Head Injuries in Moped and Bicycle Collisions
Implications for Bicycle Helmet Design

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ABSTRACT

The effectiveness of crash helmet wearing for riders of heavy motorcycles is not a matter of serious discussion in the public. Wearing rates of up to 95% are usual. On the other hand, crash helmets are not very commonly seen with mopedists and the wearing of a helmet for a non-racing bicyclist seems to be out of discussion for most people. (A moped is defined in Switzerland as a motorcycle with 50 ccm and a maximum speed of 30 km/h, also called "mofa"). However, data on head injuries within the latter two categories strongly suggest the usage of suitable head gear.

After a literature review on head injuries with light two-wheelers and helmets the results of three different in-depth studies with a total number of 940 cases (243 bicycle and 697 moped accidents in the Canton of Zurich) are discussed as to 1. the exact localization of head impacts with bicyclists supplying data for the design of suitable helmets for bicyclists (1. study), 2. the difference in severity of head injuries with bicyclists and mopedists (2. study), and 3. as to the general injury severity and location with mopedists (3. study).

I. Introduction and Literature Overview

The protective effect of crash helmets for motorcyclists is proven sufficiently and has therefore not to be reitertated here. A part from that, a number of studies draw attention to the particular risk of suffering head injuries for drivers of mopeds and bicycles.

a) Mopeds

- Reich et al. (1975): It is highly probable that 51% of injured riders of mopeds would have survived had they worn a helmet.

- Walz et al. (1976): Most frequent cause of death in moped accidents in the city of Zürich are head injuries (70 %). Helmets should be made mandatory for mopedists also.

- Löffelholz et al. (1977): There can be no doubt as to the protective function of helmets for riders of mopeds. With a wearing rate of 100% there would have been 140 casualties, 2200 severely injured and 4400 slightly injured persons less in Germany in 1976.

- Otte (1980) requests mandatory helmet wearing for riders of mopeds and suggests the usage of protective helmets for all two-wheelers. Cyclists show head injuries of the same severity as motorcyclists.

- Suren et al. (1980): Because of low impact velocity, riders of mopeds more frequently suffer primary head impact against the car they hit. As a consequence there is a substantial accumulation of head injuries.

- Langwieder (1982): Low operating speed of mopeds does not reduce the risk of being injured. Moped riders suffer even from more head injuries than motorcyclists. Wearing a helmet should become mandatory for moped riders as well.

b) Bicycles

- Otte (1980): Cyclists show head injuries of the same severity as motorcyclists.

- Hoekstra (1984): Based on a comprehensive EEVC report wearing of a (specially designed) helmet is recommended.

- Kroon et al. (1984): Bicycle accidents increased significantly during the last 5 years and are now responsible for the largest group of casualties in the Göteborg area.

- Chamouard (1984): A bicycle prototype helmet withstanding impact velocities of up to 5.4 m/s against a rigid flat surface was presented. Special attention was given to aerodynamics and free air flow between the inner upper shell and the top of the head to avoid heat congestion.

- Dorsch (1984) proves that the risk for cyclists of suffering fatal head injuries can be reduced by 80% if bicycle helmets with hard shells are worn.

II. Injuries to Unhelmeted Moped and Bicycle Drivers

Three studies were conducted on the subject of two-wheeler accidents, special attention being given to head injuries. One focussed on the localization of head injuries of bicycle riders in view of developing a functional bicycle helmet, a second one compared head injuries of unhelmeted riders of bicycles and mopeds and the third study analyzed the injuries to moped drivers in general.

a) Accident Rates

Overall accidents in the Canton of Zürich (excluding the cities of Zürich and Winterthur) in 1982 present themselves as follows:

5050	traffic accidents
2243	injured persons
119	fatalities

Injured persons and fatalities can be broken down as follows:

Category	Number of injured	Killed (excl. one collision bus-train with 40 deaths)
Bicyclists	235 (11%)	6 (8%)
Mopedists	367 (16%)	7 (9%)
Motorcyclists	343 (15%)	8 (10%)
Car drivers	974 (43%)	40 (50%)
Pedestrians	247 (11%)	17 (42%)
Others	77 (3%)	1 (1%)
Total	2243 (100%)	79 (100%)

Figure 1 : Share of injured (N=2243) and killed road users (N=79+40) in the Canton of Zürich 1982

