UTILISATION OF SECURITY HELMETS FOR TWO-WHEELED VEHICLE RIDERS

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SUMMARY

This report deals with safety helmets of two-wheeled vehicle riders in the European Community.
Recommendations are described and presented regarding:

- the improvement of the safety of drivers/passengers of two-wheelers by the use of a helmet, subsequently recommendations on the raise of the positive effect of the helmet.
- the description of an ideal situation in the field of a common legislation on behalf of the safety requirements on the helmet and on its use.

These recommendations are based on:

- description of the existing situation in EC Member States regarding the legislation on the use of helmets and on the requirements to be met by helmets
- background-data in the twelve Member States on the ownership and use of two-wheelers and on accidents and casualties among drivers and passengers
- scientific knowledge e.g. on injuring due to traffic accidents of drivers and passengers of two-wheelers, divided into users and non-users of helmets.

The information for the report was obtained in two ways. Firstly, a questionnaire was sent to the twelve EC Member States (Annex 1). Secondly, the relevant literature was collected and studied.

Of the 12 EC countries, two countries failed to provide any information. In some cases, the questionnaire was not completed in full. Efforts were made to obtain the missing information by other means.

The survey among the twelve Member States learns that the number of categories of two-wheeled vehicles per country (including bicycles) varies from three (Denmark, Ireland and Luxembourg) to six (Federal Republic of Germany). However, the categories themselves differ from one country to another. There are also sharp differences in regulations on maximum speeds and the minimum age of the riders (Table 1).

The proportion of cyclists in the total number of road accident casualties is highest in the Netherlands (20.6% of fatalities, 22.9% of injuries), followed by Denmark (12.2% and 19.4% respectively). Lowest proportion are reported in Greece: only 1.4% of fatalities and injuries and in Spain (1.8% resp. 1.4%).

The relative amount of moped casualties is highest in the Netherlands (8.8% of fatalities and 22.7% of injuries) and lowest in Great Britain (1.5% of fatalities and 3.3% of injuries). The proportion of motor cyclists (> 50 cc) in total accident killed is highest in Luxembourg (25.0%), followed by France (16.4%) and Great Britain (15.7%) and lowest in the Netherlands (4.5%).

Interpretation of a comparison of accident statistics for motorized two-wheeled vehicles is made more difficult because of the variations in categories, as shown in Table 1.

Head injuries are by far the most common type of injury suffered by cyclists in road accidents, followed by leg injuries. The percentage of moped riders who suffer head injuries is significantly lower. A difference in the percentage of head injuries between cyclists and moped riders is also reported in other studies.

Helmets are an accepted method for the protection of most motorized two-wheeled vehicle riders in almost all EC countries. Until now no legal obligation exists in Spain for moped riders and for light motorcycles (between 50 and 75 cc) outside urban areas.
Compulsory use by pedal cyclists exists in none of the Member States.
In Belgium, FRG and the Netherlands, there is a category of two vehicles with a maximum speed of 25 km per hour. Riders of these vehicles do not have to wear helmets in traffic.

A large number of studies have been conducted into the effects of wearing helmets. All of them conclude that helmet-wearing has a positive effect in terms of reducing the chance of head injuries in a road accident and as a result in a reduction of casualties.
The estimated reduction in the number of casualties after helmets become compulsory varies from 10% to 50%.

The risks of (fatal) head injuries for those who do not wear helmets in traffic are, on average, four times as high as for those who do.

Research provides no support for the alleged negative effects of helmets, such as reduced perception of sound signals and a reduced field of vision. Studies show that, as for riders of motorized two-wheeled vehicles, helmets are a highly effective method of protection for pedal cyclists.

The risk of a fatal head injury is three to ten times as high for a pedal cyclist who does not wear a helmet as for one who does.
Adapting the fronts of passenger cars may reduce the severity of (head)-injuries of pedestrians and cyclists in case of a collision to the same level as helmets do. At present a Working Group of EEVC is working on a concept regulation.

In Belgium, the Netherlands, Britain and the FRG (with the exception of the 'MOFA'), all riders of two-wheeled vehicles wear helmets if these are compulsory. In Denmark, 99% of motorcyclists and 85% of moped riders wear helmets. In France, helmets are worn by 98% of motor cyclists and 88% of moped riders. There is no information on helmet-use for Greece, Ireland, Italy, Luxembourg, Portugal and Spain.

A number of accident studies report the fact helmets sometimes came of the head in an accident. A number of activities were started as a result, including research into the construction of helmets and the use of chin straps.
On the basis of research, a test procedure has been included in the international certification standards for helmets (ECE 22) to check whether a helmet will come off.

A study in the Netherlands shows that even when helmets are worn, this is not always done in accordance with the law. Moped riders, in particular, do not always make (optimal) use of chin straps: 15% did not fasten the straps at all, while 50% fastened them so loosely that the helmet could not always be expected to remain in place in an accident and therefore in no way provided optimal protection. In the FRG a similar study has been conducted. The results corresponded to the Dutch ones. There is no information on this matter from the other countries and additional research is to be recommended here.

The results of research into fastening of chin straps strongly indicate that ergonomic and comfort factors are the reasons why straps are not fastened. Particularly important are the chin guard and type of fastening on the use of chin straps, as well as the large number of moped riders who do not fasten straps tightly enough. It seems that the problem could be solved by the sale of helmets which cause discomfort when chin straps are not fastened and are comfortable when they are. Replacement of the buckle system by push button fastenings would already be considerable improvement.

If efforts are made to find a standard fastening system, the problems created by many different fasteners and the related difficulties in effective first aid would also be solved.

The condition of the helmets was also investigated in the Dutch study. This showed that 19% of the helmets had no certificate of approval. The number of helmets without a certificate rises with age. However, a remarkable 13% of helmets less than a year old had no certificate.
Almost 30% of the helmets studied carried transfers or had been painted by the wearer.
Accident studies show that in identical circumstances, the outer shells of helmets with transfers or a layer of paint break much more easily than those which have not been touched. More over, the average number of severe head injuries is higher in the first group than in the second.
On this basis, it seems that a large proportion of Dutch moped riders are wearing helmets in which the outer shell can probably no longer offer the statutory standard of protection.
At the request of some consumer organisations: Consumentenbond and ANWB (The Netherlands); Stiftung Warentest (FRG); Verbruikersunie (Belgium); Forbrukerrådet (Norway) a research was carried out concering the quality of helmets for sale. It appeared that one third of the helmets did not fulfill the requirements of ECE 22 (Consumentenbond, 1989).

In most EC countries, helmets worn in traffic by riders of motorized two-wheeled vehicles must meet the ECE 22 international standard (currently Version 03).
Some countries, such as Britain and France, use their own standards which differ from ECE 22.

The main properties for which helmets are tested in inspection procedures are shock absorption, rigidity, resistance to penetration, the retention system and roll off. No ergonomic or comfort requirements are set.

Although the ECE 22-03 and the British BS 6658 differ on a number points, both can generally be said to contain valuable elements. The BS 6658 seems to be somewhat more up-to-date than the ECE-standard.

There are some national standards for cycling helmets, including European ones (British and French). As yet, there is no ECE certificate of approval for these helmets.

For some time the generally-used head injury criterion (HIC) has been exposed to criticism, but at present, no acceptable alternative is yet operational. The necessary developments are in progress, but better understanding of the causes of head injuries is needed in efforts to produce an optimal helmet.

Research shows that existing helmets are too rigid for lower impacts. The use of new materials which offer good absorption at both high and low levels of shock could counter this criticism. Several shock absorption tests would have to be conducted, including tests at lower speeds of collision, within the test procedure.

The outer shell of a helmet is exposed to UV radiation and chemicals. It is also known that the mechanical properties of some plastics change in time. Research into this phenomenon is recommended.

At present a European Committee for Standardisation (CEN) Technical Commission (TC 158; 'Protective helmets') is drawing up standards for helmets at the request of the Commission of the European Communities (Directorate General III, Internal Market and Industrial Affairs).
The activities are divided over four groups and will involve the preparation of standards for industrial safety helmets, vehicle users' helmets, fire fighters helmets and pedal cycle helmets. Existing requirements will be used as a basis for discussion in each group. Some of the work of these groups, which is still at a preparatory stage, closely corresponds with the objectives of this study. It would be advisable for all EC Member

States to be involved in drawing up requirements aimed at one European certification standard for helmets.

CONTENTS

1. INTRODUCTION

From theoretical considerations and from research it is evident that the use of a helmet leads to less and less serious head injuries for moped riders, if it is worn correctly and meets certain requirements.
In a number of countries the use of a helmet has become compulsory for motorized two-wheelers (drivers and passengers).

In a number of countries of the European Community (EC) the use of a helmet is compulsory for drivers and passengers of all categories of motorized two-wheelers, in some others only for certain categories. Moreover the member states of the EC have a different categorization for motorized two-wheeled vehicles.
In some countries of the EC the requirements to be met by helmets are those imposed by ECE 22-02. In other countries there are national requirements.

In no country of the EC it is compulsory for cyclists yet to use a helmet, though in some countries requirements are being developed for helmets for cyclists.

The obligation to use a helmet is not always complied with, but an overview of the situation in the EC countries does not exist.
From recent SWOV research in the Netherlands the helmet appears to be used nearly always, but in such a way that there is a good chance that the helmet comes off from the head in an accident. One of the main causes is the inaccurate use of the chin strap.
From contacts with other countries and from (not yet published) research inaccurate use of the fasteners appears to exist there also.

A number of studies has been completed on the (positive) effect of a helmet. These studies were executed in some countries during the introduction period of the compulsory use of the helmet. They give an impression of the effect of the introduction of the obligation on the number of casualties. Especially in the USA where the compulsory use is decided on per State and where in some states the obligation was on and off, studies on the effect have been carried out.
Moreover studies have been made of the influence of the helmet on the injury risks and injury patterns of the casualties.

The effect of the use of a helmet by bicyclists only has been described in a few studies.

2. PURPOSE OF THE STUDY

Within the EC there is no unanimity in the field of legislation on the use of a helmet by two-wheel drivers and passengers. An overview of the situation in the member states is lacking.
The requirements to be met by helmets are also different in the various countries.
The EC has asked SWOV to make a study. The purpose of the study is:
To give a description of the state of the art in the member states of the EC concerning the legislation and the use of helmets by two-wheeler drivers and passengers in road traffic.
To collect and study scientific (medical and biomechanical) reports from the member states of the EC and some other countries on injuries due to traffic accidents of drivers and passengers of two-wheelers, divided into users and non-users of helmets.

On the basis of the existing situation and of the analysis of the results reported in literature recommendations must be given regarding:
The improvement of the safety of drivers and passengers of two-wheelers by the use of a helmet and to raise the positive effect of the helmet.
The description of the ideal situation in the EEC: a common legislation on the safety requirements for the helmet and on its use.

3. SET UP OF THE STUDY

The study consists of four parts:

1. A written survey (see Annex) of authorities among the EC member states, like national statistic agencies, research institutes, Ministry of Transport on:
- Effective legislation on the use of helmets in road traffic by drivers and passengers of two-wheelers according to types of vehicles (bicycle/-moped/motorcycle) and helmets.
- The effective legislation on the requirements to be met by helmets used in road traffic (e.g. ECE 22-02 or a national standard).

2. The collection of data in EC member states on:
- The use of helmets by two-wheelers, divided into types of vehicles, drivers or passengers and ages.The use of the chin strap will also be investigated, because earlier SWOV research showed the importance of a correct use.
- The ownership and use of two-wheelers divided into types, related to the amount of motor vehicle traffic.
- The amount of numbers of accidents and of casualties among drivers and passengers of two-wheelers, subdivided into type of two-wheeler and use or non-use of the helmet in the accident.

3. The collection and study of scientific (medical and biomechanical) studies in the member states of the EC and some other countries, like the USA and Japan on injuries due to traffic accidents of drivers and passengers of two-wheelers, divided into users and non-users of helmets. Investigation whether there are specific injuries for non-users. The influence of the use of the helmet on the risk, pattern and seriousness of injuries as a function of the type of helmet and the type of two-wheeler.

On the basis of the data obtained comparative overviews will be produced in this report:
- Effective legislation in the EEC on the use of helmets by two-wheel drivers and passengers and on the requirements to be met by helmets.
- The number of two-wheelers, divided into categories.
- Compliance with the legislation on helmet use, by type of two-wheeler and age of driver and passenger.

- The number of accidents of two-wheelers, possibly divided into users and non-users of helmets and age groups.
- The results of the literature research.

4. On the basis of this report and SWOV assessment a coherent package of recommendations will be produced on the increase of safety for two-wheeler drivers and passengers using a helmet. Finally recommendations will be given for a harmonization of the legislation on the use of a helmet by motorized two-wheeler drivers and passengers and on the legal requirements to be met by helmets.

4. RESPONSE

Six of the twelve EC countries returned a completed questionnaire within two months whilst other countries had to be reminded repeatedly.
Two countries were extremely tardy in their response. In a few cases, questionnaires were not properly completed.
Some of the missing information was obtained from other sources, for example surveys published by the BASt, UN (1986) which were made available by the Royal Dutch Touring Club (ANWB) and the Dutch Standards Institute.

5. THE HELMET

A good description of the helmet and its constituent parts is given by Pedder et al. (1982):
'The obvious function of the helmet is to protect the rider's head in an impact situation. Ideally, the helmet should stay on the rider's head throughout the entire sequence and provide maximal protection against direct blows, sharp penetration and abrasive surface contacts. In addition to this primary role, the helmet should be comfortable and aesthetically acceptable to the wearer and it should be financially attractive to both manufacturer and rider. Finally, the helmet should fulfill the requirements of safety standards.'

Taking all these conditions into consideration, it is not entirely illogical that most helmets should be made up of the following parts:
1. The outer shell. The primary purpose of the outer shell is to distribute the impact load over a large area. It may also provide resistance to penetration by sharp objects and protect the rider's head from abrasive surfaces. In addition, the shell may absorb some of the energy of the impact.
2. The protective padding. The main purpose of this padding is to absorb the impact energy. The energy absorption is achieved through the complete or partial destruction of this material.
3. The comfort padding. This padding is to ensure that the helmet is a comfortable fit and to accommodate different head shapes.
4. The retention system. Designed to hold the helmet in position on the rider's head. The most popular method is straps. These are secured to each side of the helmet shell and secured under the rider's chin with a fastening device.

In principle, three types of helmet can be distinguished; the partial coverage helmet, which covers only the part of the head above the ears, the jet helmet, which covers almost the entire head, with the exception of the face, and the integral helmet, which also covers part of the face (Figure 1).

6. STATISTICS

This section provides a review of the extent to which the various categories of two-wheeled vehicles are used, of their safety on the road, expressed in terms of the number of deaths and injuries, and of the statutory requirements for wearing helmets in EC countries.
Most of the information was supplied by the countries themselves in questionnaires. Unfortunately, even after repeated reminders, the response rate was not as good as it could have been, so that some of the figures were obtained from UN (1986) national statistics (par. 6.2.1).
Par. 6.2.2 provides a review of accident data on two-wheeled vehicles, insofar as this is relevant to the use of helmets. This information is obtained from the literature.

6.1. Review of the use of two-wheeled vehicles in EC countries

The overall review of the categories of two-wheeled vehicles in the different countries and the extent to which they are used is given in Table 1.

The number of categories of two-wheeled vehicles in each country (including bicycles) varies from three (Denmark, Ireland and Luxembourg) to six (Federal Republic of Germany). But there are also national differences between the categories themselves. In total, there is a very wide range of categories of two-wheeled vehicles in EC countries. Maximum speed limits also vary enormously. For instance, an average moped with a cylinder capacity of no more than 50 cc can travel at a maximum of 40 km per hour in Belgium, Italy, Portugal and Spain (both within and outside built-up areas).

In Denmark the speed limit is 30 km per hour, in France 45 km, in Luxembourg 50 km and in the Netherlands 30 km per hour inside built-up areas and 40 km per hour outside.

There also a fair amount of differences in minimum ages for riders. The minimum age for the moped mentioned above is 14 in France and Italy, 15 in the FRG and 16 in other countries.

To ride a moped on a public highway in the FRG, Britain, Greece and Portugal, a license is required. In the other countries, the only requirement is age.

The number of the various categories of two-wheeled vehicles is shown in Table 3.

6.2. Review of accident statistics

A distinction can be made between the information normally gathered by the national statistical offices and information obtained from the literature.

6.2.1. National statistics

The data for this paragraph were largely supplied by respondents to the questionnaire. As there was not a 100% response, some information had to be obtained from other data files. Unfortunately, this means that it was not possible to collect all the data, which means that the squares for some countries are empty.

The absolute and relative numbers of victims in each category of two-wheeled vehicles is shown in Table 3 and 4.

