## RECOMMENDATIONS FOR IMPROVEMENT OF THE INJURY SITUATION FOR THE USERS OF TWO-WHEEL VEHICLES

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## 1. INTRODUCTION

The two-wheel vehicle takes an important place in todays world of traffic, due to the fact that it is used by young and old, and also in view of its high value for recreation purposes. The motorized two-wheeler serves especially the young as an entry into the world of motorized traffic.

Users of two-wheelers represent a proportion of 32.5% of all traffic accident victims in the German Federal Republic (1). 60% of them are users of motorized two-wheelers. This fact urgently calls for measures in the accident prophylaxis.

The term 'motorized two-wheel vehicle' refers mainly to the group of motorcycles. In the German Federal Republic, however, this group includes mofas (motor-assisted bicycles) (21% of injured users of motorized two-wheelers) as well as mopeds/mokicks (8% of injured users of motorized two-wheelers), and motorcycles, including light-powered motorcycles and motor scooters (71% of injured motorized two-wheelers). When summarizing this group, the differences between the individual types must always be taken into consideration.

The great risk faced by riders of two-wheelers in traffic accidents is mainly due to two facts:

- the instability of the two-wheel vehicle, in comparison with the four-wheel construction of the motorcar,
- 2. the absence of the protecting passenger compartment and the safety belt as well as other devices for passive protection.

For this reason, accidents with two-wheelers are, as a rule, in

most cases connected with personal damage. While almost 50% of the officially recorded accidents with cars result in material damage only, the majority (98%) of accidents with motorized twowheelers, and 99% of bicycle accidents involve personal damage (1).

## 2. OBJECTIVE

Numerous national (among others JESSL (2); BEIER (3); SCHÜLER (4) as well as international studies (HURT (5); HIGHT (6); WALZ (7); CHINN (8); WALFISCH (9)) regarding the injury situation of the two-wheeler user do already exist. Beyond injury description, injury mechanisms, and the protective effect of helmets and leather clothes in these studies as well as already realized effective modifications, there are no definite recommendations to improve the situation. SPORNER (10) recommended the optimation of the fly-off angle for the injured two-wheeler user, and the use of an airbag (11). Recommendations like safety belts for motorcyclists (SCHIMMELPFENNIG - 12) and safety cages (13) are not very realistic and can only be valued with reservation, in view of the accident and injury kinematic.

The authors, however, are of the opinion that solutions for an improvement of the accident prophylaxis for the two-wheeler user can be derived from present-day cognitions about the accident and injury situation as well as the collision and accident mechanisms.

It is the objective of this survey to point out these possibilities. The advantage of any steps taken in this direction has to be measured against the frequency and severity of any incured injuries and their reduction. In order to realize this objective, an exact compilation of the injuries received, divided into type, severity and location is necessary. This compilation has to correlate exactly with the reconstructed accident and collision situation, the cause for which will have to be evaluated some later time. The methods used in the study 'Investigations at the Place of Accident' (14) appear to be useful prerequisites for a detailed accident analysis.

## 3. METHOD OF ANALYSIS

## 3.1 Accident investigation

Since 1973, an interdisciplinary medical/technical team at the Medical University of Hannover is engaged in accident investigations. This research project is carried out as a joint action by the Institute for Vehicle Techniques of the Technical University Berlin and the German Federal Highway Department. The team investigates and records traffic accidents with personal damage in the town and rural destricts of Hannover (OTTE - 13). The team, consisting of doctors and engineers approach the site of an accident in specially equipped vehicles. Data collection of the accidents, i.e. final positions of vehicles and any impact points, as well as the final position of the injured is started immediately. True-to-scale drawings of the accident scene, including any secured traces can be produced with the help of stereo photography, for each individual case. This makes an exact reconstruction of an accident possible, the kinetic process as well as the injury mechanisms. All injuries are recorded, divided into type, severity and exact location, and finally evaluated in accordance with the AIS scale (American Association of Automotive Medicine, 1980 (15)). A correlation of the established damages, the kinetic processes, and the diagnosed injuries on a physical, bio-mechanical and kinetic basis is made possible by this medical/technical cooperation.