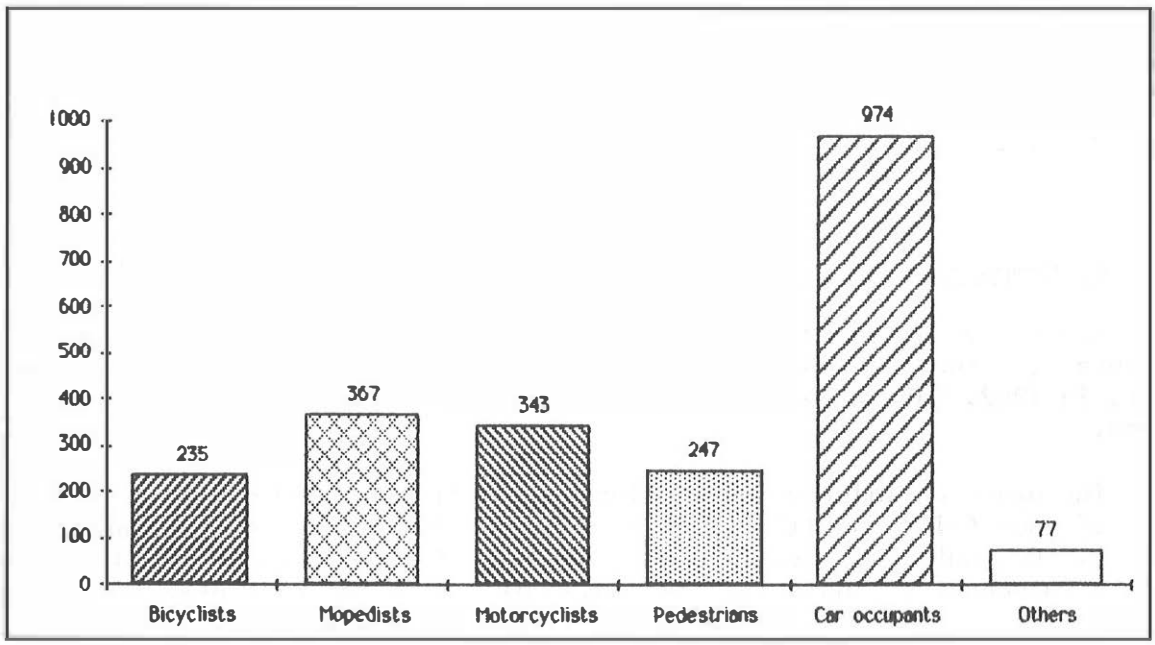

Figure 2 : Share of injured road users (N=2243) in the Canton of Zurich 1982

For two-wheeler accidents, it becomes apparent that, in Switzerland as a whole, absolute figures of injured and killed riders of mopeds and bicycles taken together surpass those of motorcyclists: In 1982, 2559 cyclists, 5024 moped riders and 5185 motorcyclists were injured. Fatally injured were 75 bicyclists, 144 riders of mopeds and 159 motorcyclists (see Figure 3).

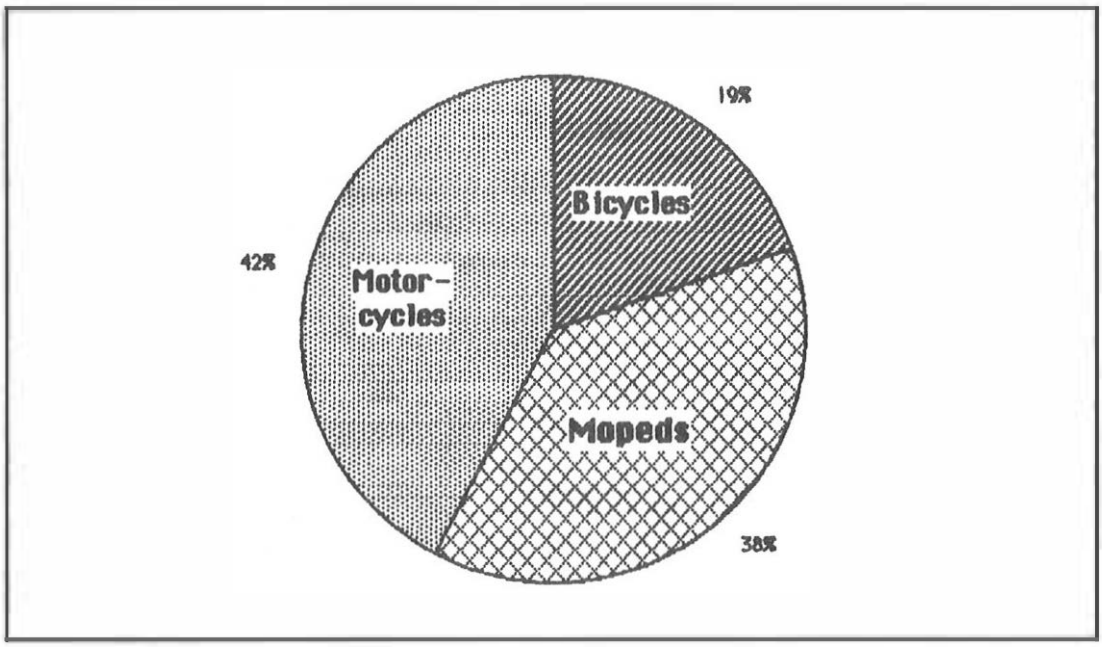

Figure 3 : Share of killed different two-wheelers in Switzerland 1982

b) Comparison of Injur y Severity with Mopedists and Bicyclists

One study was based on 228 accidents of unhelmeted bicycle and moped drivers in the Canton of Zürich, excluding the cities of Zürich and Winterthur, in 1982. Data were gathered by means of police reports and hospital files.