The proportion of cyclists in the total number of accident victims is highest in the Netherlands (20.6% of fatalities and 23.5% of injuries), followed by Belgium (16.4% and 7.2% respectively) and Denmark (11.6% and 20.9% respectively).
The lowest relative proportion of cyclists involved in accidents is found in Greece.

Comparison of motorized two-wheeled vehicles is difficult, because of the large number of different categories.
The relative proportion of moped riders among accident victims is highest in the Netherlands (8.8% of fatalities and 22.7% of injuries).
The proportion of motor cyclists (> 50 cc) among total accident victims is highest in Luxembourg (25%), followed by Greece (19.6%), France (16.4%) and Britain (15.7%).

6.2.2. Accident studies

This paragraph provides a review of the information in the literature on injuries, the type of contact surface and whether the helmet stayed on during accidents. Some of this information derives from in-depth accident studies. The information provides a general insight into the protection which helmets must provide and the problems which can arise with this. The description has been sub-divided into a description of the injuries, the type of contact surface and whether the helmet came off in an accident.

1. Cyclists

A. Injuries

The foreign literature shows a wide range of injury classifications among injured cyclists. Differences in registration procedures, definitions and the severity of the injuries studied are obvious reasons for this.

Technisearch (1981) provides a review of the classification of injuries of 21,265 American cyclists admitted to hospital. This shows that head injuries are the most common type (36%), followed by injuries to legs (29%) and arms.

Walz et al. (1982) observed in 134 in-depth, at the scene accident studies with 99 cyclists that 51 of these victims suffered head injuries. The researchers defined a number of injury severity categories: admission to hospital, first-aid treatment and treatment by a general practitioner (GP). They found that the percentage of victims with head injuries rises with the severity of injury: GP treatment 27%, first aid 50% and hospital admission 79%.

Alruz et al. (1986) list the injury categories observed in the in-depth accident study in Hannover: 86% of all cyclists injured suffered head injuries, while 74% had injuries to lower limbs.

Huijbers (1984) surveys injuries to cyclists admitted to hospital in the Netherlands. This survey shows that head injuries predominate among cyclists (51%), followed by leg injuries (24%). The percentage of moped riders with head injuries was significantly lower (36%).

The difference in the extent and percentage of head injuries between cyclists and moped riders is also reported in other studies. The differences reported are as follows:

	Cyclists	Moped and Motorcycle riders
Nicholl et al. (1980)	75%	52%
Otte (1980)	85%	60%
Gratan et al. (1976)	48%	26%

B. Type of collision. Accidents

The collision opponents of cyclists are listed by the European Experimental Vehicles Committee (EEVC, 1984). In all the studies mentioned, cars are the most frequent collision opponents, rating from 50 to 90%.

C. Causes of injuries and type of contact surface

Injuries to cyclists are caused by impact with the collision opponent, the cycle itself and the environment. Some researchers have tried to determine the cause of the injury in collisions, not always specifically considering head injuries.

They found that if all injuries were considered, impact with the ground was the most frequent cause of injury, followed by impact with a passenger car. The cycle could be regarded as the cause of injury in just 6% of cases (Cross et al., 1977; Roland et al., 1979; Appel et al., 1979). When only the serious injuries were considered, impact with a passenger car took first place, followed by impact with the ground. The share of cycles was even smaller in these cases. Autopsies of cyclists involved in fatal accidents showed that in every case, the contact surface was a blunt one (Fife et al., 1983). No similar description of less severe injuries was found in the literature.

2. Motorized two-wheeled vehicles

A. Injuries

The division of injuries to riders of two-wheeled vehicles according to the type of vehicle is described by the countries taking part in an EEVC working group; FRG, Britain, France, Italy, the Netherlands and Sweden. In this report, it is stated that it is hardly possible to compare the reported injuries in accident studies because of some major differences, e.g. differences in levels of injury severity in the sample, or differences with respect to accident type. What matters are the main tendencies common to all studies and the differences between, and similarities in injuries in separate studies. When all injuries are considered, the arms and legs are the most frequently injured body areas. When the more severe injuries (AIS > 2) are taken into consideration, the head is the body area most frequently injured.

B. <u>Type of contact surface</u>

Beier et al. (1985) describe the results of an in-depth accident study conducted in Heidelberg (FRG). The data file consists of 120 accidents involving 145 persons, 142 of whom suffered injury. The minimum criterion for injury was that outpatient medical care was required.
Accident data were collected using an in-depth method and were classified according to the Motor Cycle Accident Severity Index (MCASI). The following elements play a role here: delta v, angle of impact, abrasiveness of the contact surface and the angle of motion of the motor cyclist.
The helmets were completely dismantled and measured from top to bottom.
Of the 142 victims, 82 were wearing helmets; 80 an integral helmet, one a jet helmet and one a partial coverage helmet.
Of the contact surfaces, 6% were sharp, 35% were angled and 59% were smooth.

Otte et al. (1985) list the impact points of helmets in accidents.

Pedder et al. (1982) reported that 'The 68 helmets that were fully examined had sustained at least a total of 135 blows.' In 41 (60%) of cases, the helmets had suffered two or more observable shell impacts.
In the light of the observation that polycarbonate helmet shells can sustain a blow without visible shell damage, the true number of shell impacts is likely to be higher.
Although it is difficult to distinguish different blows to the same site, individual impact marks on the helmet shell often overlapped.' However, the report makes no further statements on the extent of this phenomenon, saying only that modern impact liners can barely absorb a second blow.

In line with the comments of Aldman et al. (1978) on the occurrence of oblique impacts, the researchers reported that the ground was identified as a primary head impact source for 20 (39%) fatally injured riders.

C. Dislodging of helmets

Various studies report that helmets came off the head in accidents and thus offer little or no protection. A review of the literature showed the following:

According to Beier et al. (1985), 11 of 82 helmets came off the head in accidents. Of these 11, the chin strap was not fastened properly in 7 cases. Another two helmets were dislodged between the first and second blow. In total, only 69 helmets therefore offered protection.

Otte et al. (1985) found that 13.5% of helmet wearers lost their helmets in accidents: 0.6% before the first blow to the head, 7.7% after the first blow and 2.6% after the second blow. It was found that 16% of integral helmets, 18% of jet helmets and 25% of partial coverage helmets became dislodged.

Pedder et al. (1982) list the causes of dislodging. Half can be explained by shell break-up or retention system failure (objective evidence of overload and thus release of some part of the retention systems). The researchers themselves say of the causes in the other cases, for which there is no empirical explanation: 'Obviously there must always be some doubt about how the helmets were fastened prior to the accident. But it was reliably reported that at least eight of these helmets (of 33) were found with the chin straps still fastened.'

Whitaker (1980) reports: 'Helmet loss: 14 helmets came off when the strap was fastened, 12 of which were fitted with chin cups.'

White's data (1980) are drawn from the Michigan (Illinois) data base. This contains data on 4933 motor cyclists involved in accidents, some of whom (20.7%) were not wearing helmets. Of the 'partial coverage' helmets, 34% came off the head (57 of 113), and of the integral helmets, 7% (249 of 3298). The study did not show what caused them came off.

The effects of dislodged helmets on the severity of head injuries was reported. Riders whose integral helmets came off the head had significantly more severe head injuries than those whose helmets remained in place (chi-square 272.9, 4 df, $p<.005$). No significant difference existed between the head injury patterns of unhelmeted riders and the dislodged integral helmet group (chi square 0.16, 4 df, $p<.995$).

One possible cause of dislodging, faulty use of the retention system, is discussed in more detail in par. 7.2.

6.3. Review of statutory obligations to wear helmets in traffic in EC countries

In most EC countries, it is compulsory for riders of motorized two-wheeled vehicles to wear a helmet. At present, it is not compulsory in any EC country for pedal cyclists to wear a helmet. This issue is under discussion in some countries, but has not yet led to concrete legal measures. To some extent, this is probably due to the fact that there is strong opposition to the idea of cyclists wearing helmets. This is particularly true in countries such as the Netherlands, where bicycles play an important role as a means of transport.
It is compulsory in the Netherlands for racing cyclists to wear helmets in races. Partly because of this, the use of cycling helmets for recreational purposes by touring cyclists on sports cycles appears to be on the increase.

Table 2 shows the statutory obligations for riders and any passengers of motorized two-wheeled vehicles to wear helmets in EC countries. The table also shows the date on which the relevant legislation came into force.

In almost all EC countries, it is compulsory for riders and passengers of motorized two-wheeled vehicles which can travel faster than 25 km per hour to wear a helmet. An exception is Spain, where moped riders do not have to wear helmets and riders of motor cycles with a cylinder capacity of between 50 and 75 cc only have to wear helmets outside built-up areas
In some countries (Belgium, FRG and the Netherlands), there is a category of vehicles which may not travel faster than 25 km per hour. Riders of these vehicles do not have to wear helmets in traffic.

Most countries made helmets compulsory in the 1970s. The exceptions are France (1980), Luxembourg (1982) and Italy (1986).

7. COMPLIANCE WITH STATUTORY OBLIGATIONS

Compliance with the statutory obligation for riders of two-wheeled vehicles to wear helmets is described in par. 7.1. As it is not compulsory for cyclists to wear helmets in any EC country, this section will concentrate on riders of motorized two-wheeled vehicles.

Dutch law also provides that helmets must be properly fastened on the head. There was no information on this point in the other EC countries. The SWOV conducted a study into this area in the Netherlands. The report is contained in par. 7.2.

The above SWOV study also devoted consideration to the condition of the helmets involved in the investigation. A brief review of this will be given in par. 7.3.

7.1. Wearing of helmets

Despite the fact that it is compulsory to wear helmets for most of the categories, it can be said that the law is not always obeyed.
Compliance with the statutory obligation to wear a helmet is shown in Table 2.
Compliance is 100% in Belgium, the Netherlands, Britain and FRG (with the exception of the MOFA, 98%). In Denmark, 99% of motor cyclists and 85% of moped riders wear helmets. In France, compliance among motor cyclists is 98% and among moped riders 88%.
No information is available on compliance in other EC countries.

7.2. The use of the retention system

In literature high numbers of helmets that came off during accidents are reported. Percentages range from 7 to 36%: e.g. Pedder et al. (1979); White (1980); Otte (1980). Because only a part of these cases could be explained by (mechanical) failure of the retention systems of the helmets a survey of the use of these systems by moped riders and motor cyclists was undertaken in The Netherlands (Huijbers et al., 1985, 1987, 1988b). For a careful inspection of the use of the retention system the motorized two-wheel rider had to be stopped. More than 1000 moped riders and 1000 motorcycle riders were interviewed and their helmets examined.

The use of the retention system was defined in the following categories:

<u>LOOSE</u>: The retention system was not used at all.

<u>TOO LOOSE</u>: The retention system was used but in such a way that the chin strap could be easily pulled over the chin. If there was a chincup available the use of the system was always defined as too loose.

<u>FASTENED</u>: The retention system was used and the chin strap could not be pulled over the chin. Even if the retention system is used the buckle may be improperly fastened.

The main results:
It appeared that 15% of the <u>moped riders</u> did not close the retention system at all, 50% closed the system too loose and 10% did not properly use the buckle (Table A)

<u>Table A</u>. Use of the retention system by use of the buckle. Moped riders.

USE OFF THE RETENTION SYSTEM	%		
	USE OF THE BUCKLE		TOTAL
	PROPER	IM-PROPER	
LOOSE	.	15.4	15.4
TOO LOOSE	43.4	6.6	50.0
FASTENED	31.4	3.2	34.7
TOTAL %	74.8	25.2	100.0
N	833	280	1113

The use of the retention system by the motorcycle riders was better. A possible explanation for this behaviour (stated by the motorcycle riders spontaneously) is the average higher speed of the motorcycles in comparison with the mopeds. Helmets that are not fastened well will come off during the ride.
Of the motorcycle riders 2% did not close the system, 13% did close the system but too loose and 1% did not use the buckle in a proper way (Table B).

Table B. Use of the retention system by use of the buckle. Motorcycle riders.

USE OFF THE RETENTION SYSTEM	% USE OF THE BUCKLE PROPER	% USE OF THE BUCKLE IMPROPER	% TOTAL
LOOSE	-	2.3	2.3
TOO LOOSE	13.3	1.1	14.4
FASTENED	81.5	1.8	83.3
TOTAL %	94.8	5.2	100.0
N	1001	55	1056

Many different retention systems exist. For this project nine different types were defined. (Figure 6) But for the analyses only the two major types were distinguished: 'strangle' ('Sliding Bar': type 1 and 'Double D': type 2) and 'push-button' systems. One of the results of this study is the knowledge that all chin straps equipped with a chincup were closed. Therefore these helmets were excluded from the further analysis of the use of the retention systems as presented in this paper.

The use of the retention system by moped riders is shown in Table C. A selection from the group under study has been made (no chincups, only integral or jet helmets, only 'strangle' and 'push button' systems). There is a significant difference (T test: t= 4.35, df=887) in the use of the buckle between the users of an integral helmet and of a jet helmet: 21% of the integral helmet users did not close the buckle in comparison with 10% of the jet helmet users.
There is also a significant difference (T test: t= 5.07, df=887) in the use of the buckle between the 'strangle' and 'push button' systems: 19% of the 'strangle' systems were not closed in comparison with 5% of the 'push button' systems. This is true for the integral as well as for the jet helmet users.
'Push button' systems are closed more often 'too loose' than is the case with the 'strangle' systems. This is true for the integral as well as for the jet helmets.

Table C. The use of the retention system by moped riders by type of system (selection: no chincups, only integral and jet helmets, 'strangle' and 'push button' systems).

USE OF RETENTION SYSTEM	RETENTION SYSTEM		
	STRANG	PUSH-B	TOTAL
LOOSE	19.1	4.5	18.0
TOO LOOSE	40.8	52.2	41.6
FASTENED	40.1	43.3	40.4
TOT. %	100.0	100.0	100.0
N.	822	67	889

(chincups, other retention systems, other type of helmet, unknown n= 224)

The use of the retention system by motorcycle riders is much better, only a small group of them (2.1%) didn't close the system. Therefore no split up by type of helmet has been made in Table D. There appeared to be no difference in the use of the buckle between the two retention systems. Only 'strangle' systems were closed more often too loose than the 'push button' systems.

Table D. The use of the retention system by type of retention system. (selection: no chincups and only integral and jet helmets)

USE OF RETENTION SYSTEM	TYPE OF RETENTION SYSTEM STRANG.	PUSH B.	TOTAL
LOOSE	2.1	2.1	2.1
TOO LOOSE	13.6	8.8	12.5
FASTENED	84.3	89.1	85.4
TOTAL %	100,0	100,0	100,0
N	756	240	996

(Other type of helmets, type of retention system and unknown: n=60)

The results of this project indicate that the use of the retention systems of helmets, especially by moped riders, is not quite optimal in the Netherlands.
A comparable study was not found in the literature. One has been started in FRG, but no publication has yet been issued. Initial information from this project (Schüler, 1988) shows a simular use of the retention system in FRG.

7.3. Condition of the helmets

A British report lists the condition of helmets following accidents (Ravensdale, 1980).

It was reported that: 'Perhaps the most overwhelming fact to emerge was that the majority of helmets were found to be unfit for use, having been painted, covered with transfers, become chipped, worn and damaged to such an extent that true evaluation of helmets per se was totally unacceptable. 'After discussion with helmet manufacturers, it was agreed that the general life expectation of a polycarbonate helmet should not exceed two years and a glass fibre helmet should be renewed after three years.' Of the helmets studied, 23% came off the head during the accident.

The Dutch study of the use of chin straps (Huijbers et al., 1987, 1988b) also considered the condition of helmets. In view of the nature of the study, only criteria which were easy to establish could be studied. In 19% of the helmets worn by moped riders, no certificate of approval was found. This was lacking not only in older helmets, but even in 13% of those which were no older than one year.

Almost 30% of the helmets had been painted or held one or more transfers. It was also found that 17% had already sustained a blow in an accident and had not been replaced afterwards.

The condition of the helmets worn by motor cyclists was better. Of those studied, 13% had no certificate of approval, 1.8% had been painted and 14% carried one or more transfers, while 7% had sustained previous blows in accidents.

At the request of some consumer organisations: ANWB and Consumentenbond (The Netherlands), Verbruikersunie (Belgium), Forbrukerrådet (Norway), Stiftung Warentest (FRG) a research was carried out concerning the quality of helmets for sale. It appeared that one third of the helmets examined didnot fulfill the ECE 22 requirements, mainly due to failure of shock absorption (Consumentenbond, 1989)

8. SURVEY OF HELMET REQUIREMENTS

Helmets that are to be worn in traffic have to meet a certain standard. This standard prescribes the minimum criteria as well as the test methods to determine these criteria. National legislation regulates the standard applied in individual countries.