## 3.2 DESCRIPTION OF THE EXAMINED COLLECTIVE

The study collective consisted of 436 involved motorized twowheelers, with 543 riders. 410 bicycles, with 415 riders were also at our disposal for the evaluation. In these accidents, all collision partners were considered (table 1), but the motorcar was involved most frequently.

vehicle type	collision partner							
	car	truck	two- wheeler	pedes- trian	object	multiple	total	
	%	%	%	%	%	%	n	
Mofa	72,9	14,1	-	-	11,8	1,2	85	
Moped/Mokick	74,6	12,7	1,8	1,8	5,5	3,6	55	
Kleinkraftrad	60,0	20,0	3,3	-	3,3	13,4	30	
Leichtkraftrad	59,5	14,9	2,1	4,3	14,9	4,3	47	
motorcycle	50,9	7,1	7,5	5,7	19,4	9,4	212	
motor-scooter	85,7	14,3	-	-	-		7	
motorized two- wheelers total	60,3	11,0	4,4	3,4	14,2	6,7	436	
bicycle	77,3	11,7	4,4	1,5	3,9	1,2	410	

table 1: Collision partner of two-wheeler riders in the analyzed accidents

For motorized two-wheelers, in comparison to bicycles, a distinctly higher proportion of collisions with objects like leading planks, trees and such like could be observed.

More than 50% of all two-wheeler riders, motorized as well as nonmotorized, received slight injuries of severity degree MAIS 1/2 (table 2).

wahista tura	injury severity grade MAIS						
venicie type	unin-	MAIS	MAIS	MAIS	un-	total	
	jured	1/2	3/4	5/6	known	totai	
	%	%	%	%	%	n	
Mofa	4,4	52,2	32,2	10,0	1,1	90	
Moped/Mokick	8,6	55,7	25,7	8,6	1,4	70	
Kleinkraftrad	5,3	63,1	18,4	13,2	-	38	
Leichtkraftrad	6,2	62,5	25,0	4,7	1,6	64	
motorcycle	6,6	53,5	27,3	11,4	1,1	271	
motor-scooter	10,0	80,0	-	10,0	-	10	
motorized two- wheelers total	6,5	55,8	26,5	10,1	1,1	543	
bicycle	2,7	60,2	23,9	11,3	1,9	415	
percentage of fatal involved persons	-	1,7	17,9	74,4	6,0	117	

# table 2: Distribution of injury severity degrees (MAIS) in the analyzed accidents

## 4. DETAILED INJURY SITUATION

## 4.1 Motorized two-wheeler riders

The 508 injured users of motorized two-wheelers, documented in this study, received a total of 3,838 individual injuries, in most cases to the lower extremities (81.2% of the users - table 3). Soft-part injuries represent with 75.7% the main proportion of these. The tibia is especially exposed to fractures (18.6%), while the quite frequent knee injuries (49.7%) are, as a rule, softpart types. The same great injury risk like to thigh and tibia also applies to the ankle-joint and foot region, where 23% or 16.2% respectively received injuries. Only one fifth to one quarter of the persons involved suffered injuries to the body trunk (thorax incl. shoulder, abdomen and pelvis). Here, damages to the organs occurred in approximately 7%, to the vessels up to approximately 2%. The head is another body region very much exposed to injuries (48.4% of the injured persons - 73% of those without helmet, and 42% of helmet wearers). Injuries are also frequent to the upper extremities (56.2% of the injured).

## 4.2 CYCLISTS

The 403 injured cyclists suffered an injury total of 3,535; 74% of them received leg injuries. The head, however, is with 76.1% of all injured the most frequently traumatized body region, with many soft-part injuries (70.6% of all injured people), and with skull-brain trauma (48.7%). In comparison with motorized two-

wheeler users, cyclists receive injuries more often to the elbows (24.3%), to the hands (36.4%, and slightly more injuries to the ankle-joint/foot region (25.8% and 17.6% respectively).



table 3: Frequency of injuries (n=3838) to the different body regions of motorized two-wheeler riders



table 4: Frequency of injuries (n=3535) to the different body regions of cyclists (n=403)

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the elbows, to the wrists and hands. The legs (ventral), incl. the foot region and especially the knees, often receive softpart injuries.