The group of injured two-wheelers was made up of 109 cyclists (43% children of age 6-15) and 119 riders of mopeds (43% adolescents between 16 and 25 years). One out of 50 cyclists and one out of six riders of mopeds was under the influence of alcohol (i.e. over 0.8% blood alcohol concentration).

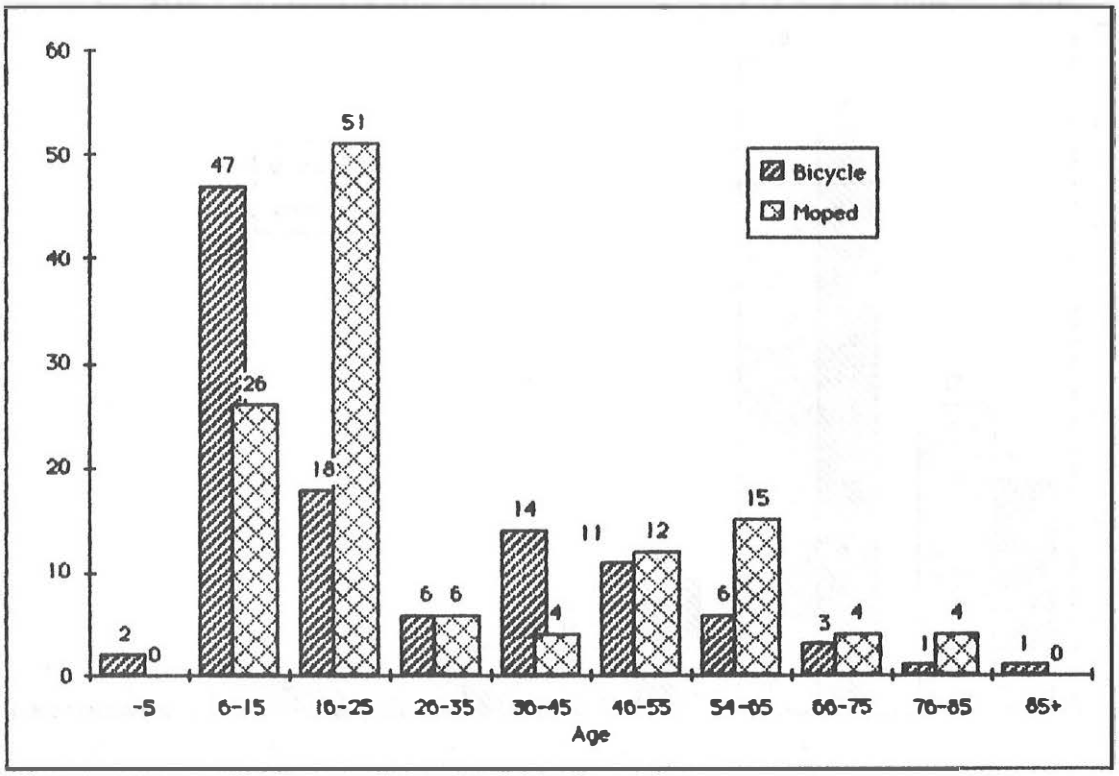

Figure 4 : Age distribution of light two-wheelers

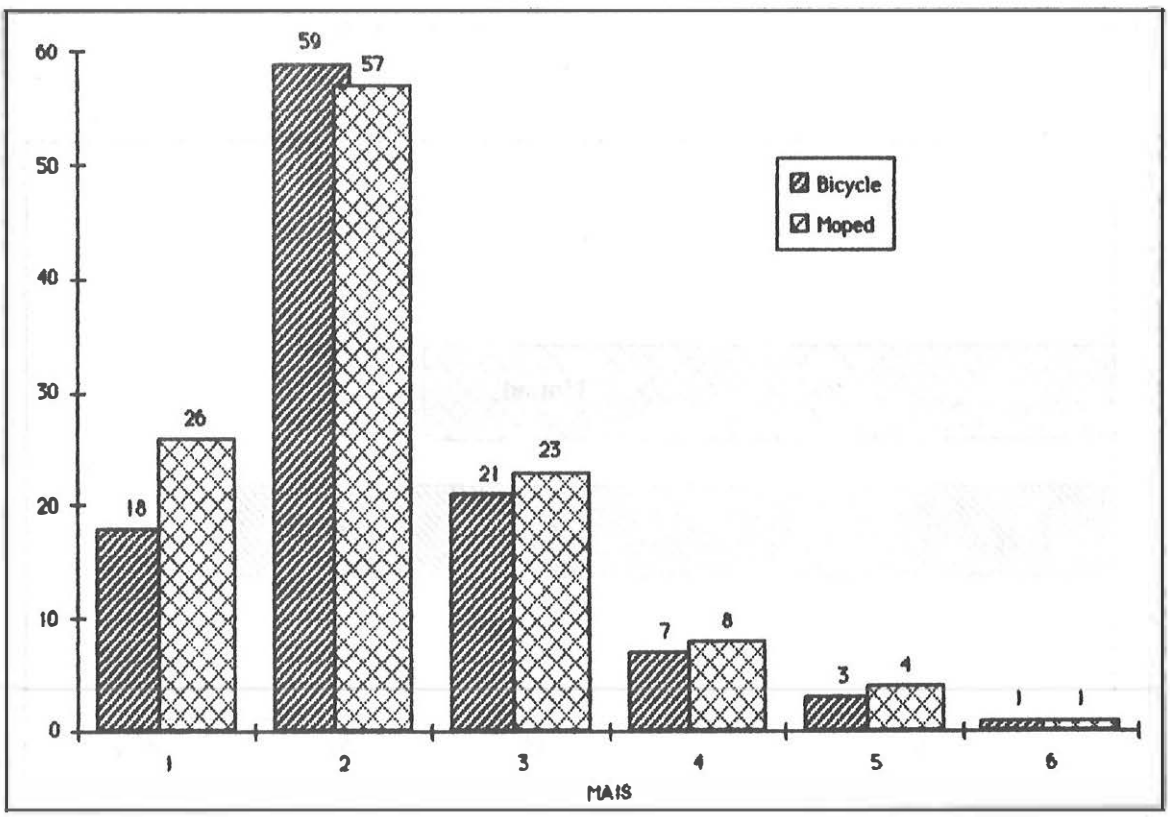

Figure 5 : MAIS distribution among light two-wheeler categories (overall severity)