In theory the following aspects should be taken into consideration when determining the standard for the helmet:
- The type, place and impact to the head in accidents.
- Head-injury criteria with respect to the target group of helmet wearers.
- Aspects dealing with ergonomics and comfort.

However, the literature mentions a number of limitations to this theoretical approach; for example, objections to the principle criterion in current use for head injuries: HIC (See par. 10.1).
In consultations on helmet criteria, technical and financial aspects, as well as constraints to trade, also play a role.

Many years ago, standards were prescribed for helmets for the users of motorized two-wheeled vehicles. This is not the case for the cyclist's helmet.
The helmet standard for the users of motorized two-wheeled vehicles will be discussed first in this section.

A survey will be made of the principle requirements incorporated in current standards.
In most European countries the ECE 22 regulation is applied to the helmets of users of motorized two-wheeled vehicles (ECE, 1988). The British national standard, BS 6658 (BSI, 1985) will be used to illustrate national standards.

At the request of the Commission of the European Communities, a Technical Committee (TC 158; 'Protective helmets') of the European Committee for Standardisation (CEN) is presently determining helmet standards.
Activities have been divided into four groups, each group determining requirements for either industrial safety helmets, vehicle users' helmets, fire fighters' helmets or pedal cycle helmets. As grounds for discussion, the groups will be using the existing package of requirements. The work for the groups is still in the preparatory stage.

8.1. Helmets for the users of motorized two-wheeled vehicles

In most EC countries, the ECE 22 regulation prescribes the helmet of motorized two-wheeled vehicle users.
The ECE is based on an agreement reached in Geneva in 1958; countries voluntarily undertake to approve and recognize mutual products and accept products that satisfy regulations. Products are issued with an 'E' letter as a certificate of approval. All countries in Europe may ally themselves to the agreement. A number of non-European countries (Japan and the US, for example) attend ECE meetings as observers. 'Reporting groups' discuss proposals and draw up draft regulations which are then sent for approval to the Working Parties. WP29 deals with helmets and may, if it sees fit, introduce changes to a draft regulation. Any two countries prepared to accept the regulation may act as its sponsor and submit the regulation to the Secretary-General of the UN in New York.
If amendments to existing regulations are to be made, they are first discussed in the reporting groups. Within the WPs, a minimum number of signatories must reach an accord. The UN Secretariat then sends the amendment to those countries party to the agreement.

If, within three months, no objectives have been recorded, the amendment is enforced two months later. If one of the signatories should lodge an objection, the amendment is dropped.

Some countries of the EEC, such as France and Britain, still use their own national standard. Several years ago quite a few countries also upheld their own standard; for example the FRG (DIN) and the Netherlands (TNO) had not as yet signed ECE 22.

With the exception of Greece and Ireland, most of the EC member states participate in the ECE consultations in Geneva. Table E shows which EC member states have signed ECE 22 so far:

Table E. Survey of EC Member States and their response to ECE 22

EC Member States	Signatory to ECE 22
1. Belgium	yes
2. Denmark	yes
3. France	no
4. Greece	no
5. Great Britain	no
6. Ireland	no
7. Italy	yes
8. Luxembourg	yes
9. The Netherlands	yes
10. Portugal	no
11. Spain	yes
12. West Germany	yes

In countries which are not party to ECE 22, national standards are upheld, as in Britain (BS 6658) and France (NF s72 305). Information about standards in Greece and Portugal was not forthcoming.

A. General requirements

ECE 22:

Helmets taken from a reserve of not less than 20 specimens of various sizes: at least one of which shall be subjected to tests and one retained by the technical service responsible for conducting the approved test.
The basic construction of the helmet shall be in the form of a hard outer shell, containing additional means of absorbing impact energy and a retention system.
No component or device may be fitted to or incorporated in the protective helmet unless it is designed in such a way that it will not cause injury and that, when it is fitted to or incorporated in the protective helmet, the helmet still complies with the requirements of this regulation.
No materials may be used of which it is known that contact with perspiration or substances in toiletries will initiate an ageing process or cause the user to suffer ill-health.

BS 6658:

The first notable difference with the ECE requirements is that two types of helmet, A and B, are specified. Both types are intended to be adequate for use on public roads.

Type A corresponds to the former high-protection standard and is intended for competitive events and for use by wearers who demand an especially high degree of protection. Type B is intended for the ordinary motorcycle rider on public roads. The Type A specification consists of the Type B specification with more stringent requirements; specifically, the test conditions for shock absorption and resistance to penetration are more severe for Type A than for Type B. The foreword of the standard states that:

The structure of the helmet may be damaged in absorbing the energy of impact. Therefore any helmet that sustains a severe blow needs to be replaced, even if damage is not apparent.

To achieve the performance of which it is capable and to ensure stability on the head, a helmet should be as closely fitting as possible, consistent with comfort; in use, it is essential that the helmet is securely fastened, with any chin strap under tension at all times.

Similar conditions to those stipulated in ECE 22 prescribe the sort of materials to be used in the manufacture of helmets.

B. Ageing and effect of UV radiation

ECE 22:

The properties of the materials used in the manufacture of helmets shall be known not to undergo appreciable alteration under the influence of ageing, or of the circumstances of use to which the helmet is normally subjected, such as exposure to sun, extremes of temperature and rain. The helmet is exposed to UV rays for 48 hours using a 125W Xenon lamp at a distance of 25 cm. This criterion is considered by many to be too mild. An impact test then follows.

BS 6658:

If the outer shell of the helmet is manufactured from a thermoplastic material or a material which is known to be adversely affected by contact with hydrocarbons, cleaning fluids, paints, transfers or other extraneous additions, then the helmet shall carry on its information label an appropriate warning as specified.

Appendix A to BS 6658 describes a test procedure whereby the helmet is exposed to weather conditions for one year. This method is applicable to all shell materials and to surface coating on shells.
At present this test is not included in the standard.

C. <u>Temperature and humidity</u>

<u>ECE 22</u>:
The helmet shall be exposed to a temperature of 25 C +/- 5 C and a relative humidity of 65 per cent +/-5% for at least 4 hours. Heat cond. 50 C +/- 2 C for not less than 4 hours and not more than 6 hours.
Low temperature - 20 C +/- 2 C for not less than 4 hours and not more than 6 hours.

<u>BS 5568</u>:
Almost the same conditions as for ECE 22 apply, except that BS 5568 prescribes a longer period in the conditioning cell (24 hours).

D. <u>Impact absorption</u>

<u>ECE 22</u>:
The mass of the headform depends on its size and varies from 3.1 kg (size 50) to 6.1 kg (size 62).
Contact velocity must be 7 m/s on a flat steel anvil with a circular impact face of 130 diameter +/- 3 mm and 6 m/s on an hemispherical steel anvil, with an impact face of 50 mm radius +/-2 mm.
Each test shall be carried out first with the flat anvil and then with the hemispherical anvil on the same helmet at two close but separate points i.e. at a distance of 15 +/- 5 mm from one another.
Six points of impact are defined for each type of helmet; in the frontal area (B), in the lateral area (X) and at two points above area AA, selected by the laboratory (P).
The conditions are atmosphere, high temperature, low temperature, radiation and rain.

The absorption efficiency shall be considered sufficient where the resultant acceleration measured at the centre of gravity of the headform is = < 150 g for any 5 m/s continuously and at no time exceeds 300 g.

BS 6658:

A headform with a fixed mass of 5 kg is tested for all sizes. The mass of the headform (without helmet) is 5 kg.
Number of impacts: 2 on each side of the 3 sites.

Maximum delay of 300 g. No time limit is fixed.

Impact test survey (BS and ECE)

Impact	Anvil	Impact velocity (m/s)		
		BS		ECE
		Type A	Type B	
1st	flat	7.5	6.5	7.0
	hemisph.	7.0	6.0	6.0
2nd	flat	5.3	4.6	-
	hemisph.	5.0	4.3	-

E. Resistance to penetration test

ECE 22:

The helmet is subjected to a penetration test at two points. These points are at a minimum of 75 mm from the areas of impact.
The mass of the punch is 0.3 kg +/- 10 g. The angle of cone forming the punch head 60) +/- 1).
The radius of the rounded top of punch head: 0.5 mm.
The mass of the drop hammer: 3 kg +/- 25 g.
The height of fall: 1 m +/- 0.005 m.
The criterion: during the test, the head of the punch shall not come closer than 5 mm, measured vertically, to the headform.

BS 6658:

The mass of the drop hammer is 3 kg. Fall height is greater than for ECE 22: 3 m for Type A and 2 m for Type B. The criterion also differs from ECE 22: the striker shall not make contact with the test block at any point on the helmet from its uppermost point down to the limit of rotation of the helmet on the test block.

F. Retention system

ECE 22:

The helmet shall be held in place on the wearer's head by means of a retention system which is secured under the lower jaw and is firmly attached to the shell.

If the retention system includes a chin strap, the strap shall be not less than 20 mm wide under a load of 150 N +/- 5 N, applied under the conditions prescribed in Par. 7.6.2/6.11.2. The chin strap shall not include a chin guard.

Push button fasteners are permitted. To prevent self-releasing, push button fasteners should not spring open when pressed with a rigid sphere of a diameter of 100 mm.

BS 6658:

Various fastening devices are permitted.

A great many tests on fastening systems are carried out, for example:

Strap slippage: The grip shall not exceed 10 mm.

Under a load of 20 N, a frequency of 0.5 Hz - 2 HZ and an amplitude of 50 mm, the chin strap is stretched 520 times.

A chin guard is not always forbidden: a chin guard shall not be fitted to any system consisting of a single chin strap. Where a helmet is fitted with additional straps, one of them may carry a chin guard.

If a retention system includes a quick release mechanism, then the method of release of this mechanism shall be self-evident. Any levers, tabs, buttons or other components which need to be operated to release the mechanism shall be coloured red, those parts of the rest of the system which are visible when closed, shall not be similarly coloured while the mode of operation shall be permanently indicated.

The system should not release when a rigid sphere of a diameter of 40 mm is pressed with a load of 100 N.

In addition a durability test is carried out on the push button part. The chin strap is pre-stressed and subjected to 2500 opening and closing operations. If the fastening mechanism contains metal components, the same test is carried out under humid conditions.

If the helmet is designed to be retained on the head without a chin strap, it shall retain the lower part of the headform system when tested by a test method.
A drop weight falls from a height of 750 mm and pulls on the fastening. This test is carried out twice. Thereafter it must be possible to release the fastener.

G. Dynamic test of retention system

ECE 22:
The retention system is dynamically tested by dropping a 10 kg mass from a height of 750 mm.
The dynamic displacement of the point of application of the load shall not exceed 35 mm. After the test, residual displacement under the pre-load of the head mass (15 kg) must not exceed 25 mm after a period of 2 minutes. Damage to the retention system shall be accepted provided that it is still possible to take the helmet easily from the headform given the displacements just described.

BS 6658:
Dynamic: a 10 kg mass is allowed to free fall from a height of 750 mm. Unlike ECE 22, this test is carried out twice. Dynamic extension is 32 and 16 mm for the first test and 25 and 8 mm for the second test. Thereafter the fastening mechanism must still open.

H. Retention of the helmet on the head

ECE 22:
This test shall be verified when the dynamic retention test is carried out. The helmet subjected to this test shall be that presenting the least favourable conditions (such as the thickest padding).
The helmet, previously conditioned at ambient temperature and humidity, is attached to the appropriate headform.

A device to guide and release a falling mass (3 kg +/- 0.1 kg) is hooked onto the rear part of the shell in the median vertical plane of the helmet. The falling mass is then released and drops in a guided free fall from a height of 0.5 m +/- 0.01 m.
After the test, the angle between the reference line situated on the crown of the helmet and the reference plane of the headform shall not exceed 30°.

BS 6658:
Almost an analogue test method but the headform is modified. To simulate hair, the top of the headform is covered with an acrylic wig to a hair length of 70 mm. This is not the case in the ECE.
The neck area of the headform is also modified; a piece of foam is added. The BSI requirement is also different to that of the ECE as BSI stipulates the helmet must not fall off the head.

I. Marking

ECE 22:
Every protective, approved helmet shall bear, sewn to its retention system, a label consisting of a circle surrounding the letter 'E', followed by the distinguishing number of the country which has granted approval, the approval number and, after the approval number, a dash followed by a production serial number.

BS 6658:
Each helmet shall be legibly and durably marked in such a way that the following information is accessible to the user:
number and date of standard;
year and quarter of the month of batch release;
name or trademark or Kitemark licence number of manufacturer; country of origin of helmet;
size or size range;
destination of model;
optional flammability.

J. <u>Information for wearers</u>

<u>ECE 22</u>:

Every protected helmet offered for sale shall bear a clearly visible label with the following inscription in the national language, or in at least one of the national languages, of the country in which it is offered for sale:

'For adequate protection, this helmet must fit closely and be securely attached. Any helmet that has sustained a violent blow should be replaced'.

Additionally, where hydrocarbons, cleaning fluids, paints, transfers or other extraneous additions affect the shell material adversely, a separate and specific warning shall be emphasized in the above label, worded as follows:

'Warning. Do not apply paint, stickers, petrol or other solvents to this helmet'.

Every protective helmet shall be clearly marked with its mass to the nearest 50 grammes and with its size.

<u>BS 6658</u>:

In common with the ECE, BS 6658 stipulates that every helmet offered for sale must contain the following information:

A recommendation to fasten the helmet properly when in use; replacement of the helmet after an accident; not to make changes to the helmet; fasten chin strap properly under jaw; use no chin guard.

It is recommended that only cleaning fluids produced by the manufacturer should be used.

In the case of a quick fastener, the method of use must also be indicated.

Helmets with a thermoplastic outer shell must contain a separate label with the warning 'do not paint or apply solvents'.

K. <u>Included in BSI but not in ECE:</u>

<u>Solvent conditioning</u>

The helmet is smeared with a mixture of 'iso-octane and any grade of toluene' in a 50:50 ratio (minimum of 5 sec). No further conditioning or testing during the following 30 min.

Inadvertent release by inertia

The system is again subjected to 3 fall tests using special equipment.

Oblique impact resistance

The rotational induced forces which result when an unrestrained helmeted headform is dropped vertically onto an inclined anvil are measured in the longitudinal axis of the anvil. Both the peak force and its integral with time, over the duration of the positive impulse, are used as performance criteria. Velocity at the moment of contact with the anvil is 10 m/s (drop height 5.2 m).

Chin guard

A striker with a mass of 5 kg is dropped from a height of 2.5 m. The peak acceleration is measured. It shall not exceed 300 g. The chin guard shall not develop or generate any additional hazard for the wearer and any internal padding shall remain in place.

L. Included in ECE but not in BS:

Rigidity test

After being exposed to temperature and humidity conditions, the helmet is clamped between two vertical plates. The loads applied range from 30 N (2 min) increasing to 100 N and 630 N (every two minutes). The distance between the plates is measured after every step.

Thereafter back to 30 N (5 min). This occurs (with a new helmet each time) in an AP and LAT direction.
The distance between the plates at 630 N may be a maximum of 40 mm smaller than by 30 N.
On reduction to 30 N, the distance must not be smaller than 15 mm for the first (initial) load of 30 N.

Conformity of production and routine tests

To ensure that the manufacturer's production system is acceptable, the responsible service shall carry out some tests of production quality. The 'responsible service' is not however specified.

Minimum requirements for production quality testing

The first month's production of each new, approved helmet type shall be subjected to production quality tests.

For this purpose, 40 helmets shall be taken at random, 30 of them of average size and 10 of a size determined by the technical service. Random tests are made depending on the number of manufactured helmets. Of the 40 helmets, at least 15 shall be subjected to the retention test.

Of the 40 helmets, three batches each of not less than 10 helmets shall be taken. The technical service decides which conditioning procedure will be followed for each batch. Thereafter the impact absorption test is carried out on all helmets.

Minimum requirements for routine quality control by the manufacturers

The holder of an approval, granted pursuant to this regulation, shall be obliged to carry out continuous quality control on a statistical basis and by sampling, or to see that it is carried out, so as to ensure that the production of helmets is uniform and conforms to the provisions of this regulation.

The manufacturer, or his duly accredited representative, shall, in particular, be required to carry out the absorption and retention tests. The part of the production to be tested depends on the number of helmets that have been manufactured and moreover is described in some detail in ECE 22.

Whenever a defect is revealed, the manufacturer must take all measures necessary to restore conformity of production in that respect. He is expected to keep the test reports for control purposes.

Minimum requirements by the Governments

The tests shall be carried out on helmets offered or intended for sale.

If the requirements of the production quality test are satisfied, the manufacturer, or his duly accredited representative, shall divide the helmets into batches. A batch shall consist of no more than 3,200 units.