They suffer, however, fewer injuries the cervical vertebra (5,5%), to the forearms, the wrists, thighs and knees. They also receive evidently fewer intra-abdominal injuries (3,6%, compared with 6,6% of the motorcyclists), and fewer fractures to forearm and hand region, but more fractures to the thorax and head.

Each individual injury was analyzed, according to its exact location. The most frequently injured body regions for two-wheeler riders (motorized an non-motorized) are illustrated in the pictograms (hatchings) in diagrams 5 and 6.

In view of the very great injury frequency, these body regions require special protection. These cognitions result from the summing-up of all individual injuries, divided into soft-part injuries and fractures.

## 4.3 BODY REGIONS WITH HIGH INJURY FREQUENCY

4.3.1 Motorized two-wheeler users (diagram 5)

Soft-part injuries are very frequent for shoulders, the lateral region of thorax, abdomen and pelvis, dorsal to forearms, incl. Fractures are predominant in the shoulder region, the upper arms (proximal), the forearms (distal), incl. hands and wrists. The thorax fractures are frequent in the front-rib region. The occur also to the whole of the pelvis as well as the thigh (centre third) and the whole of the tibia.

Injuries to the head are mainly soft-part defects to the front an side of the facial skull. Here most fractures are also found (s. JESSL - 16).

4.3.2 Cyclists (diagram 6)

Soft-part injuries to the cyclist are especially found in the region of the facial skull as well as the back of the head. To the latter, however, exclusively in an almost circular region above the regio occipitalis. Further outstanding injury points are the elbows, the surface of the forearms and the hands, also in the region of knees, the ankle-joint and foot. Fractures are found in the whole of the skull, but more frequently in the facial skull, in the whole of the front-rib region, the pelvis, especially the hunchbone. Further to the thigh (in the proximal and distal third) as well as the whole of the tibia. Fractures to the arms may often occur in the centre third of the upper arms as well as the distal third of the forearms, and in the region of the wrists.



diagram 5:



diagram 6:

It is remarkable that cyclists suffer an increased injury frequency to the left side of the body, where soft-part injuries (to the lateral thorax and lumbar region) are slightly more frequent.

## 4.4 CONSTRUCTION OF PROTECTIVE DEVICES

Protective devices can be designed for exposed body regions as an objective measure for the injury reduction. These devices must have power-dispersing as well as shock-absorbing effects. When inserted in leather clothing, they will be an asset for increased protection. Realistic models are already on the market in Sweden (17) and Germany (18).

## 5. QUANTITATIVE DETERMINATION OF INJURY CAUSES AND EVALUATION OF OBJECTIVE MEASURES

The injuries are basically traced to four different causes. These are parts of

	motorized two-wheel riders	cyclists
cars	32.6%	50.2%
trucks and commercial vehicles	7.78	3.4%
accident site	47.6%	42.6%
own two-wheel vehicles	12.1%	3.8%

## 5.1 MEASURES TO BE TAKEN ON CARS

Measures on the car for the purpose of injury reduction must have priority, in view of the fact that 25% of all injuries to the motorized, and even 50% of the injuries to the non-motorized twowheeler user are inflicted by car parts. Injuries by the car front, including the bumper and edge of the bonnet front (diagram 7) are especially frequent. These regions together cause 13.7% of all injuries to the motorized, and 20.1% to the non-motorized two-wheeler user. The car front and especially the bumper and main front edge cause injuries mainly to the tibia and the knee. The pushing forces are transferred directly to these regions by the hard and rigid tin structures. Shock and energyabsorbing elements fitted to these vehicle regions appear to be most sensible for the injury prophylaxis. These are broad and thick rubber coverings for the bumper, in foot-rest level for motorized two-wheelers, if possible.