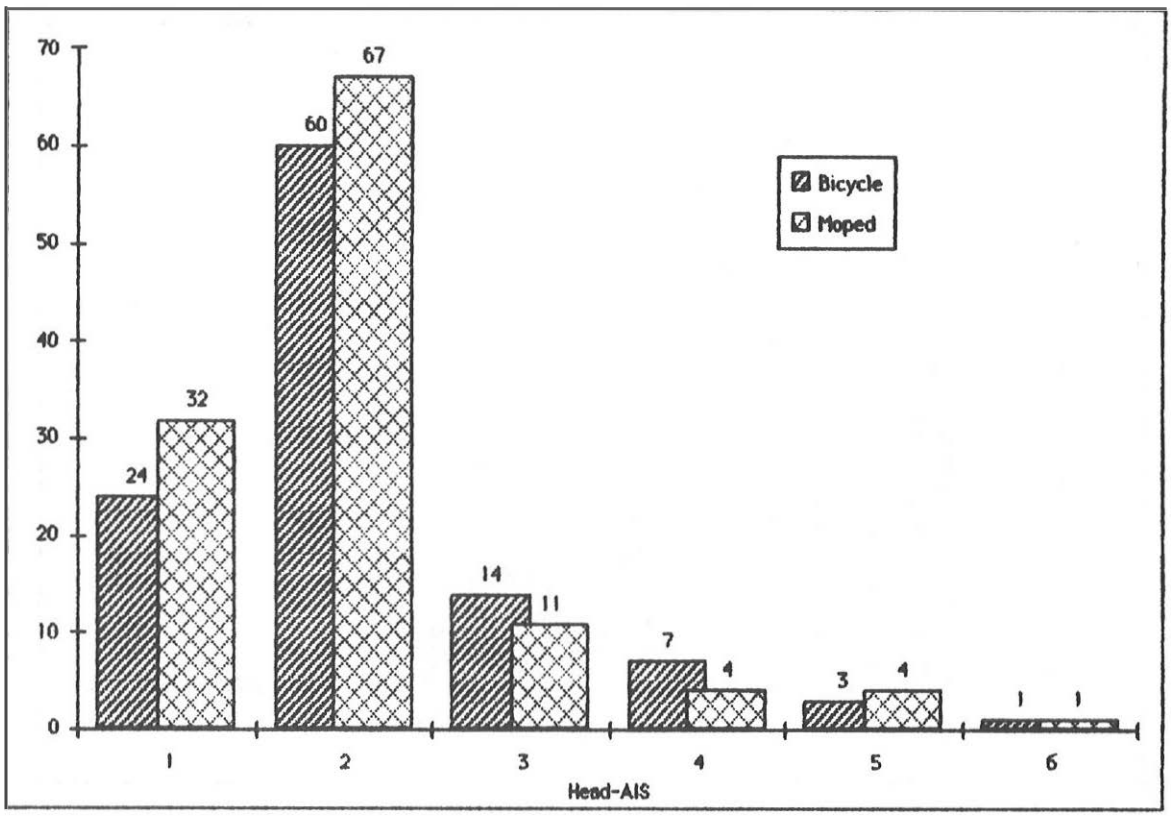

Figure 6 : Head-AIS among light two-wheeler categories

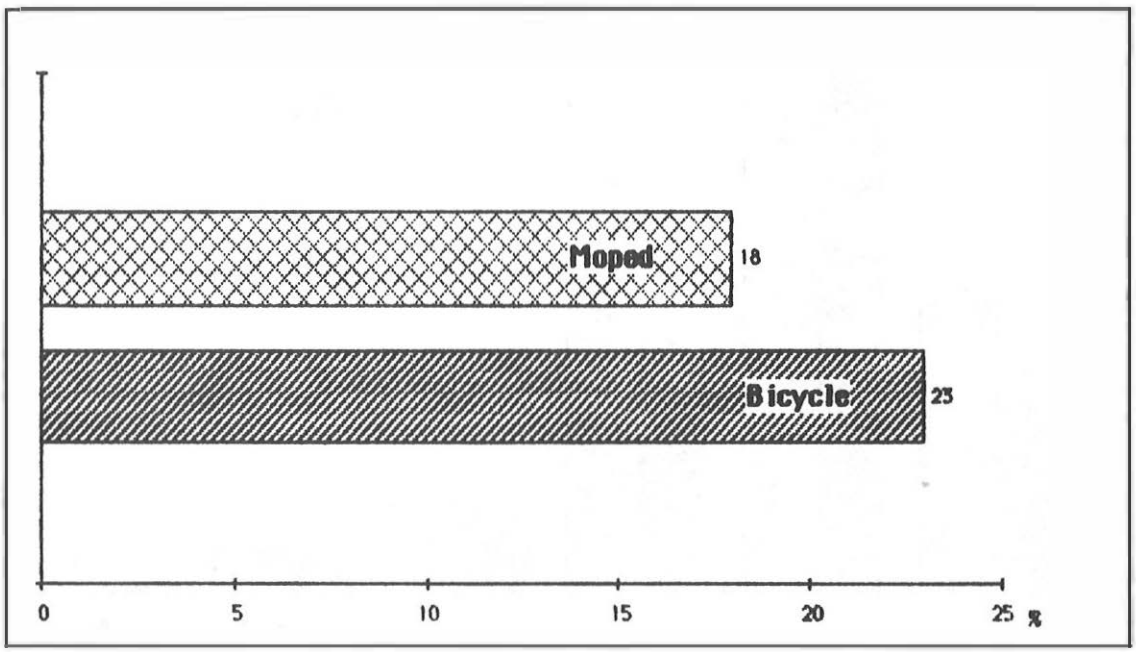

Figure 7 : Share of severe head injuries (head AIS 3-6) of all head-injuries

Minor to moderate head injuries were recorded in 77% of cyclists and 82% of mopedists. Severe head injuries (head AIS 3-6) were observed in 23% of cyclists and 18% of moped riders (Figure 7). The Chi-Square-Test did not show any significant differences concerning either head AIS or MAIS (overall injury severity) for the two light two-wheeler categories.

It is commonly believed that motorcyclists run a higher risk of being injured than riders of bicycles and mopeds. However, "slow" cyclists run a high risk through collision with other vehicles (usually cars) that are responsible for the resulting collision speed. There was a striking number of severe injuries such as brain contusions and fractures of the base of the skull among bicycle riders.

c) Localization of Head Injuries in Bicycle Accidents

In Switzerland, the obligation for motorcyclists to wear a helmet was introduced in July 1981, accompanied by a recommendation to do so for riders of mopeds. Even though it is out of question to extend this obligation to cyclists, we should consider whether it makes sense for bicycle riders to wear some sort of head protection. Since 1973, the number of bicycles, together with the number of injured cyclists, has risen continuously in Switzerland.