A sample shall be taken from each batch (prescribed in ECE 22). Tests shall include at least two impact absorption tests and the retention test. In accordance with a test results' scheme outlined in ECE 22, batches are either approved or rejected. (Depending on the number involved, not all helmets need satisfy the criteria precisely. If a defect is discovered, a second procedure is instigated based on a greater sample size, before rejection is decided). Depending on the results, 'an approval withdrawn' decision may be reached.

Modification to the protective helmet type

Any modification of the protective helmet type shall be notified to the administrative department which approved the protective helmet type. The department may then either: determine that the modification does not effect the certificate of approval or that a further test report is required from the technical service responsible for conducting the tests.

8.2. Bicycle helmets

None of the EC member states compel cyclists to wear a helmet on public roads. There are, however, a number of (national) standards for bicycle helmets, as in Britain (BS 6863).
A few countries, Federal Republic of Germany and the Netherlands for instance, are currently drawing up standards.
Some of the helmets on sale in Europe have been tested in accordance with American or Australian standards.
However, a large number of helmets have not been tested. As described in par. 9.2, some bicycle helmets are not equipped with energy absorbing padding.

Just as in the case of helmets for motorized two-wheeled vehicle users, requirements should be based on the effects of impact in an accident, injury criteria and aspects considering ergonomics and comfort. The latter should receive even more attention as the cyclist himself has to propel his own vehicle.
In the literature, a number of standards have been prescribed: for example, the Australian AS 2063 (Technisearch, 1981), the American ANSI (ANSI, 1984) and the British BS 6863 (BSI, 1987).

The most important aspects:

- energy absorption
- strength of chin strap
- limitation of size and place of ventilation holes.

In the Australian standard, the following deceleration values are permitted during a 1.5 m fall of helmet and headform:
As max = 400 (g)
As t=3ms= 200 (g)
As t=6ms= 150 (g)

In the American standard Z90.4 (ANSI, 1984) conditions are prescribed with regards protection, field of vision and strength of chin strap.
Deceleration value: a peak value of 300 (g) is tolerated by a fall of 1 m onto an anvil.

In Sweden, where bicycle helmets are in general use, deceleration requirements are fixed at 2500 m/s2 by a fall height of 1.5 m.

In France a concept for a standard has been drawn up by the 'Federation Francaise de Cyclisme' (Chamourard, 1984). The permitted decelerations are:
As max = 300 (g)
As t=5ms = 150 (g)
This is in accordance with the ECE. The fall height is 0.9 m.

In Britain, requirements for bicycle helmets have been drawn up by the British Standards Institute (BSI, 1987). Some of the principle requirements are as follows:

The materials are the same as for the helmets of motorized two-wheeled vehicle riders.
A singular requirement concerns the helmet's construction - 'the helmet shall not have an integral chin guard'.
The same criterion applies for the shock absorption test carried out on helmets for motorized two-wheeled vehicle riders: a maximum deceleration of 300 (g), without time-dependence. The fall height is 1 m.
A dynamic load requirement is also demanded for the retention system; extension shall not exceed 32 mm residual 16 mm. A 10 kg mass is allowed a free fall of 300 mm.

It is notable that the effectiveness of the retention system (Retention System Effectiveness) is also examined. Load mass 4 kg/fall height 0.5m. The push button fasteners must also undergo a similar test whereby 2500 open and close operations check durability.

Summary: Shock absorption for bicycle helmets

	AS 2063	Z90.4	BS 6863	France	Sweden
Fall height (m)	1.5	1	1	0.9	1.5
Maximum deceleration (g)	400	300	300	300	254.8
Time-dependence (g)	200 (3ms) 150 (6ms)	-	-	150 (5ms)	-

9. THE EFFECT OF WEARING A HELMET

In principle, the effect of wearing a helmet and the extent and the seriousness of injuries can be calculated by a number of methods.
On the basis of the known shock absorption values of helmets, and together with data on (head) injury tolerance and data on energy levels that occur during an accident, effect estimates can be calculated.
However, knowledge of injury tolerances and any occurring energy levels is so scanty that there is hardly any basis to produce a reliable estimate. The calculation of effects are therefore usually based on a comparison of the injuries of wearers and non-wearers.
One problem that arises in these studies is that the injuries of persons with minimal injuries are compared, for example, with hospital cases. Due to the means of protection, in this case the helmet, a shift in serious injuries occurs to the disadvantage of the helmet-wearer as wearing a helmet also means that a certain percentage of casualties need not be admitted to hospital because they wore a helmet. The effect therefore would be smaller than it actually is if calculations were made on this basis.

Calculations with respect to the effects of the helmet have been carried out for a long time now. One of the first calculations was compiled by Hugh Cairns (Cairns et al., 1943). After studying 106 cases, he observed that helmet wearing 'reduced severity of injury: one-fourth the frequency of fractured skulls, and a reduction of one-half in hospital treated injuries for helmet users.'

This study was followed by several other comparable studies; for example that of Chandler and Thomson, who examined 7010 injured motorcyclists (Chandler et al., 1957). On the basis of their findings they came to the conclusion that by wearing a helmet the risk of sustaining head injuries decreased by 30-40%.

In this section, a survey is presented of effect calculations described in the literature. Studies from EC countries will be examined first. Studies concerning the effects of bicycle helmets will be treated separately.

9.1. Motorized two-wheeled vehicle riders

9.1.1. Studies carried out in EC countries

Federal Republic of Germany

Langwieder (1977)

In this study, a cost-benefit analysis was drawn up on helmet-wearing in the FRG. For the period July 1976-July 1981, the main costs involved in wearing a helmet were collated. E.g: the purchase of a helmet (written off in 5 years), the cost of new helmets in this period as well as replacement of used helmets and the replacement of visors by integral helmets.
The total costs amounted to between DM 118.5 - 880.1 million. The effectiveness of wearing a helmet was fixed at 25% and the number of head injuries 70% of the fatal injuries, 100%. On this basis, calculations showed a saving of 147 fatalities, 2206 serious injuries and 4408 minor injuries.
The cost of a fatality was calculated at 500,000 DM, a serious injury at 66,000 DM and a minor injury at 5,000 DM. These costs are taken from Jager et al., 1977.

However not all injuries are prevented by wearing a helmet. Thus fatalities become seriously injured and seriously injured, slightly injured etc. Savings are then made from 500,000 DM to 66,000 DM, thus 434,000 DM etc. The yields per year are calculated at between 147.7 and 220.4 million DM.

Calculations were also made on the minimal effectiveness of a helmet in order to break even. The percentage arrive at was then 13.6% minimum.

Löffelholz et al. (1977)

This report makes mention of a shift from contusions to concussions in sustaining injury when wearing a helmet. Contusions are far more serious and are often the cause of more severe and permanent consequences. The report surveys the effects of wearing a helmet, using various sources/-studies (N=21). Reductions are around 10-50%.

Beier et al. (1985)

In Munich and the Landkreis Oberbayern, a study was made of accidents involving motorized two-wheeled vehicles in the period January-September 1980, that led to 309 casualties.
The effect of wearing a helmet was found to be as follows:
The risk of sustaining a (fatal) head injury by non-helmet wearers on public roads was on average four times greater than for helmet wearers.
Divided into various two-wheeled categories, the results were as follows:
- moped/mokick inside built-up areas: 6 times greater chance serious injury without helmet;
- light motorcycle inside built-up areas: 8 times greater chance serious injury without helmet;
- motorcycle inside built-up areas: 11 times greater chance serious injury without helmet.

The risk of head injury is reduced by the crash helmet AIS > 2 by 94%; AIS > 3 and AIS >=4 by 94%.
If the type of injury is examined, fractured skulls among helmet wearers, causing severe injury or fatality, are likely to occur 4-7% less than among non-helmet wearers.

Otte et al. (1985)

On the basis of a literature survey, the conclusion was reached that wearing a helmet caused the following reductions:
30-50% of all injuries, 50% of severe head injuries and 40-83% of fatal head injuries.

The Netherlands

SWOV (1978)

SWOV executed research into the effect of the compulsory use of helmets for moped riders and passengers in the Netherlands, based on the number of casualties.
Effectiveness was calculated on the basis of a change in the number of fatalities, corrected by the number of kilometres driven, making use of SMR data. The latter is a data bank where the injuries of 95% of all hospital cases in the Netherlands are registered. Over a period of time, the SWOV study examined the developments of head injuries among moped riders and compared them with those of cyclists (Table 5).

The result was: 'the risks of being killed on public roads were decreased by 40% if a helmet was worn, while head injuries decreased by 30%.

Passies (1986)

A more recent study in the Netherlands was carried out by Passies at a regional level.
The effect of wearing a helmet on the number of injured was for the most part limited to hospital cases, as in the SWOV study. This study examined the effect of compulsory helmet use on a number of casualties receiving outpatients' care at the University Hospital in Groningen. The group, moped riders, was compared with bicycle casualties. The major finding was the fact that the number of moped riders had greatly decreased in the period 1970-1979, the average annual kilometre distances had decreased by 1975 and thereafter slightly increased.
The number of cases of moped rider casualties treated at the University Hospital in Groningen in this period had decreased, while the number of cyclists treated had increased. In order to reduce the effect on this trend of the shift in usage of bicycles and mopeds, only the percentage of head injuries was examined for each category. It was also found that in this period the age range of the victims had changed: lower for moped riders, higher for cyclists. As this fact could effect head injuries - older people are relatively more prone to head injuries - the effects per age group were examined.

In the first half of the period 1970-1979, the percentage of moped rider casualties with head injuries was higher than bicycle casualties: of the moped riders, 36.5% suffered head injuries compared to 31.8% cyclists. In 1975, when compulsory helmet use was introduced, a sudden decrease of head injuries for moped riders is noticeable.

Moreover, after 1975, head injuries among moped riders were considerably less when compared to the period 1970-74. At the same time the percentage of head injuries among cyclists increased somewhat.

After this period, 36.8% of bicycle casualties and 27.6% of moped rider casualties suffered head injuries. An examination of age groups demonstrates that this decrease cannot be attributed to the difference in age.

Examination of the type of injury shows a decrease in almost all head injuries under moped riders with the exception of 'commotio cerebri' and contusion of the softer parts: 'Besides a large decrease in the frequency of head injuries such as lacerations and open wounds, there is evidence of a decrease in the number of fractures to the roof and the base of the skull, facial fractures and superficial injuries. There are also fewer cases of contusion of the brain but a slight increase may be observed in the number of concussions'.

The study demonstrates that wearing a helmet effects the number of severely injured hospital cases as well as the number of cases receiving outpatients' care for less serious injuries.

OECD

A working group set up by the OECD includes in its report (OECD, 1978) a survey of the effects on head injuries of wearing a helmet. 'There is abundant literature on the effectiveness of crash helmets.

The first papers on this subject were published by Cairns (1946), followed by articles on before-and-after studies relating to the implementation of the obligatory use of crash helmets (Lunenfeld and Varady, 1970, Parsons, 1970, Foldvary and Lane, 1964) and comparison between casualties with and without crash helmets (Chandler and Thomson, 1957).

In the publication of Lunenfeld, the material of various investigations has been summarised and calculations have been made, showing that when using a helmet, the risk of being killed is reduced on average by 40 percent and the risk of sustaining a head injury often by 30 percent. American studies performed later on, have quantified the small effect of helmet wearing on auditory capability and field of vision and also confirmed the decrease in fatality rate after the introduction of compulsory helmet wearing (Henderson, 1975; Gordon and Prince (1975) and Robertson (1976).
The report also includes a comparative survey of helmet requirements and the different standards.

9.1.2. Studies undertaken outside Europe

Most studies have been carried out in the United States. An ideal situation presented itself to calculate the effects of wearing a helmet because in a number of states a crash helmet was at first compulsory, then this regulation was repealed, and in many cases reintroduced.

NHTSA (1980)

This report gives a survey of the history of compulsory helmet wearing in the United States:

In 1966 Georgia was the first American state to enforce compulsory helmets.

Other states quickly followed and by 1969, 40 states had introduced compulsory helmets. By 1975 this was 47.

In order to increase this number, the Secretary of Transport drew up a plan 'to initiate judicial procedures against the other states to force them to introduce compulsory helmet wearing'. As a means of pressure, he planned to withdraw Federal funds.

Before he was able to initiate this plan, Congress passed the Highway Safety Act in 1976. The Act deprived the Secretary of the right to compel states to enforce helmet wearing and moreover deprived him of the right to use financial sanctions. In addition, the interests of various organisations and 27 states succeeded in bringing sufficient pressure to bear to repeal the law on compulsory helmet wearing or to change it to such an extent that compulsory helmet wearing on public roads was only applicable to motor cyclists under 18 years of age. The increased number of fatalities among motor cyclists was immediately significant: from 3312 in 1976 to 4850 in 1979 (+45%). Due to the dramatic increase, Congress decided a further study of this phenomenon was necessary.

Shortly after the Highway Safety Act was enforced in 1976, the NHTSA contracted 4 states (Colorado, Kansas, Oklahoma and South Dakota) to determine the effect of the repeal of the regulation to compel helmet wearing.

After Congress had decided in 1978 to carry out further study, the objective of the project in the four states was widened: information should now be collated about the usage and value of wearing a helmet while economic aspects should also be considered. The results of the in-depth study commissioned by the NHTSA and carried out by the University of South California are also included in the NTSA report.

During the period of compulsory helmet wearing, observations showed that helmets were worn by 95-100% of riders, while voluntary helmet wearing produced percentages of 50-60%.
The lowest percentage of helmet wearing was found among young people, 'resulting from their failure to appreciate the potential consequences of not wearing a helmet'. In view of the long-term effects, special attention is paid to this group.
The familiar picture of the decrease in the number of fatalities per 10,000 motor cyclists in the USA is shown in Figure 4.

The most important arguments against wearing a helmet are: Helmets are not effective, helmets cause neck injuries, helmets cause accidents due to inadequate vision.

Neck injuries with respect to wearing a helmet are only found sporadically among motorcycle casualties: 2% could be said to have sustained such injuries (Hurt, 1979; Newman, 1974).

Wearing a helmet reduces the field of vision. The NHTSA has carried out a study on this subject (Gordon et al., 1975). A diminished field of vision was the subject of study among 19 experienced motor cyclists. The study concluded that the integral helmet diminished the field of vision by less than 3% in the horizontal plane.

Henderson 1975
The motorcycle rider is exposed to a great many sources of noise: the engine, wind, the noise volume that can penetrate to him will be little affected by the helmet. As a helmet is far more aerodynamic than a normal head, which experiences a variety of rotations and boundary release problems, which the wearing of a helmet only reduces.

The effect of wearing a helmet: 'Head injury rate for helmeted riders = head injuries to helmet riders *1000/all helmeted riders in crashes'.

The same definition for non-helmeted riders: 'Non-helmeted riders experienced two to three times as many head injuries per 1000 crash-involved riders as the helmeted riders. The difference in head injury rates between helmeted and non-helmeted riders are statistically significant at $p < .0001$ level. When the degree of severity of injury is increased, the effectiveness of the helmet in protecting the head against serious head injury is even more pronounced. Utility and effectiveness of the helmet is most dramatic when one examines the fatal head injuries per 1000 crash-involved riders, for helmet users and non-users.
A three to fivefold increase in fatal head injuries is observed when one compares the fatal head injuries of helmeted and non-helmeted riders. The obvious interpretation of these data is that crash-involved riders not wearing helmets increase the risk of a fatal head injury three to fivefold'.

The effect of the repeal of the compulsory helmet on the defined injury rates: 'The head injury rates from the states range from one-half to almost two times greater in the post-repeal period than in the pre-repeal period. In the post-repeal period, when mandatory helmet use was not in effect, a substantial increase in most severe head injuries per 1000 involved riders is noted'.

The effect of the repeal of the compulsory helmet viewed economically: 'The decrease in helmet usage resulting from helmet law repeal has been shown to have significant impact on increases in medical costs and length of hospital stay resulting from the more severe head injuries sustained by non-helmeted riders as compared to helmeted riders. The estimated increase in medical costs is understated since it does not include the estimated costs for rehabilitation and loss of income resulting from permanent physical impairment'.

Hurt (1979)
Based on the in-depth study of 899 motor accidents and the analysis of 3600 motor accidents reported by the City of Los Angeles: Some conclusions: 'The use of a safety helmet is the single critical factor in the prevention or reduction of head injury. The safety helmet is a significantly effective injury countermeasure.

Safety helmet use caused no attenuation of critical traffic sounds and no limitation of pre-crash visual field; no element of accident causation was related to the safety helmet.
Four cases (out of 899) of 'minor' (AIS=< 1) injuries were attributable to the safety helmet, but each was associated with helmet protection from severe to fatal head injury'.