As far as the injury frequency for motorized as well as non-motorized two-wheeler users is concerned, the centre third of the front bonnet and the front windscreen are of importance. These regions of the car are clearly the most dangerous for cyclists, with 19.8% of all injuries, and thus partly the cause of a great number of head injuries. The lateral door frames as well as the fender structures in back and front cause injuries to motorized two-wheeler users remarkably often. Serious injuries of severity degree AIS > 2 are often caused by the bumper, the edge of the front bonnet, the windscreen and A-posts.



Recommended measures are:

- rounded broad-leveled vehicle edges, for the dispersion and reduction of transmitting forces to the body
- energy absorbtion regions provided by shock-absorbing devices like plastic foam. These are especially suitable for the centre front bonnet region. Besides injuries to the upper and lower extremities, injuries in the region of thorax and shoulder are caused here. Especially injuries to the head region of cyclists and users of mofa/mokick.

The windscreen region is often responsible for head injuries, mainly to cyclists, in an impact with the glass compound. Here an improvement can only be expected by fitting a laminated safety glass windscreen, with more elastic quality than that of the single-plate safety glass. The lateral A-posts as well as the upper roof edge should be smooth and shock absorbing. The connection between front bonnet and windscreen has to be broad panelled and without edgy structures (dropped windscreen wipers, drawn-up front bonnet). Lateral injurious vehicle regions are the roof edge, door structures, including upper A, B, C and (if installed) D-posts as well as the upper fender edges in back and front. These too should be shaped rounded and yielding, in order to reduce the impact of the upper body by energy absorbtion and dispersion. The installation of special impact absorbers to these regions appears to be feasible.

## 5.2 MEASURES ON TRUCKS

7.7% of all injuries to the users of motorized two-wheelers, but only 3.4% of injuries to cyclists are caused by parts of commercial vehicles (diagram 8). The front area of the truck most frequently influences the occurring injuries.



<u>diagram 8:</u> Truck parts causing injuries to riders of two-wheel vehicles (100% = all injuries)

The rider of a two-wheeler collides as a rule with the front of a truck, as a result of an impact of his whole body with the complete front area of the commercial vehicle. Multiple injuries to his body are the consequence. There are several reasons for the overrolling of the cyclist. One of them is the unfavourable mass relation and the rather rigid front area of the truck. Another is the differing and very diverging height relation between the twowheeler and the truck bumper. During the collision of the twowheeler with the front of a truck, the deformation of the truck results in the reduction of the transfered energy. The same applies to the impact of a two-wheeler with the side of a truck, which often has the most serious consequences. Additional injury risks are the edgy frame members of the vehicle body (garbage vehicles, agricultural vehicles). Due to the relatively unprotected region between front and rear axle, the side of the truck is another risk for injuries by overrolling. Realistic measures for the truck could be as follows:

- underdrive protection for front, side and rear
- shock absorbtion for front areas (fitting of impact absorbtions)
  rounded, broad leveled vehicle edges, for dispersion and reduction of the transferred impact force to the body
- bumper fitted with broad and thick rubber cover, for the rider of a motorized two-wheeler preferably at foot-rest level
- elimination of edgy external parts.

#### 5.3 MEASURES FOR ACCIDENT SITE

Some parts of the accident site are a major cause for injuries to the two-wheeler user. A strikingly frequent cause is the tarmac, which is responsible for 32.5% of all injuries to the cyclist, and for 34.2% to the motorized two-wheeler user (diagram 9). These are mainly minor injuries of severity degree AIS 1/2. Impacts with masts, posts or trees are very dangerous, and quite often cause serious injuries. Impacts with leading planks, with only 2.1% of often minor injuries, are of subordinate importance to the total pattern of injury causes for motorized two-wheeler users (s. OTTE - 19; DOMHAN - 20).

Safety precautions for the environment are feasible only to some extent, like covering of posts, leading planks or such like (SCHULER - 21). The protection against injuries caused by the site of accident should in our opinion be fixed directly to the rider of a two-wheeler (analog diagrams 5 and 6, chapter 4.2). This demand is supported by the fact that the main proportion of injuries result from rolling or gliding-down movements of the body on the tarmac (72.7% of motorcyclists, and 89.4% of bicyclists). As a rule, these as 'slight' classified soft-part injuries can effectively be prevented by clothes and helmet. This refers especially to the cyclist, for whom a head protection would provide a great measure of passive safety.