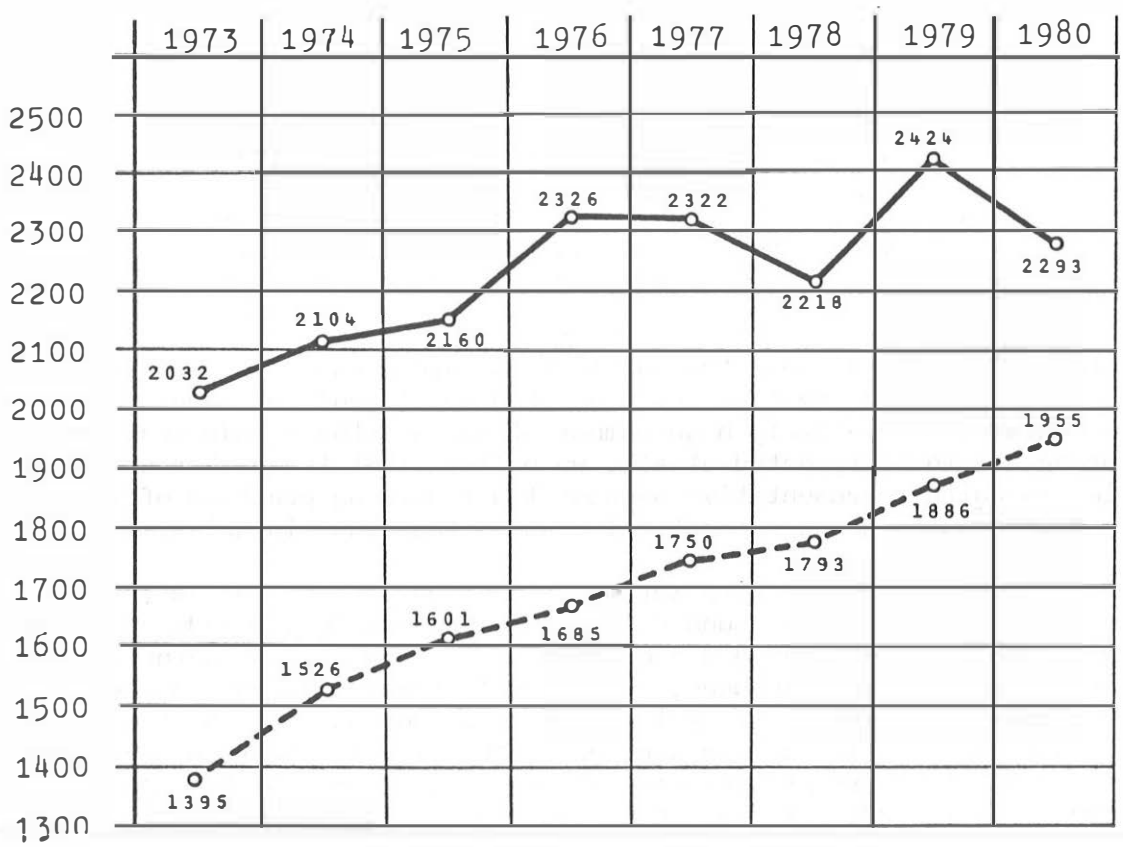

Figure 8 : Number of bicycles in 1000s (----) and injured cyclists (——) in Switzerland from 1973 to 1980

Studies on two-wheelers, especially bicycle accidents, show that more than half of the injuries due to accidents are located in the head region.

While in the US and in Australia bicycle helmets have become relatively frequent, in Europe, head protection measures are applied almost solely in bicycle races. Such protection usually consists of leather rolls, a hockey or a mountaineering helmet. There are a few specially designed bicycle helmets. The question remains, however, whether these helmets really offer protection at the places where most accident injuries are located.

Data Material

Every police report of the City police of Zürich in 1980 was checked and the relevant data on bicycle accidents were extracted. Descriptions of injuries were obtained from hospital files. From a total of 51 cases with head injuries, additional written information could be obtained in 27, additional information by telephone in 12 cases. In 4 cases, the localization of head injuries was unknown or too inaccurate. The sample is assumed to be rather complete as to injuries of AIS greater than 1; however, it is known from other studies that especially single accidents of bicycles with minor sequelae are underreported to a great deal (Kroon 1984).

Results

Sample of bicycle accidents during one year in Zürich:

Fatalities		2 (1.5%)
With Injuries	99 (74%)	
With Head injuries		51 (38%)
No injuries	35 (26%)	
Involved in accidents	134 (100%)	

Kroon et al. (1984) pointed out that in some areas 75% of all bicycle accidents (the minor ones) are not reported to the police; however, since our sample contains a relatively high number of cases without injuries (26%) which are prone not to be reported at all, we believe that the number of cases with injuries is quite representative because the reporting practice of the Zürich police is obviously quite accurate also as to the minor injuries.

In 105 collisions, 88 cars were involved. 50% of persons with head injuries were involved in such collisions. Motorcycles, mopeds and bicycles, trucks and pedestrians played a secondary role as collision partners. 22% of the accidents were self-induced, i.e. bicycle riders had caused them themselves for lack of attention. 17 cyclists fell for no apparent external reason. In 22 out of 29 self-induced accidents, the bicycle rider suffered head injuries, a visible overrepresentation of head injuries: 43% of head injuries were caused by the 22% self-induced accidents.

Age distribution of the accidents investigated corresponds rather well to literature findings. 44% of those involved in accidents were under 20 years. Children from 10 to 14 are particularly endangered: there were 16 children with head injuries in a total of 19 injured children. 57% of all injuries rated AIS >= 2 were confined to the head; with mopedists the corresponding share was only 46% (Kosik 1978) (figures see Appendix). For 96 injuries, the head was the body region injured most often. Lower extremities (48 injuries) were second and upper extremities (36 injuries) third.

Among the two fatalities, one AIS 6 injury of the head was found, a contusion of frontal lobe, cerebellum and brain stem with fractures of the base of the skull through all cranial fossae. The patient died three days after the accident. The other fatal injury was confined to the thorax.

No head AIS 5 was registered, and 1 AIS 4. The cyclist concerned suffered bilateral longitudinal pyramidal fractures with otoliquorrhea, bilateral calvarial parietal fractures and a paresis of the facial nerve. For the purpose of graphic description of head injuries, the different types of injuries were transferred to a head model (Figure 9).