Muller (1980)

According to Muller, the repeal of the compulsory helmet law in various American states was not based on a cost-benefit analysis. 'At least $61 million could have been saved if all motor cyclists had worn a helmet. It is estimated that helmet law repeals may produce annually between $16-18 million unnecessary medical costs. This sum does not take into account the value of pain or lives lost'.

McSwain et al. (1984)

As well as describing the events following the repeal of the helmet law in the United States, this report also gives a survey of the results from a number of states.
Colorado: 'In less than a year after the helmet law repeal, the fatal crash rate increased by 66% and the injury rate by 17%'.
Comparisons were made of the injuries sustained between helmeted and non-helmeted riders. This method of comparison demonstrates that if a helmet is worn, less severe injuries do not include head injuries and do not lead to hospitalization.
These cases were not recorded and were not included in the comparison.

'The rate of occurrence of head injuries for riders not wearing helmets was 228.7 per 1,000 riders, 3.6 times greater than the rate of 64.1 computed for helmeted riders. The rate for most severe injury occurring to the neck was slightly less for riders not wearing helmets; however, these findings were based on very few observations'.

'With respect to upper body injuries, non-helmeted riders showed an overwhelming tendency for most severe injury to the head; thus the opportunity for the neck and face to receive the most severe injury was greatly reduced. A review of the data when the three most severe injuries are combined, shows that the injury rates for three body locations - head,

neck and face - were all higher for the non-helmeted riders: 369.4 injuries/1,000 non-helmeted riders to 129.1 injuries for riders wearing a helmet.
The rate of occurrence of AIS 6 for non-helmeted riders was 23.5 or 2.8 times greater than the rate of 8.5 injuries/1,000 involvements for helmeted riders'.
Similar results were found by the other states.
In the Kansas study, attention was given to the financial consequences. 'There was a significant difference in the days of disability of the helmeted riders versus those without a helmet. The mean hospital costs for non-helmeted riders were nearly twice as high than for helmeted riders'. The study arrived at the following final conclusion: 'Helmet usage is significantly less where use is not mandatory. Helmets significantly decrease head injury, death and disability. The costs of medical care for a non-helmeted rider is twice that of a helmeted rider. The amount of permanent disability is significantly increased when helmets are not worn'.

Kansas expressed the outcome of the study as follows:
'The pattern is clear. The impact of the Kansas motorcycle helmet law has been extremely costly in terms of debilitating injuries, deaths and financial burdens. If personal freedom is the issue here, and debatable, the people of the state of Kansas are paying a high price for this particular study in terms of financial assistance and loss of life and limb'.

<u>Evans et al. (1987)</u>
To calculate the effect, use was made of the 'double pair comparison method', applying it to Fatal Accident Report System (FARS) data in the period 1975-1984. The selected accidents involved cases in which either the motorcyclist or the passenger was killed. Accidents were selected in order to eliminate any distortion from variables, as follows: male riders, while the age difference between rider and passenger was not to exceed three years. The effectiveness of the helmet in preventing fatal injury comes to 27% (+/- 9%) for both men and women, riders and passengers alike. For the year 1985, of the 4000 fatalities among motorcyclists in the USA, less than half wore helmets at the time of accident.
The report's final conclusion was that 'the estimated increase in rider fatalities from repeal is 19%'.

Goldstein (1986)

In this study which made use of a multi-variate analysis technique, it was found that wearing a helmet did not significantly influence the risk of death. The conclusion reached by Evans et al. (1987) is as follows: 'the frailty of multi-variate analysis, using ten or so variables, especially if they are selected after examining the data, the different choices of variable, transformations, etc. can often generate just about any conclusion'.

Evans et al. (1988)

In this more recent study, FARS data covering a longer period were used. The effectiveness of the helmet is expressed in terms of reducing the risks of sustaining a fatal injury and is set as (28 +/= 8)%, while the 'estimated increase in rider fatalities from repeal is 20%'.

Wilson (1989)

Based on FARS data from 1982 through 1987, motorcycle helmets are estimated to be 29% effective in preventing fatalities. A matched-pair technique was used to produce the effectiveness estimates of motorcycle helmets by comparing the probability of fatalities of drivers and passengers under helmeted and non-helmeted conditions. The general methodology employed in this analysis has been utilised in numerous reports to estimate the effectiveness of various restraint systems, for example, Evans et al. (1988).

The FARS data from the NHTSA, show that helmets are estimated to be 27% effective in preventing driver fatalities and 30% effective in preventing passenger fatalities in crashes in which both a motorcyclist and passenger were involved. On average, helmets are effective in reducing fatalities in motorcycle crashes. For the years 1982 through 1987, it is estimated that 4,645 motorcyclists' lives were saved as a result of helmet usage. In total, if all motorcyclists had worn helmets, both drivers and passengers, an estimated 9,030 lives could have been saved over this six-year period. In the matched-pairs method, the ratio of driver fatalities to passenger fatalities, and passenger fatalities to driver fatalities are calculated for each of four possible helmet use groups. This matched-pairs method assumes that the only factor causing the reduction in fatalities in these fatal crashes is helmet usage. Another possible shortcoming of the technique is the limitation to motorcycle crashes involving both a driver and a passenger on the same vehicle in which one or both were killed. These fatal crashes represent only a small portion of total motorcycle fatalities.

The effect of the helmet expressed in types of helmet

Walz (1976) and Bourret (1976) both state that the jet helmet provides less protection than the integral helmet. Their findings, however, are based on a small number of accident cases.

Vaughan (1977)

On the grounds of a study of police reports involving accidents sustained by 1651 victims, Vaughan reaches the conclusion that integral helmets offer significantly better protection than jet helmets as far as facial injuries are concerned. He also finds that the jet helmet offers no better protection against other head injuries.

Aldman (1979)

On the basis of a study of data involving 91 motorcycle crashes, Aldman discovered differences in facial injuries and head injuries for the various types of helmet, in favour of the integral helmet.

Whitaker (1980)

An in-depth study of 483 motorcycle crashes in Britain. These crashes had been reported to the police and studied by a special team. 'There is a significance in the proportion of facial injuries between open and full face helmets (at a 2.5 percent level).
Full face helmets give a lower relative incidence of facial injuries when compared with open face helmets'.

Hurt (1981)

From his analysis of 900 accidents involving motorcyclists, Hurt concluded that the wearers of integral helmets sustained 'spectacularly' less facial injuries than the wearers of jet helmets.
As far as head injuries were concerned, no difference was found between the two types of helmets. There was however a difference with the partial coverage helmet, a type that is rarely seen nowadays.

Cannell (1982)

A study was made of the hospital and police reports on 45 motorcycle accidents. On average, Cannell found less severe facial injuries - soft tissue and bone - among users of the integral helmet than users of the jet helmet. However the average severity of head injuries was lower among the jet helmet users than among the users of the integral helmets. Seeing the slight difference and the number of cases studied, this difference is hardly significant.

Material of the outer shell

Beier et al. (1985, 1986)

This study found that the proportion of cases without head injuries wearing a glass fibre helmet (60%) was much greater than for those cases wearing a polycarbonate or acrylonitrile butadiene styrene (ABS) helmet (30%).

A possible reason for this difference - the difference in density of the lining between the two helmet groups - was rejected by this study. At present there are also ABS helmets on the market fitted with a higher density lining as well as GFK helmets with a lower density lining.

Otte et al. (1985)

The report makes use of old data from an accident study. The findings show that a helmet with a polycarbonate outer shell will fracture more easily than a glass fibre helmet. The wearers of damaged polycarbonate helmets sustained more severe injuries than glass fibre wearers.

9.2. Cyclists

It is more difficult to calculate the effects of wearing a bicycle helmet than to calculate the effects of helmets for moped riders and motorcyclists, as the cycle helmet is still relatively uncommon. Another problem is that there is no generally accepted standard as yet and moreover a great variety of helmets need to be examined and their effectiveness calculated. Very often these helmets have not been specifically manufactured for cyclists and are, for example, used by ice hockey players or mountain climbers.

Three types of helmet are in use by motorized two-wheeled vehicle riders (Section 5): the partial coverage helmet, jet helmet and the integral helmet. The partial coverage helmet is hardly ever used nowadays (Huijbers et al., 1985).
The three types are also available for cyclists, especially the partial coverage helmet. A variation of the partial coverage helmet is the 'hairnet' popular among professional cyclists (Dorsch et al., 1984) or the banana helmet (Spolander, 1982).
There is very little difference in construction between helmets for moped riders and those for motorcyclists. This is not the case, however, for cycling helmets. Sometimes the protective padding is missing and is replaced either by a band system or nothing. The helmet will then consist only of an outer shell and a 'comfort' padding.

Most reports assume that in wearing a helmet, the cyclist limits the extent and severity of any head injuries, and, in view of the great number of head injuries sustained by cyclists, the authors recommend the use of a helmet. Reports also include descriptions of test programmes or the findings of comfort tests: e.g. Lewicki et al. (1975), Spolander (1982), Chamouard et al. (1984) and Gillies (1980).

McDermott et al. (1982) study the effects of cycle helmets by comparing injury data among cyclists with injuries sustained by motorized two-wheeled vehicle riders. They also observe that the number of registered victims of traffic accidents among motor cyclists is two to three times the number of injured cyclists. The number of registered head injuries among cyclists is significantly higher than among motor cyclists.
In addition, the number of injured cyclists who had only sustained head injuries is twice the number of injured motor cyclists.
In a recent study, McDermott et al. (1985) refined their work by including less severe injuries and accidents involving only the victim. Moreover the severity of the injury could be classified using the AIS method. The findings from this study, as of those of the previous study, show that although motor cyclists sustain on average more severe injuries, the average severity of head injuries was higher among cyclists than among motor cyclists.
A similar difference in the percentages of head injuries between cyclists and motor cyclists is often found in national statistics. According to

Huijbers (1984) a survey of the literature showed that in spite of differences in absolute height, the trend described by McDermott was observed in all studies (See also par. 6.2.2). It was obvious that any explanation would cite the use of the helmet. However a number of other causes can be responsible for this difference, for example, difference in types of accidents and collisions, or, as expressed by Dorsch et al. (1984): 'In such a study a lot of differences between pre-crash and post-crash factors in the two groups could contribute to erroneous conclusions about the potential, protective effect of bicycle helmets'. Therefore it was decided to undertake an effectiveness study by comparing groups of users with non-users.

To this end, the members of five cycling clubs in Australia were sent questionnaires requesting information about age and sex and asking for details about any possible involvement in an accident in the last five years. No indication whatsoever was given of the purpose of the questionnaire. In total 1300 questionnaires were returned a response of 68%. 866 forms were usable. In total 197 persons said they had been involved in a cycling accident within the last five years and had experienced a blow to the head. The helmets involved in these incidents were sub-divided into the 'hairnet', the 'poor hard helmet', a helmet without pro- tective padding and the 'good hard helmet', a helmet with protective padding. Of the 197, 38% had worn no helmet, 35% had worn a 'hairnet', 19% a 'poor hard helmet' and 8% a 'good hard helmet'.

After a study of the rough data, the conclusion was reached that: 'The observed association of head injury severity and helmet status is statistically significant. Helmets appeared to protect against brain injury and external soft tissue damage but not against skull fracture'. The latter phenomenon was only observed five times.
Moreover the group wearing helmets experienced fewer neck injuries than the group not wearing helmets. After correcting the results on the basis of age, sex and 'crash violence', it was found that helmet users had been significantly protected against head injuries. A final analysis was carried out with 'PODS' (Somers, 1983). This is the natural logarithm of the individual's risk of dying on the basis of a combination of AIS scores of the two severest head injuries. This analysis showed that the risk of dying as a result of a head injury, was three to ten times greater for a

non-helmeted rider than a helmeted rider. (Three times for the 'poor hard helmet', five for the 'hairnet' and 10 for the 'good hard helmet').

No investigation on possible deviations was carried out among the non-response group.

In a more recent study carried out by Wasserman et al. (1988), it would seem that the study carried out by Dorsch is the only one to make any judgment on the effect of wearing a bicycle helmet, basing findings on an actual situation. Their study was carried out in the neighbourhood of Burlington. In total, 516 cyclists were stopped and questioned. 19% said they had a bicycle helmet but only 8% wore them. The reasons given for non-use were discomfort and the short distance to be cycled. Education and marital status seemed to correspond best with the use of a cycling helmet.
Of the 19% that said they owned a bicycle helmet, 21 (4%) had had an accident resulting in a blow to the head, 7 of the 21 had sustained head injuries. Of the 21, 8 had been wearing a helmet at the time of the accident.
It was concluded from the data that: 'Within these limitations, these data offer very suggestive evidence that helmets afford protection from head injuries while cycling'. It was also concluded that these results corresponded with those gained by Dorsch.

9.3. An alternative to the bicycle helmet

In addition to offering road users protection in the form of protective clothing, other methods to reduce (severe) injuries involve modifying the construction of motorized vehicles. For example, for quite some time now, studies has been underway to investigate the possibilities of adapting the front of passenger cars in order to afford the pedestrian extra protection in case of collision. At present, a working group of the European Experimental Vehicles Committee (EEVC), with the financial support of the EC, is working on a concept regulation. Such measures would also prove effective for cyclists. Protective measures could be divided into the modification of both shape and construction.

Huijbers et al. (1988) have been able to show that shape influences the severity of head impact with a passenger car. With the aid of the model, MADYMO, head impact velocities and cyclist accelerations have been calculated for collisions with a number of widely varying passenger cars. 'The simulations indicate that the shape of the car has a considerable influence on the relative head impact velocity in case of a collision. Head impact velocities can be twice as high for an impact with a car with a relatively low front-end in comparison with a relatively high front-end. The peak acceleration values resulting from head/car impact show the same tendencies. For the adult in cruising position, peak values of head accelerations can be three times higher in contact with a relatively low vehicle front than with a high front'.
Construction modifications would aim at bringing the force of impact down to an acceptable level by, for example, making use of energy absorbing materials.

Given the fact that the majority of injuries are caused by contact with a vehicle (par. 6.2.2), and the great effect of wearing a helmet, as described in this report, the use of energy absorbing materials (a helmet for the passenger car) would also greatly contribute in reducing injuries. These activities fall outside the scope of this study. A survey of the results and the possibilities involved are described by the EEVC (1982, 1984).

10. OTHER ASPECTS

In the literature a number of other aspects with respect to the helmet, its usage and the effects thereof, are examined.
For example, the discussion on head injury criteria, dislodgment of the helmet, visors, a more effective combination of the protective padding and shell and the outer shell material. These aspects will be discussed in this section.

10.1. Head injury criteria

A. Head injury

In the past, various tests with animals under anaesthetic have attempted to answer the question, which factors are of importance when injury to the head occurs, in particular injury to the brain. Important researchers in this field have been Guardjian (1978), Ommaya (1971-1974) and Gennarelli (1982). These studies also considered the importance of acceleration in respect to head injury.

Ommaya refined this problem later by considering translational and rotational acceleration separately. These studies formed the basis for the theory that 'impact causes acceleration, which causes injury in sequence. Logic implies that minimizing injury risk is best achieved by limiting both components of acceleration'.

B. Head injury criteria

The most well-known criterion at present is the 'Head Injury Criterion' (HIC).

HIC

Expressed as a formula:

$$HIC = \left| \left[\frac{1}{(t2-t1)} \int_{t1}^{t2} a(t).\,dt \right]^{2.5} (t2-t1) \right|_{MAX}$$

The HIC is an 'acceleration weighted analysis' in which the factor time plays an important role.

Viano (1988) reviews the background of the origins of HIC via Holborn (1943), Patrick (1963), Gadd (1966), the Wayne State Tolerance Curve and the GSI. As the measurement of rotational accelerations was not technically possible at the outset of HIC, rotational acceleration has not been studied in further developments. However, the author (Holborn), did indicate the importance of this component as a cause of injury.
Since 1970 HIC is in common use. Recently the HIC procedure has been modified (Prasad et al., 1985): calculation is only permitted for head impact. In other cases the time interval is maximized. This is done to counteract misleading interpretations caused by HIC values in the absence of head impact.

However, if the study of data is approached differently, as Viano has done, much overlapping is observed between injury and non-injury. In actual fact, therefore, the HIC does not provide proper bio-mechanical predictions on injury.

Separate mechanisms will have to be defined for the various types of head injuries: i.e. skull fracture, vascular laceration, cortical contusion and neural and axonal injury. Descriptions would also have to emphasize soft tissue injury as the 'bio-mechanical cause of neural or vascular disruption'.

A great many researchers object to the use of the HIC as an injury criterion. The major objection is that calculations only consider translational acceleration. According to many researchers, it is rotational accelerations, rather than translational ones, which cause injuries.

