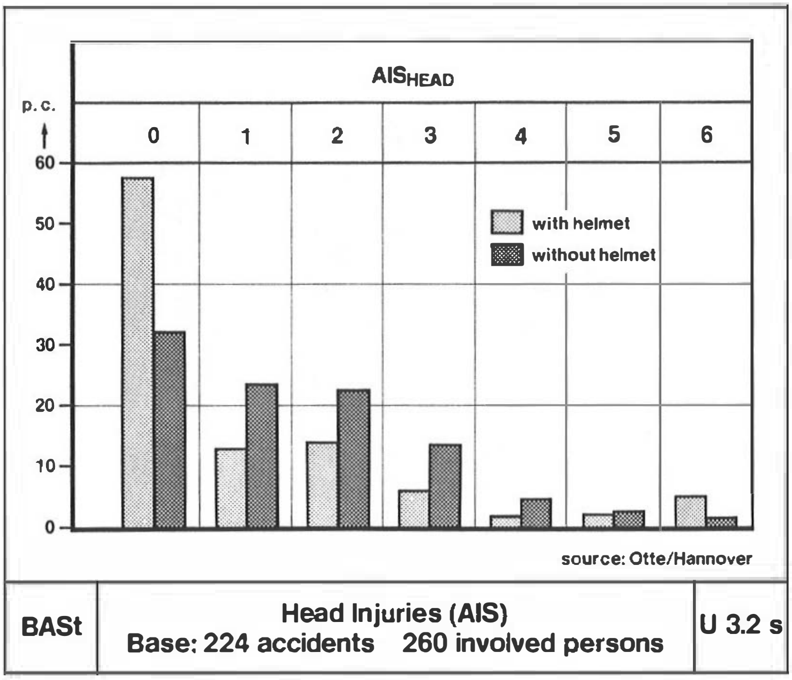


Figure 6

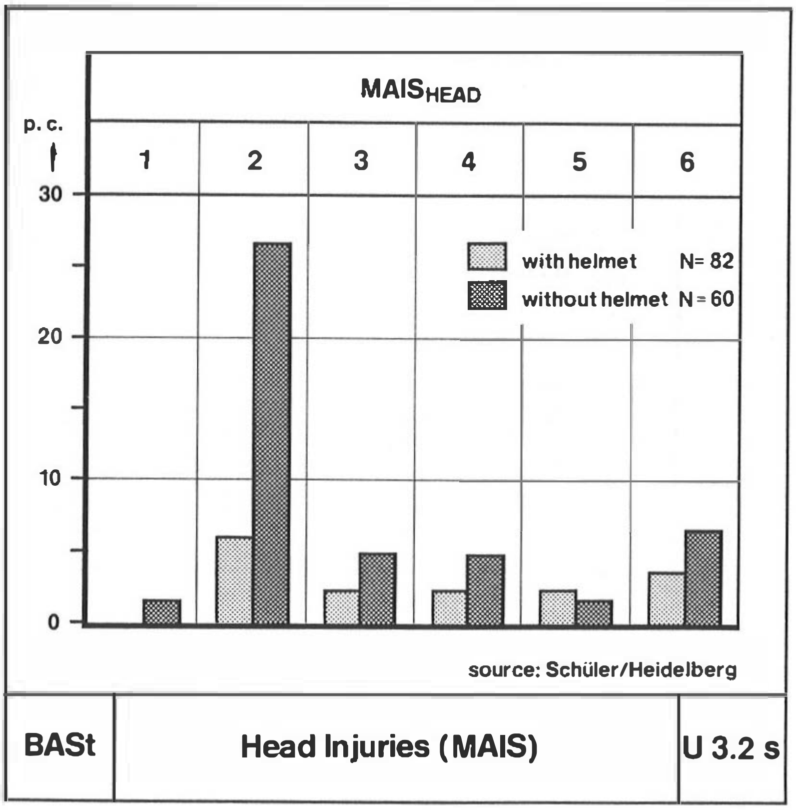
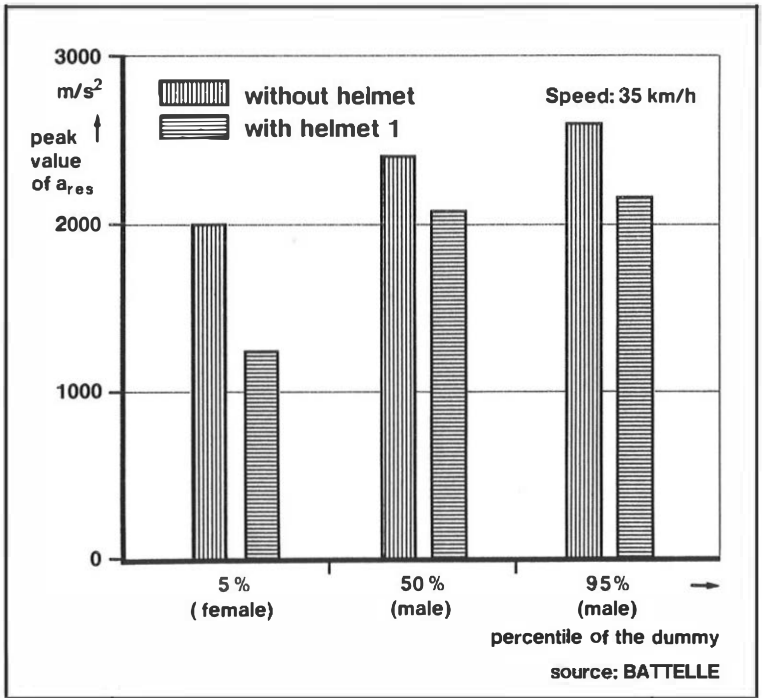
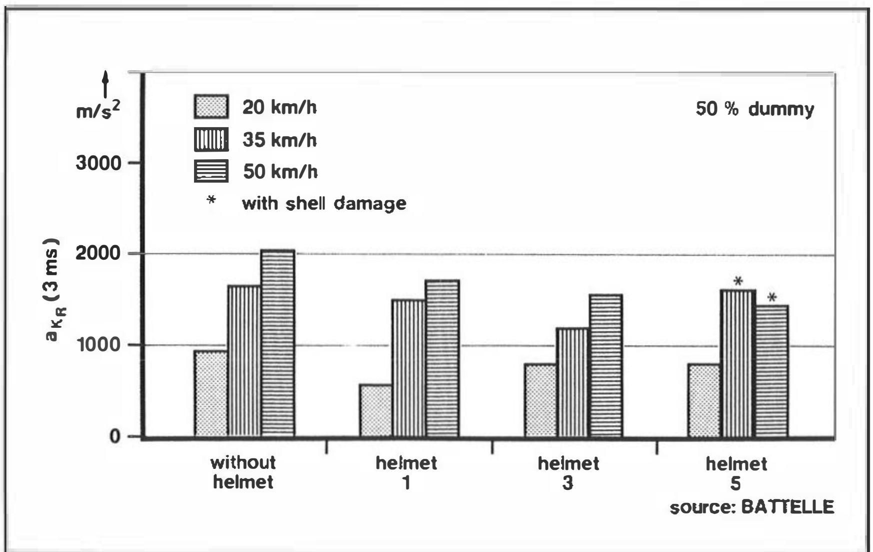


Figure 7



BASt	Deceleration values (peak values)	U 3.2 s

Figure 8



BASt	Deceleration values (average about 3 ms)	U 3.2s

Figure 9