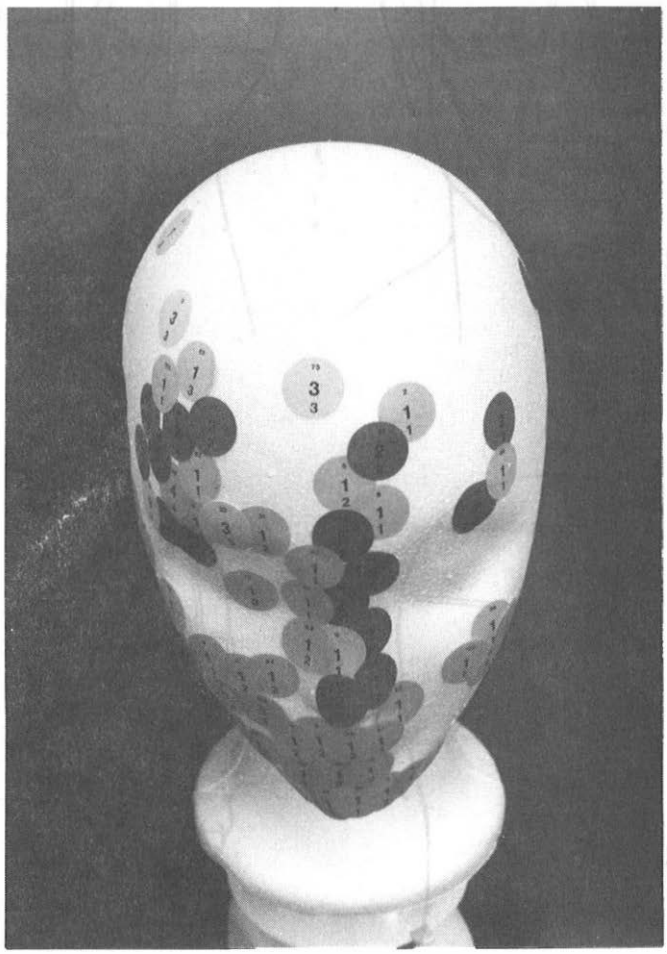

Figure 9 : Head model with impact locations and subsequent head injuries AIS >= 1
The central figure indicates the head AIS resulting from this impact. The upper figure stands for case number, the lower for the MAIS.