Gilchrist et al. (1987) and Newman (1986) have recently strongly criticized HIC. Newman 'doubts that the dynamic process which occurs in brain injury can be correlated by an average kinematic parameter such as HIC'. Chamouard et al. (1986) who performed a series of drop tests with cadavers with and without helmets also concluded that 'there was no relation between HIC and injury severity'.

Aldman et al. (1978) have stressed 'the importance of oblique impacts in motorcycle accidents, resulting in rotational acceleration forces being applied to the skull and the brain'. They have suggested that in most of these accidents, head impacts would be oblique rather than perpendicular. Viano (1988) is also rather dubious as to the use of HIC as head injury criterion. Acceleration of the head alone is not the foremost criterion in describing the cause of head injury. A better explanation would be the rapid motion of the skull in respect to the soft tissue of the brain, that cannot manoeuvre so quickly because of its greater slow-moving mass. The deformation of the soft brain tissue places great strain on the blood vessels and causes them to rupture.

The 'Viscous Response', the production of the strain/stress rate, is the 'underlying cause of neurological trauma'. At present the deformation of the skull is not yet included in this criterion. Nevertheless it is a better approach than the HIC.

C. <u>Other theories for head injury criteria</u>

Viano (1988) developed a theory for skull and facial injuries: the force of impact causes a motion of the skull, resulting in fracture and also infiltration of the brain.

Skull injury:

IMPACT .....> FORCE (strain) .....> INJURY (fracture)

The same is valid for facial injury. Viano illustrates that measurements on the HYBRID III provide considerably higher values than in the case of a human being. As the human face is able to undergo many more transformations, the mechanical forces that occur will be far less. An impact with the HYBRID III gives a force of 17 KN and an HIC of 1100. Using a human cadaver, the same experiment gives a force of 5 KN and an HIC of 200.

Brain injury:

IMPACT .....> ACCELERATION (transl/rotat.).....> RAPID SKULL MOTION (displacement/velocity).....> BRAIN/SKULL INTERACTIONS (strain/stress rate).....> INJURY.

The bio-mechanism for brain injury is described by using the 'viscous mechanism'.

In the past, research has been undertaken on fractures occurring in the liver and heart etc. using this criterion. The viscous response (VR) is a measure of the visco-elastic reaction of tissue on dynamic displacement. Two parameters are of importance: strain or C-compression, and strain rate or V (velocity of deformation). Recent research has shown that there is a better correlation with neural trauma.

In the late 1960s and early 1970s, research was initiated in which the heads of human beings and animals were steered at different frequencies. On the basis of the measurements, which included resonances, a spring-damper model of the skull and brains was constructed (Mean Strain Criterion MSC).
The peak tension and displacement resulting from the induced velocity and calculated from the accelerations measured, was a standard for head injury risk. Later, Stalnaker improved the bio-fidelity of the model (NMSC model). According to Stalnaker, the energy dissipation of the damper elements correspond well with the risk of brain injury.
Another method to estimate the risk of brain injury was studied by General Motors. In principle, this method is partly analogous to Stalnaker's approach. The model described by GM makes use of more springs and dampers.

On the basis of the results, the mass-spring systems were found to predict reasonably well, however they have not, as yet, been fully elaborated. These systems also lack a rotational component although they do have credibility. Any model able to describe the interaction between skull and brain mass, must be able to provide better predictions than the surface model that only considers accelerations. Besides, it is known from practical situations that upper dura injuries especially often lead to severe consequences.

<u>Trosseille et al. (1988)</u>
A reconsideration of the HIC by introducing the 'Skull Bone Condition Factor' (SBCF). Emphasis on side impacts for head injury criteria. This is one of the attempts to improve the HIC prediction performance by incorporating more variables in the model, e.g. thickness of skull, diameter of head, mineralisation of skull, head mass (SBCF).

$HICp = HIC - (2.528/0.007) * SBCF$

However, HICp gives no description of some brain injuries and moreover does not include the occurrence of rotational accelerations in determining the injury.
The model works specifically in the lateral impact field where none or hardly any head rotations occur.

Goldsmith (1989)

'The current global acceleration criteria for closed-head injury should be replaced by a two-tier system of load limits based upon skull fracture determined from contact analysis of an elastic/brittle sandwich shell and cranial-trauma based, in the first level, on rupture characteristics of blood vessels, using analytical modelling of tubes representing blood vessels and an axon under dynamic loading'.

Rojanavich et al (1989)

'Head injuries are considered to be one of the most serious modes of injuries in traffic crashes.
Many studies were involved in the developments of some methods to predict the degree of head injury severity, based on measurable parameters. Unfortunately, progress was limited because most of the available head injury data from cadaver experiments and accident records, was inadequate for conducting a detailed empirical study. At the same time, a new cadaver is hard to obtain. And the experimental process involved in cadaver testing is very difficult, expensive and time-consuming'.
For the time being, little news can be expected in the field of head injury criteria.

As a valuable alternative, the authors are working with a theoretical model called TEC. The TEC was developed from the New Mean Strain Criteria (NMSC) and the Translational Head Injury Model (THIM). 'The latter model only refers to translational accelerations and does not address the consequences of angular motion. In the TEC, contusion head injuries were correlated with the energy dissipated by the damper while skull fracture was correlated with the rate of energy stored in the spring element'. An explanation was therefore found for the effect of the pulse length on head injury. More severe brain damage occurs more rapidly if the pulse length is higher than 5 m/s. A lower pulse length would probably indicate a skull fracture.

10.2. Dislodging of helmets

In the literature much is written on the phenomenon of helmets coming off the head in accidents. This aspect is reviewed in par. 6.2.2. The same paragraph also describes the Dutch study of the use of the chin strap, initiated on the basis of the results described in the literature.

In addition to the use of the chin strap, the construction of the helmet may cause it to be dislodged.

As no information on helmet fittings was available, the authors have rejected the notion that dislodgment was due to the helmet being too large.
As a further investigation, Gilchrist et al. (1988) used a special test formula to measure the heads of 500 motor cyclists and young people. These data were compared with the sizes and shapes of helmets available in Britain. It was concluded that 'the current range of sizes is far from ideal and suggestions for a better range of sizes are made'.

Most anthropometric data originate from the army. For the purposes of this study the heads of 460 students (Birmingham) and 47 motorcyclists were measured. In addition, 18 headforms from the BSI test centre in Hemel Hempstead were measured as well as the inside of the helmets with the aid of special equipment.

Results:
None of the helmets fitted 5% of the control group; they were all too small. The researchers propose that width and height sizes be included in the size system.

10.3. More optimum combination padding/outer shell

A number of studies have been published which consider further aspects of the padding/outer shell combination of the helmet. As Sarrailhe (1984) explains: 'Present day helmets for motorcyclists are highly effective in protecting the wearers but there are continuing pressures and efforts for improvement. It is considered that although the conventional test procedures have resulted in highly successful protection devices, the protection will not be improved by increasing the energy in the impact test'.

Stöcker et al. (1989)

The authors studied the optimum combination of outer shell/padding in order to minimize blow impact. Use was made of a twofold mathematical simulation technique.

In the first, classical, method, comparisons were drawn up of the equilibrium between the infinitesimal parts.
In the second method, finite element calculations were used. The variables consisted of the thickness of both the outer shell and the padding.

Results trends infinitesimal method:

Increase of accelerations with increase of thickness of outer shell.
Increase of accelerations with increase of density of the material of the padding. A slight decrease of accelerations was found as the thickness of the padding increased.
On the basis of the results, it was concluded that the best helmet was one with a thin outer shell (+/- 3 mm), a limited density of the padding (32 kg/m3) but with a greater thickness of the padding (35 mm). In view of the great difference between the ideally assumed situation (80 g constant throughout the impact interval up to 160 Nm) and the ideally calculated line that results in 200 g at 160 Nm, it was concluded the helmet could be improved.

Finite elements method:

With this method, the same trends were found as by the infinitesimal method; an increase in the thickness of the outer shell increases accelerations.
The same applies for an increase of the padding as well as decrease of its density.

The conclusion of this study is that by using this mathematical method the properties of the helmet can be calculated beforehand as the calculated values closely correspond with the measurements. In addition, considerable improvements can be made to the helmet; for example, by trying to achieve constant acceleration values as a function of the impact energy. Use of 'honeycomb' structured materials would be a step in the right direction. Grandel et al. (1987) describe tests using alternative types of foam, such as Hexcel, which demonstrate more effective absorption properties.

Hopes et al. (1989)

This TRRL report concerns the alleged shortcomings of motorcycle helmets currently used in Britain. Results were obtained from 150 drop tests of instrumented headforms and headforms under controlled conditions. The performance of practical helmets is compared with the protection that would be provided if the available space could be fully utilised for energy absorption as predicted, by applying equations of motion to an accepted injury criterion. HIC is used as the initial criterion but alternative methods of predicting brain injury are discussed and their underlying principles examined. Choice of present helmet materials and the current British Standard test procedure are examined.

Results from the project show that a 60% improvement could be achieved if more appropriate materials were used.

However 700 motorcycle fatalities still occur in Britain each year. The characteristics of a helmet, in offering protection from skull fractures, have been demonstrated by Chamoard et al. (1986). They performed a series of drop tests with cadavers, with and without helmets. In the 14 tests from a drop height of 1.8 m with a helmeted cadaver, there were no skull fractures. In the 8 tests without helmet from a height of 1.2 m, 4 fractures were reported.

Each helmet was tested 5 times: the crown, front, sides (2*) and rear of the helmet. Three rigidities of glass fibre shell were tested - standard, rigid and very rigid. Four densities of polystyrene padding were used - 25, 32, 44 and 55 g/l. Each combination of shell and padding was tested at 6.7 m/s. Standard helmets and 25 g/l padding were tested at 6.7 m/s without the shell. A purely experimental helmet consisting of an aluminium shell and a polyurethane padding was impacted at 6.7 m/s.
At least two bicycle helmets were tested.

The trend was for the HIC to increase as the rigidity of the shell and padding density increased. This was accompanied by an increase in rebound velocity. The rebound velocity was largely a function of helmet-shell design since the liner alone gave a small rebound velocity.

The tests with the bicycle helmets gave some unexpected results. The hard shell helmets gave an HIC in excess of 5000 from 6.7 m/s.

Polystyrene will crush satisfactorily to only half its depth. Even for the bicycle helmet, tested at 6.7 m/s, resulting in an HIC of 5000, the padding had crushed to only half its depth. The helmet, was in fact too strong at any (bicycle) speed. Conversely, a soft type of bicycle helmet which is often viewed as offering little protection, did give a very high HIC at 4.4 m/s, but the energy was absorbed in a perfect way. Up to an impact speed of 3 m/s, an HIC of 167 was calculated. The current British standard 6658 permits a linear acceleration of up to 300g from an impact velocity of 7.5 m/s but the pulse length is not specified. A helmet with typical rebound characteristics could give a clearly fatal HIC of 6800, yet still pass BS 6658. It seems therefore that the standard is inappropriate. As time-dependence is real it should be included in a standard test.

The problem is to find a satisfactory compromise. Greater insight into the injury tolerance values of the human head is important here.

The criteria by which helmets are judged should be based on a weighted integration of acceleration against time.

Rotational acceleration is also an important cause of injury and needs further examination.

10.4. Visors

(Christ et al., 1987)
A study of visor wearers and the findings as well as indirect lighting tests on a number of old and new visors.
In dry weather and daylight, 89% found vision through a visor good to very good.

At night and in rain, 73% found vision bad. Visors were often replaced: 38% after a period of six months, 40% after one year, 13% after two years. Various values for indirect lighting values: scratch-free average 3 (cd/m2)lx, non scratch-free 8 (cd/m2)/lx.

The researchers found a substantial difference in the extent to which the various drivers had scratched their visors after a corresponding number of km/hrs. They suggest that proper treatment and care would considerably extend the life span of a pair of visors.
The authors question whether tinted visors should be forbidden in traffic as they do not let sufficient light through.
At present the inclusion of a test procedure in ECE 22 is under discussion.

10.5. Material of the outer shell

The outer shell of a helmet must satisfy a number of requirements:
- the shell must provide resistance to penetration, avoiding injuries which could occur through impact with a relatively sharp object. The shell must be hard;
- it must distribute the impact load over a larger area of the absorption liner. The shell must therefore be elastic;
- it must not give way to the above-mentioned load as this will increase the risk of roll off.
The shell must be strong;
- if the wearer is run over, the shell must protect the head.
The shell must therefore be rigid.
From these requirements it would seem that the helmet must possess a great number of, often conflicting, mechanical properties, which it should maintain even after exposure to UV rays, water and petrol and should also remain in good condition for a long time.
Moreover, its material should be resistant to other chemical substances such as glue and paint.

The outer shell of a helmet is made from synthetic materials. The latter can be sub-divided into thermosets and thermoplastics.
Thermosets are insensitive to the effects of the variables mentioned (Motorrad, 1982). Many of the thermosets in use are glass fibre or aramide-reinforced synthetics, called KEVLAR. During manufacture, these materials demand a great deal of manual work and the helmets are therefore generally more expensive than helmets with thermoplastic outer shells.

It is not surprising therefore that most helmets have an outer shell made of thermoplastic material. Familiar examples are polycarbonate, polyamide

and ABS. However, there are also a number of differences between these polymers. Polycarbonate, for instance, is relatively cheap and moreover has excellent mechanical properties. These properties make the material especially suitable for the outer shell of a helmet although it does react adversely to UV rays and chemical substances.
The material will appear undamaged after contact with UV radiation or chemicals, but its chemical structure will have been completely disrupted. This can occur after only 30 seconds (Ravensdale, 1980).
Polyamide is not in common use now, due to its less favourable mechanical properties, although it is less sensitive to UV radiation.

In the group of ABS materials there are a number of types which differ from one another as widely as a Mercedes differs from the 2-CV (Motorrad, 1982).

Known types are TNP, used by GPA, and Ronfalin MST 42, developed by DSM. Several years ago in France, research was initiated to study the effects of the variables mentioned, on the materials used for the outer shell. Helmets of two years old were subjected to an absorption test. Of the ABS helmets, 42% did not meet the absorption requirement, while for the glass fibre and polycarbonate helmets this was 6%. The material in question was the TNP-ABS, which is widely used in France in the manufacture of helmets (Wojcieckowski, 1984).

As yet, no extensive study has been made of ageing phenomena as a characteristic of the various types of materials. Any influence attributed to this aspect has been gained from the study of accidents in which the outer shell of a number of old helmets, covered with stickers or paint, was found to have fractured completely (Pedder et al., 1982, Beier et al., 1985).
A study carried out by Valee et al. (1984) on accidents involving two-wheeled motorized vehicles, reveals a high incidence of fracturing of helmet shells (1/3 of all cases). The severity of injuries increases because of the loss of the helmet during the collision and a very poor distribution of impact forces over the shock-absorbent material. The occurrence of the fractures depends heavily on the material of the shell and the violence of the impact. Shell fractures were observed mainly in the case of the ABS material. The risk of skull fracture is three times greater when fracture of the helmet shell occurs.

11. CONCLUSIONS

1. Effective legislation on two-wheeler categories

- There is a great diversity of categories of motorized two-wheeled vehicles in EC Member States. The number of categories varies from three per country (Denmark, Ireland and Luxembourg) to six (Federal Republic of Germany).
  There are also sharp variations between countries in the laws on maximum speeds, the minimum age of riders and the required licenses.

2. Accident statistics

- In view of the substantial differences in involvement in accidents in each category of two-wheeled vehicles, the importance attached to specific measures for categories in European terms will be different for each country. In Luxembourg, Greece, France and Great Britain, riders of motorized two-wheeled vehicles with a cylinder capacity in excess of 50 cc represent a significant proportion of road accident casualties. The amount of pedal cyclists is relatively small, but in the Netherlands, Belgium, Denmark and the Federal Republic of Germany cyclists form a large proportion of accident casualties.

3. Accident studies

- Detailed accident studies lead to the conclusion that in terms of quantity and severity, head injuries predominate in the injuries suffered by pedal cyclists.

- If injuries to cyclists are compared with injuries to riders of motorized two-wheeled vehicles, head injuries prove to be far more frequent among cyclists than among riders of motorized two-wheeled vehicles (wearing helmets).

- Injuries to arms and legs appear to be the most common among riders of motorized two-wheeled vehicles. Of the more severe injuries, head injuries are the most frequent type.

4. Effective legislation on the use of helmets

- It is not compulsory for pedal cyclists to wear helmets in any EC Member State. Helmets are compulsory for riders of motorized two-wheeled vehicles in most countries. Only in Spain do moped riders not need to wear a helmet and riders of motor cycles with a cylinder capacity between 50 and 75 cc only need to wear helmets outside built-up areas.