## 5.4 MEASURES FOR THE OWN TWO-WHEELER

Injuries caused by the own two-wheeler are of importance apparently

only for riders of motorized two-wheelers (diagram 10) (12.1% of all injuries).





Diagram 10: Injury-causing parts of own two-wheeler (100% = all injuries)

The handlebar causing 5.3% of all injuries is regarded as particularly dangerous, for the cyclist as well as the user of a motorized two-wheeler. These injuries occur in most cases during the detaching phase, in which the two-wheeler user performs a forward movement. For the motorcyclist, these injuries occur to the forearms, by support on the handlebar (fractures to forearms, wrists, and the centre of the hands). Further in the region of the thigh (fractures), and to the knees (soft-part types), also by direct impact of the legs with the handlebar. Also recognized as injurious for the motorized two-wheeler user are parts of the protective coverings, often attached to the handlebar, especially when splicing synthetic materials are used. These injuries could be eliminated or reduced by bolstering the handlebar, or by fitting shock absorbtions. Protruding edged and rigid parts on the two-wheeler should be eliminated, in order to provide passive accident protection for the two-wheeler user.

## 6. CONCLUSIONS

The analysis of the detailed injury pattern for 508 users of motorized two-wheelers, and 403 cyclists, with a total of 3,500 injuries, from investigations at the site of accidents, established the regions exposed to high injury frequency. With regard to the causes responsible for these injuries the practicability of sensible safety measures is illustrated. It became evident that constructive measures to vehicles (car, truck and two-wheeler also) would contribute to a significant reduction of injuries. In the construction of regions of passive security, the criteria absorbtion and widely spaced power dispersion should always be considered in combination. The power dispersion is often decisive for the injury occurrence.

For the car, regions of increased injury risks were defined which require constructive measures. These are

- bumper
- edge of front bonnet
- windscreen including A-post and roof edges
- lateral upper door and roof-edge region.

Modifications for the truck should include the following parts: - bumper, including compatible two-wheeler level

- front area
- lateral body geometry

- drive-under prevention for side and rear.

Measures for the two-wheeler are:

- handlebar construction
- elimination of sharp-edged extension parts
- integration of energy-absorbtion regions.

For the user of the motorized two-wheeler, additional constructive modifications are necessary to improve the take-off angle during collisions. A lateral protection should be installed to prevent injuries to the lower extremities.

The improvement of selfprotection by the use of a crash helmet

and protective clothing must be regarded as the most important measure in the accident prophylaxis. By optimizing the protective devices, directly attached to the body, measures for the collision partner, the own two-wheeler and the environment or the accident site would become more effective. The authors are of the opinion that the protective clothing in its present design, and already available in the market, does not give adequate protection. The leather clothing protects the motorized two-wheeler user only against soft-part injuries (OTTE - 22). A prevention of fractures has yet to be achieved by the fitting of special shock absorbers. Protectives should, therefore, be attached to very exposed body regions. The absorbing qualities of these protectives will prevent the pushing forces to exceed the maximum bio-mechanical tolerance, and thus achieve an injury reduction.

Cognitions from the above detailed injury analysis created a basis for the modification or development of the protective clothing, which have already been included in a special research and development project for a complete safety combination. The protective value of todays crash helmets (in accordance with ECE norm (23)) can be regarded as absolutely satisfactory. Integral helmets should, however, be used exclusively with modifications to the forehead and chin region. Users of all types of twowheelers (from mofa to motorcycle) are urgently in need of this protection.

The very high injury frequency to the head of cyclists urgently calls for an effective head protection. The survey demonstrates the fact that a half-shell helmet does not adequately provide this protection. It is evident that an optimal head protection for cyclists is required, also designed as a type of integral helmet, but of a lighter weight, and maybe modified in design. Beyond this, cyclists should wear protective clothing, not necessarily of leather, but in modern style, made of material of tensile strength, and fitted with protective bolsters.

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