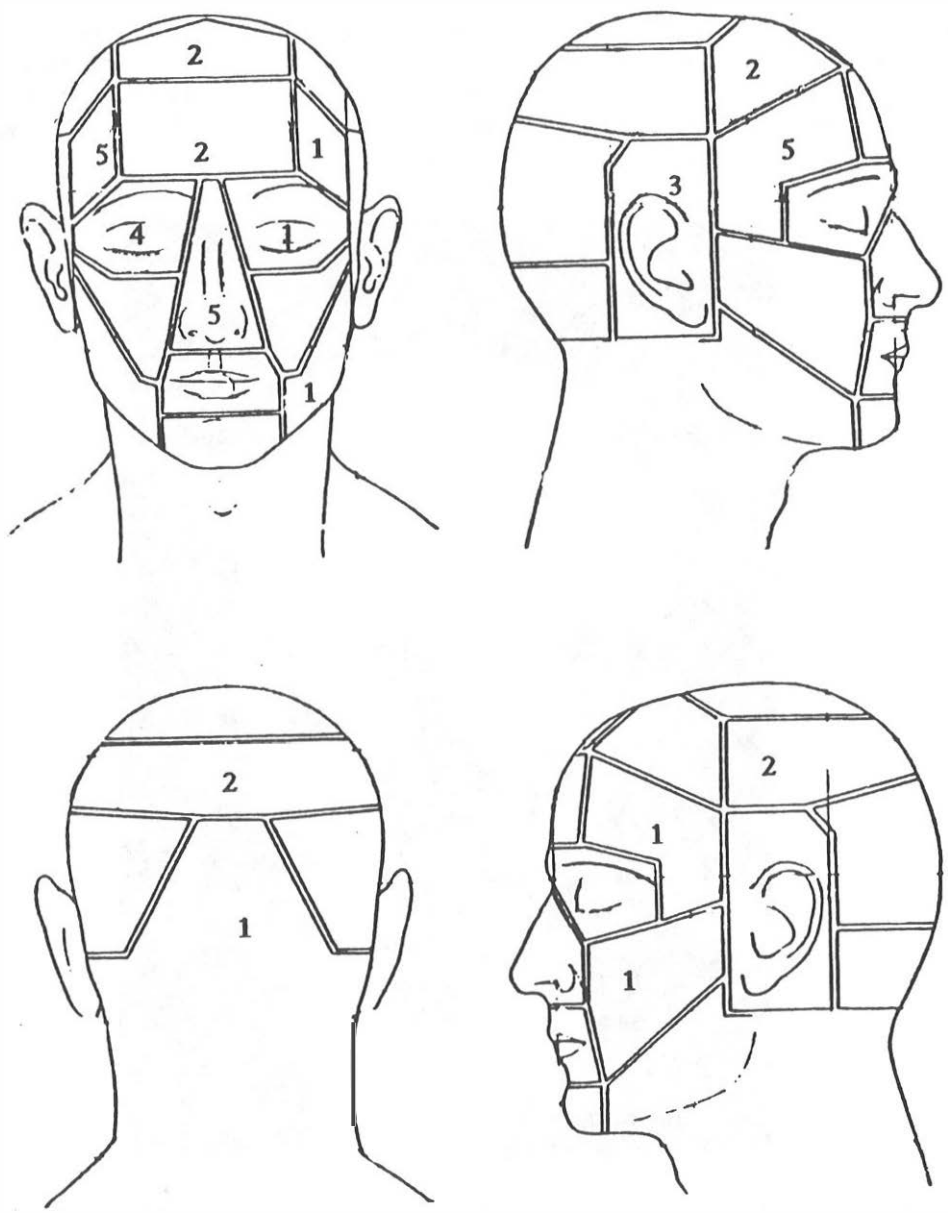

Figure 10: Number of impact locations with subsequent head injuries AIS >= 2

Considering the frequency of injury of different head regions, it appears that 78% of head injuries are found in the face. Most affected were the regions of mouth, nose, chin, right cheek bone and right eye. Studies on motorcycle accidents report comparable figures (Thomas 1977). The right half of the head (41% of injuries) was distinctly more involved than the left half (11%). Only 6.3% of injuries were located at the occiput. It is remarkable that no injuries at all were found in the upper head region (vertex, parietal superior). Otte (1984) found among 152 impacts on motorcycle helmets only 6 on the vertex area (= 4%). Similar results were also published by Mohan et al. (1984) and Harms (1984).

Urban traffic involves many dangers for bicycle riders, even though they usually do not reach high velocities. However, the impact speed of the colliding car is decisive for the seriousness of an accident. For this reason, and because of high head involvement in accident injuries, an efficient head protection - on a voluntary basis - must be recommended for cyclists with the same emphasis as for riders of light and heavy motorized two-wheelers.

To date, there is no Swiss quality lable for bicycle helmets. A recommendation by the Swiss Council for Accident Prevention (bfu), based on American and Italian standards, is available since spring 1985.

On the basis of the mentioned head injury localizations and general considerations, we can give the following requirements for bicycle helmets:

I. The helmet must be light (ca 400-500 gr at maximum) in order to be of minimal discomfort to the physically active bicycle rider.
II. Ventilation of the head surface must be guaranteed to avoid heat congestion.
III. As the upper head region (vertex, parietal superior) does not show injuries, ventilation apertures for the head surface may be located there.
IV. Especially face region and sides of the head must be protected.
V. As most head injuries are found among 10 to 14 year-olds, it is important to provide corresponding helmet sizes.
VI. Like helmets for mopeds and motorcycles, the hard shell of the bicycle helmets should be attractively shaped and colored.

Summary