Some countries, such as the Netherlands, Belgium and France, make an exception for the categories with a maximum speed of 25 km per hour (mopeds).

5. Use of helmets

- The information supplied by the countries shows that helmets, although compulsory, are not always worn in traffic.

  Compliance is 100% in Belgium, the Netherlands, Great Britain and the FRG (with the exception of the MOFA, 98%). In Denmark, 99% of motor cyclists and 85% of moped riders wear a helmet. In France, compliance among motor cyclists is 98% and among moped riders 88%. No information is reported on compliance in other EC Member States, but it is our observation that helmet-usage might be lower.

6. Quality of helmet-usage

- Various studies describe the fact that helmets sometimes come off the head in accidents. Research show that some cases can be explained by the construction of the helmet and others by the use of the chin straps by the wearers.
- Information on the use of chin straps is provided only by a study conducted by the SWOV in the Netherlands. A more or less analogous study was conducted in the FRG, but the results have yet to be published. The Dutch study shows 15% of moped riders do not fasten their chin straps at all and about half of moped riders do not fasten their chin straps securely enough (too loose). Of those who do fasten their chin straps, 10% do not used the fastening properly. Use of chin straps was found to be far better among motor cyclists than among moped riders. In the latter category, 2% failed to fasten chin straps and 14% did not fasten them securely enough.

7. Effectiveness of helmets

- The number of publications on the effect of helmet-wearing by cyclists is limited. One Australian study describes the effects of wearing cycling helmets. The risk of fatal head injuries is three to ten times as high for those who do not wear helmets as for those who do (three times as high with the 'poor hard helmet,' five times with the 'hairnet' and ten times with the 'good hard helmet').

- The literature contains descriptions of a large number of studies which have quantified the effects of helmet-wearing by riders of motorized two-wheeled vehicles. The estimated reductions in the number of casualties following the introduction of compulsory helmets vary between 10% and 50%. The risk that those who do not wear helmets will suffer (fatal) head injuries on the roads is, on average, four times as high as for those who do.

- Some studies describe negative effects of wearing helmets, such as a reduced field of vision and reduced hearing. Something which is often forgotten in respect of the frequently-heard claim that wearing a helmet has a negative effect on hearing of traffic is the total amount of noise to which riders of two-wheeled vehicles are exposed. In particular, they are exposed to noise caused by turbulence of the air around the head. This turbulence proves to produce far more noise without a helmet than with one, as helmets are often effectively streamlined.

8. Effective legislation on the requirements of helmets

- There are a number of European standards for cycle helmets (French and British). Other countries are currently preparing such standards. The majority of EC countries have accepted the ECE 22 international certification standard for helmets used by motorized two-wheeler riders. Some countries still use their own standards (France and Great Britain). For the purpose of this report, the ECE 22-03 requirements were compared with those of the British Standard BS 6658. There are no major differences between the two. The British standard appears to be more up-to-date, since in contains procedures for testing chin guards, for instance, as well as a special test for push button systems and tests for alternative fastening systems.

9. Requirements to be met by helmets

- On the basis of research results, it seems reasonable to conclude that integral helmets offer greater protection against facial injuries than jet helmets. The effect of the type of helmet is not substantial with other head injuries. In all probability, this is due to the fact that the chin section of an integral helmet is not included in shock absorption tests. Inclusion of this section in the test programme is currently under discussion within ECE.

- Some studies from the FRG conclude that there is a relationship between the material used for the outer shell and the incidence of head injuries: a smaller number of head injuries with GFK helmets than with ABS ones and a polycarbonate outer shell shatters far more easily, leading to a higher risk of more serious head injury.

- A Dutch study showed that a large number of moped riders are using helmets in which the outer shell can probably no longer provide the statutory level of protection.

- A British study compared the measurement system for helmets with anthropometric data on the head. This showed that 'the current range of sizes is far from ideal.'

- Some studies suggest that existing helmets are too rigid. The stringent absorption requirements of the certification procedures make these materials too hard at low levels of energy. The use of modern materials which have good shock absorbing properties at both high and low levels of energy would appear to offer a solution here.

- The outer shell of a helmet must satisfy a large number of requirements. The properties of the material must also be impervious to ageing and resistant to a number of chemicals and ultra-violet radiation. Little has been published on the effects of these variables on mechanical properties. One study indicated a reduction.

A consumer organisation research indicate that the quality of helmets for sale are not in agreement with ECE 22 requirements. Probably due to an unappropriate execution of the quality test procedure of ECE 22.

10. About the survey method

- The response rate of the Member States to the questionnaire was limited. About half of the EC countries returned a completed form within two months. A number of other countries responded after reminders. A number of forms were not completed in full. Information on two countries had to be gathered by alternative means.

11. Some other conclusions

- At present a European Committee for Standardisation (CEN) technical commission (TC 158; 'Protective helmets') is drawing up standards for helmets at the request of the Commission of the European Communities (Directorate General III, Internal Market and Industrial Affairs). Requirements for vehicle users' helmets and pedal cycle helmets, among other things, will be drawn up on the basis of existing requirements. A draft standard for motor cycle helmets has been prepared by a working group.

12. Summarizing

- Wearing of helmets by two-wheelers lead to less and less serious head injuries and make a major contribution to road safety, if helmets are worn correctly and meet certain requirements. From theoretical considerations and from research this conclusion is undisputable. However, there are clear indications that helmets are not worn properly, especially by moped-riders.
  Effective legislation on the use and on the requirements of helmets are not harmonized between EC Member States. Sharp variations exist also on maximum speeds, the minimum age of riders and the required licenses. Only a part of EC Member States have accepted the ECE 22 international certification standard.

12. RECOMMENDATIONS

Legislation

1. Compulsory usage of helmets for riders of two-wheeled motorized vehicles have prevented a large number of accident casualties in EC Member States. It is recommended to introduce compulsory helmet usage in the only EC Member State without legislation: Spain.
To increase the effectiveness of this measure, efforts must be made to ensure that everyone does ac- tually wear a helmet (in a proper way). In some Member States activities (information campaigns and police enforcement) could be launched to raise the compliance to 100%.

2. Regardless of whether it becomes compulsory for cyclists to wear helmets, certification standards should be drawn up for these helmets to enable cyclists who decide to wear one voluntarily to recognise a good one.

3. Problems relating to the bad use of chin straps could be solved if the only helmets available caused a high degree of discomfort to the user when chin straps were not fastened, but were comfortable when they were. Industrial innovation in this field should be encouraged.
Immediate replacement of clip systems by push button systems would already be a major improvement and is recommeded.

If efforts are also made to find a standard fastening system, the problem of many different fasteners and the related difficulties in effective first aid would also be solved.

4. At the request of the Commission of the European Communities (Directorate General III, Internal Market and Industrial Affairs), a number of CEN working groups are drawing up standards for industrial safety helmets, vehicle users' helmets, fire fighters' helmets and pedal cycle helmets. Existing requirements will be used as a basis for discussion. These activities form a good basis for the creation of a European certificate of approval for helmets: for motorized two-wheelers and cyclists.

5. The fact that removal of constraints to trade has the highest priority in the preparation of requirements is understandable in view of the ECE's objectives. Equally important selection criterion must be road safety. However, the decision-making procedure in which failure to accept a proposal by one of the member states means that the proposal is abandoned would seem to stand in the way of efficient changes in the present state of knowledge relating to injury mechanisms or developments in the field of improved materials.

6. All activities aimed at national certification requirements for cycling helmets should be halted. Activities in this field can be related to the CEN working group on pedal cycle helmets.
(Racing) cyclists who travel faster, and who not only become involved in collisions with passenger cars but also quite frequently suffer individual accidents, should certainly be advised to wear a helmet.

7. It is worthwhile to investigate the execution of the quality control procedures by manufactures and governments as described in ECE 22.

Technical requirements

8. Before recommendations can be made for improving the condition of the outer shell of helmets, the effect of the observed condition on the mechanical properties will have to be established, followed by the injury risk. In the short term, tests of a number of helmets in current use could provide useful information. If data on these helmets, such as their age, the materials used, damage etc. are known, the usual tests for certification would provide an insight into the effects on mechanical properties.
Depending on the results, the life and use of aggressive chemical elements could be included in the certification procedure.

9. Research is needed into better tolerance levels of head injuries.

10. Research is needed into the potential applications of more modern and better materials for the absorbing layer: i.e. materials which have good absorbance properties at both high and low levels of shock.

11. Requirements must be set for visors in respect of strength, ensuring that they cannot fly open while the vehicle is in motion and scratch-proofing, to prevent dangerous visual distortions at night.
Outer shells should not be painted or covered with transfers, since in some cases, the outer shell of helmets treated in this way shattered completely.

12. Ergonomic and comfort requirements should be included in the certification criteria.

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FIGURES AND TABLES

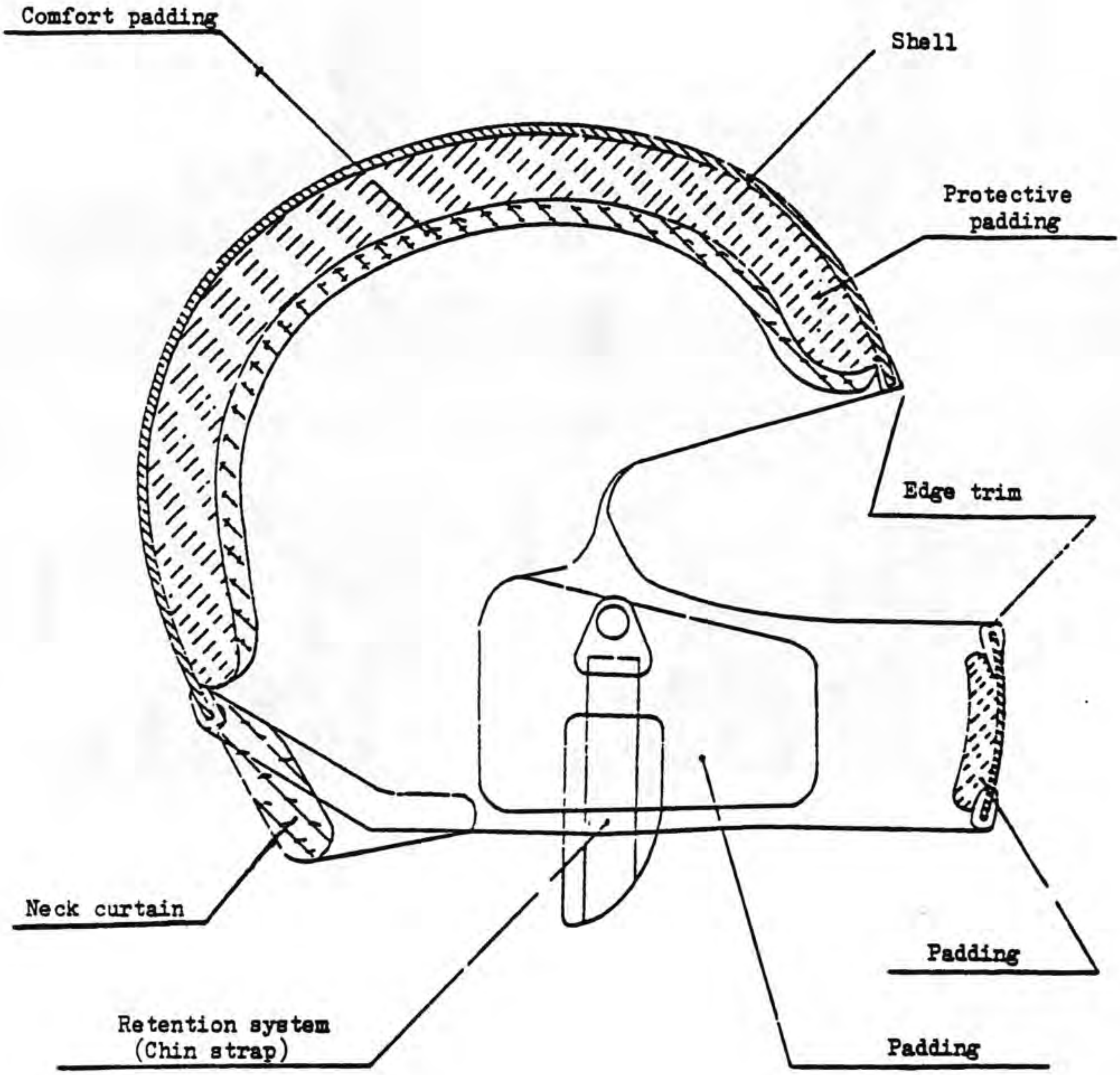
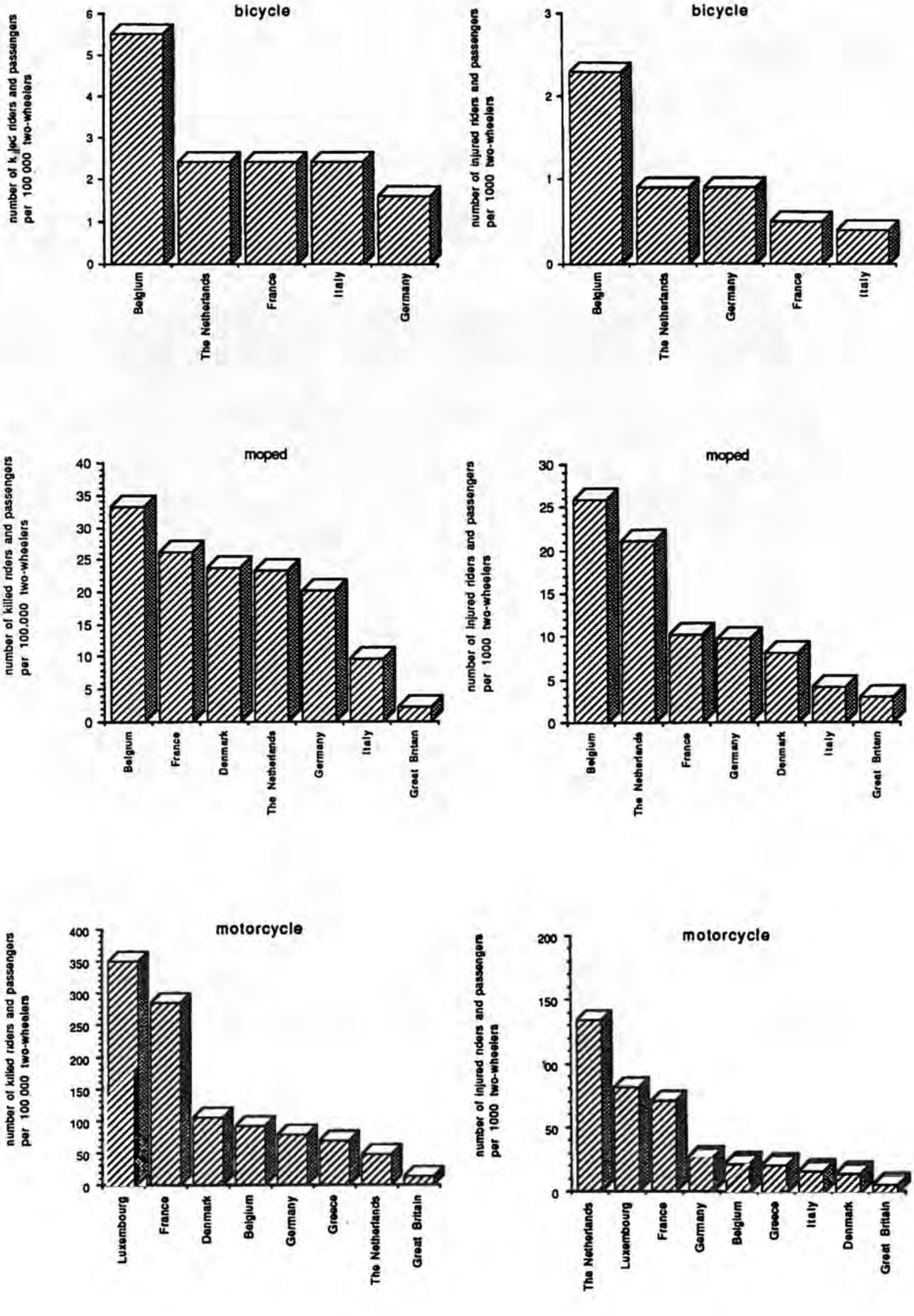


Figure 1. Cross-section of an integral helmet (ECE, 1987).