The hazard of motorcycle driving is generally acknowledged. Especially with regard to very high usage rates of crash helmets within this group more emphasis should now be given to prevention of head injuries of mopedists and bicyclists. 10% of all fatalities in the Canton of Zürich were motorcycle accidents while bicyclists and mopedists accounted together for 17% of all killed road users. Low driving speed capacity of the two-wheeler is not a sufficient protecting measure against head injuries. Several ways of analyses showed a similar involvement of moderate and severe head injuries with bicycles than with mopedists: with bicyclists 57% of all injuries rated AIS >= 2 were confined to the head; with mopedists the corresponding share was 46%. The percentage of AIS >= 3 head injuries among all head injuries was 23% with bicyclists and 18% with mopedists. Both differences were not statistically significant.

In terms of MAIS (overall injury severity) as well there was no significant difference in injury severity of bicyclists and mopedists.

Injured bicycle users were found particularly in the age group 6-15 years and injured mopedists were predominantly between 16 and 25 years old.

Head impacts with bicycle users were located mainly on the middle and the right side of the upper face. Not one impact on the vertex of the skull was found among all 134 bicycle accidents during one year in Zürich.

Head injury frequence and severity among the "slow" two-wheelers (mopeds and bicycles) are underestimated not only by the public but also by the autho-

rities. The request made in literature for an obligation to wear helmets for riders of mopeds, must absolutely be supported. Since rather sufficient data on accident circumstances and especially on the localization of head impacts with bicyclists are known the wearing of bicycle helmets with a hard shell should be promoted in order to motivate people to voluntarily usage (especially important for hobby racing cyclists on normal roads and children from 10 to 14).

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APPENDIX

		Bicycles		Mopeds	
		Study 1	Study 2	Study 2	Study 3
Head:	AIS 1	66	32	32	174
	AIS 2	23	60	67	63
	AIS 3	5	14	11	4
	AIS 4	1	7	4	1
	AIS 6	1	4	5	6
Arm:	AIS 1	28			96
	AIS 2	8			15
Thorax:	AIS 1	9			15
	AIS 2	-			9
	AIS 3	-			7
	AIS>4	1			1
Back:	AIS 1	2			
	AIS 2	1			
Shoul-	AIS 1	5			20
der:	AIS 2	3			1
	AIS 3	1			
Abdomen:	AIS 1	1			2
	AIS 2	-			1
	AIS>4	1			-
Legs:	AIS 1	40			231
(incl.	AIS 2	5			41
pelvis)	AIS 3	3			13

Participation of body regions in a total of 940 casualties.
Study 1: Burkart (1984), 134 bicycle accidents
Study 2: Dubas (1984), 109 bicycle and 119 moped accidents; focussed on head injuries only
Study 3: Kosik (1978), 578 moped accidents.
All three samples are based on police and hospital reports; for severe injuries there is virtually no bias.