<u>Figure 2</u>. Fatalities (l) and injured (r) users of two-wheelers versus number of two-wheelers (1985%1988, See Table 3)

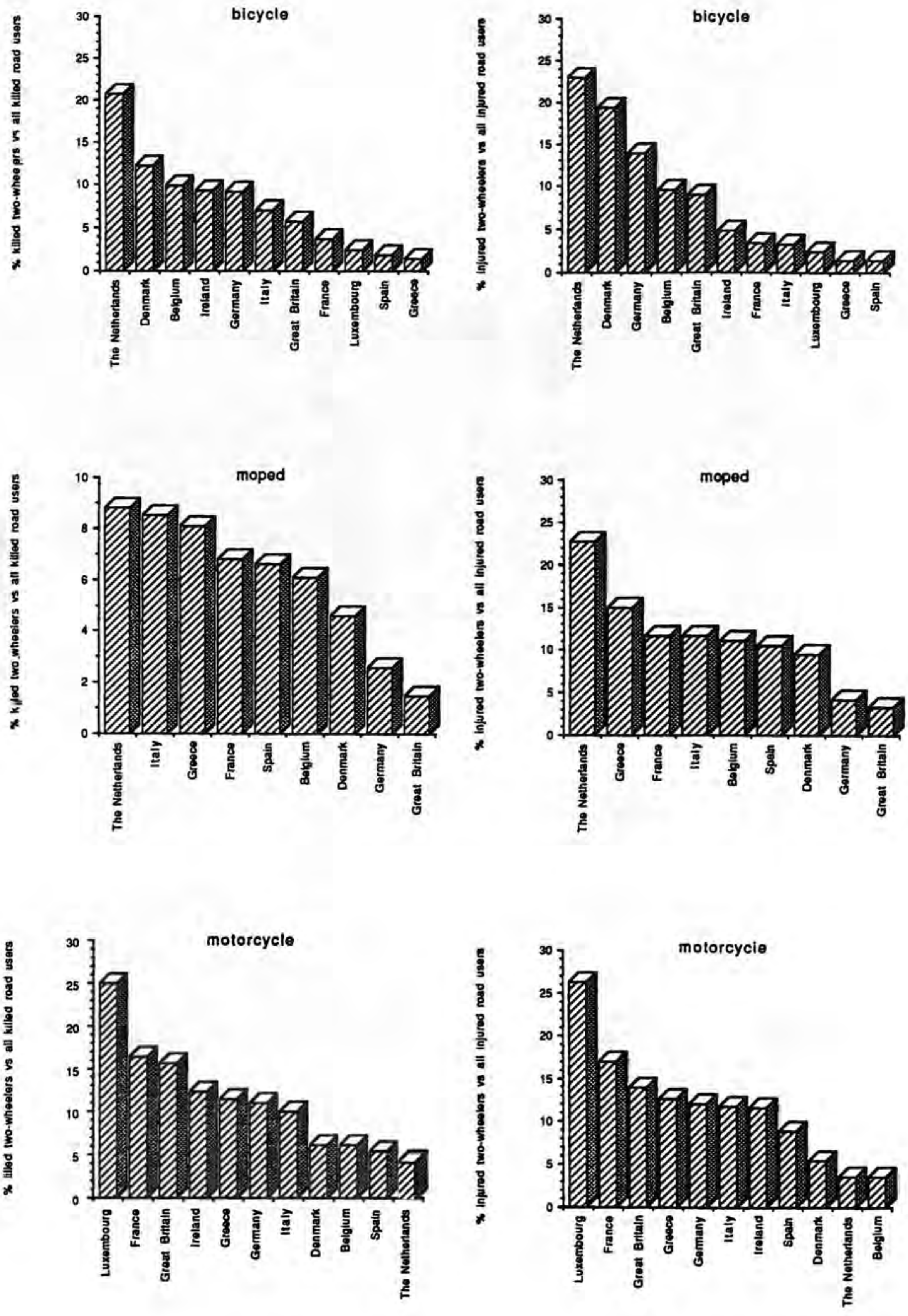


Figure 3. Fatalities (l) and injured (r) users of two-wheelers versus all road users (1986&1988, See Table 4)

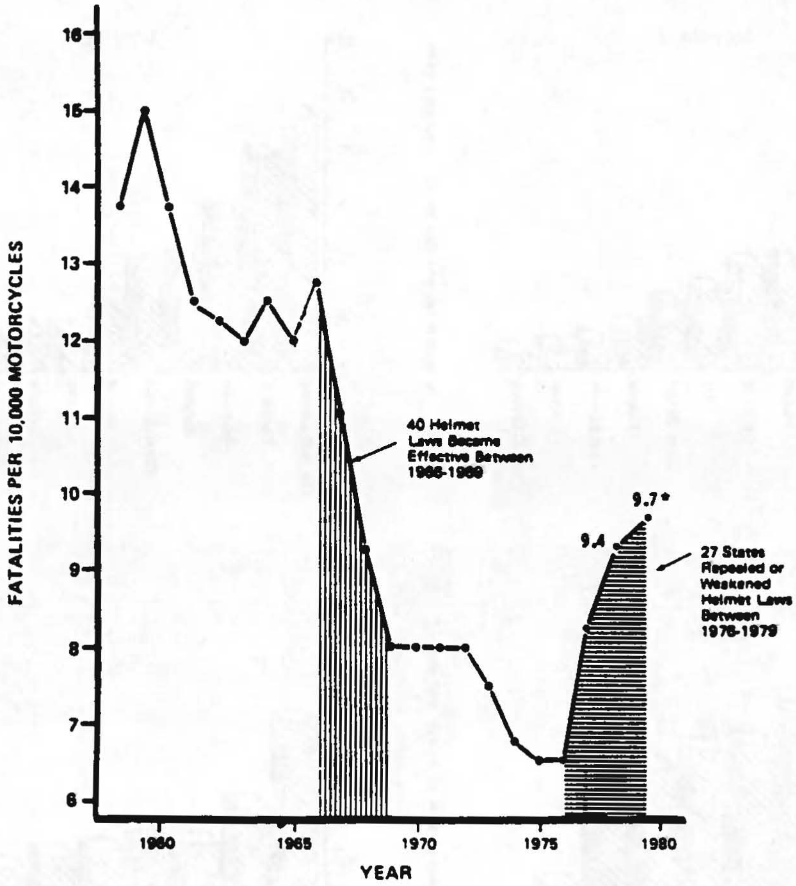


Figure 4. Motorcycle fatalities per 10 000 motorcycles 1958-1979 (NHTSA, 1980)

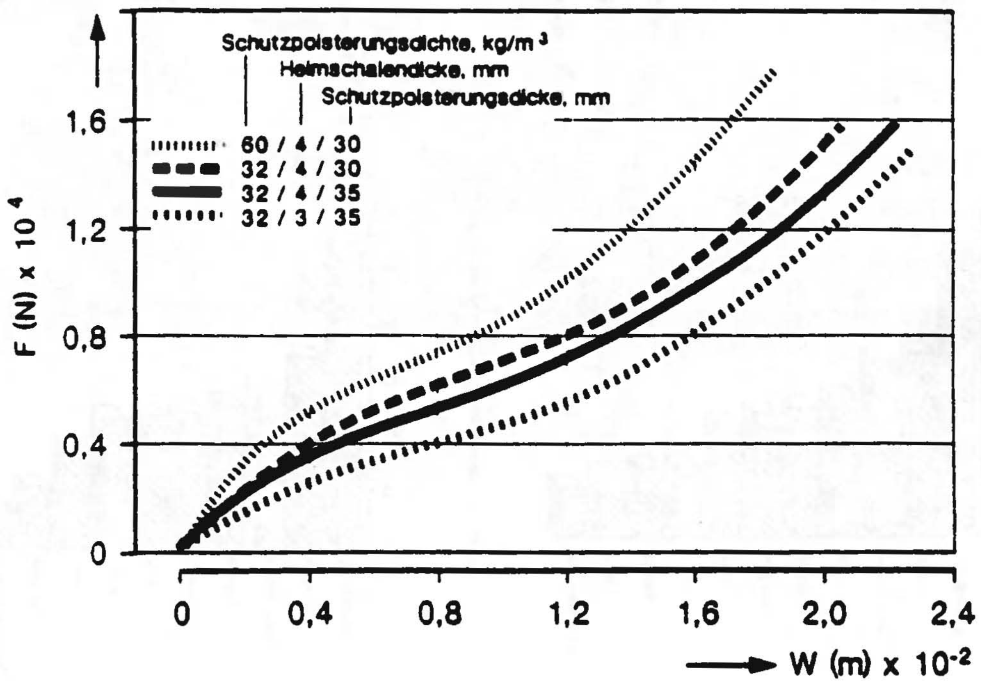


Figure 5. Load detection curve as a function of shell thickness, padding density and thickness (side impacts, finite elements) (Stöcker et al., 1989)

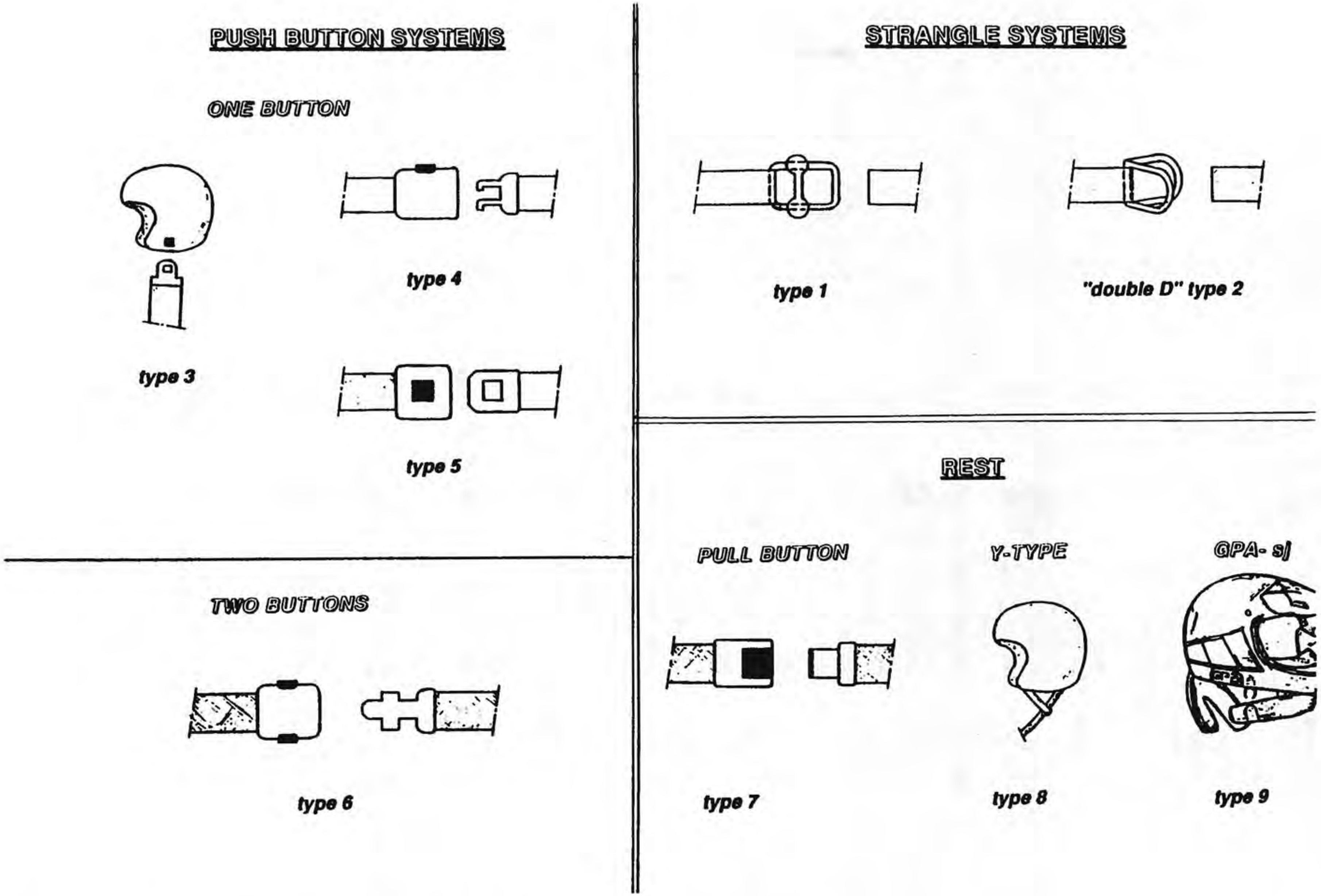


Figure 6. Different types of retention systems (Huybers et al. 1985)

Country	Piston displacement (CC)	Original name	Speed limit Inside (km/h)	Speed limit Outside (km/h)	Minimal age rider (years)	Driving licence
Belgium	< 50	bromf. A	25	25	16	no
	< 50	bromf. B	40	40	16	A 3
	< 400	motorfiets	60	90-120	18	A 2
	> 400	motorfiets	60	90-120	18	A 1
Denmark	< 50	moped	30	30	16	no
	< 400	motorcycle	-	-	18	yes
France	< 50	moped	45	45	14	no
	51 80	moto legere	60	75	16	A 1
	81 125	velomoteur	60	110-130	17	A 1
	> 125	motocycles	60	110-130	18	A
Germany	< 30	leichtmofa	25	25	15	no
	< 50	mofa	25	25	15	no
	< 50	Moped-kick	40	40	16	4
	< 80	L.kraftrad	50	50	16	1 B
	-	motorrad	50	100	18 20	1 A
Great Britain	< 50	moped	30 m/h	30 m/h	16	yes
	< 125	learner	30 m/h	30 m/h	17	yes
	> 50	motorcycle	40 m/h	40 m/h	18	yes
Greece	< 50	motorcycle	40	50	16	yes
	> 50	two-wheel	50	70	18	yes
	> 50	three-wheel	50	60	18	yes
Ireland	< 150	motorcycle	48	88	16	yes
	> 150	motorcycle	48	88	18	yes
Italy	< 50	ciclomotori	40	40	14	no
	< 150	motoveicoli	50	90	16	yes
	> 150	motoveicoli	50	90-130	18	yes
Luxembourg	< 50	bic motor	50	50	16	-
	> 50	motocycle	60	-	18 21	-
The Netherlands	< 50	snorfiets	25	25	16	no
	< 50	bromfiets	30	40	16	no
	> 50	motor	50	80-100-120	18	A 1
Portugal	< 50	moped	40	40	16	yes
	> 50	motorcycle	60	90-120	18	yes
	> 50	m.c.zijspan	50	60 90	18	yes
Spain	< 50	moped	40	40	16	no
	50 75	motorcycle	60	90-120	16	yes
	> 75	motorcycle	60	90-120	18	yes

Table 1. Classes of two-wheelers

Country	Two-wheeler class	Helmet Compulsory Rider yy-mm-dd	Passenger yy-mm-dd	Helmet use Inside %	Outside %	Helmet standard
Belgium	bromf. A	no	no	-	-	-
	bromf. B	76 10 01	76 10 01	ca 100	ca 100	ECE 22
	motorfiets	76 05 01	76 05 01	ca 100	ca 100	ECE 22
	motorfiets	76 05 01	76 05 01	ca 100	ca 100	ECE 22
Denmark	moped	77 01 01	no	85	85	ECE 22
	motorcycle	77 01 01	77 01 01	99	99	ECE 22
France	moped	80 01 01	no	88	no	NF s72 305
	moto legere	80 01 01	80 01 01	97	97	NF s72 305
	velomoteur	??	??			NF s72 305
	motocycles	73 07 01	73 07 01	97	98	NF s72 305
Germany	leichtmofa	no	no	-	-	
	mofa	81 10 01	81 10 01	98	?	ECE 22
	moped-kick	78 07 24	78 07 24	100	?	ECE 22
	L kraftrad	80 01 04	80 01 04	100	?	ECE 22
	motorrad	76 01 01	76 01 01	100	?	ECE 22
Great Britain	moped	73 06 01	73 06 01	100	100	BS6863 1987
	learner	73 06 01	73 06 01	100	100	BS6658 1985
	motorcycle	73 06 01	73 06 01	100	100	BS6658 1985
Greece	motorcycle	1983	1983	?	?	?
	two-wheel	1983	1983	?	?	?
	three-wheel	1983	1983	?	?	?
Ireland	motorcycle	yes	yes	?	?	?
	motorcycle	yes	yes	?	?	?
Italy	ciclomotori	86 07 18	no	?	?	ECE 22
	motoveicoli	86 07 18	86 07 18	?	?	ECE 22
	motoveicoli	86 07 18	86 07 18	?	?	ECE 22
Luxem-bourg	bic motor	1982	1982	?	?	ECE 22
	motocycle	1982	1982	?	?	ECE 22
The Nether-lands	snorfiets	no	no	-	-	-
	bromfiets	75 02 01	75 02 01	99	99	ECE 22
	motor	74 01 01	74 01 01	100	100	ECE 22
Portugal	moped	yes	yes	?	?	?
	motorcycle	yes	yes	?	?	?
	m.c.zijspan	yes	yes	?	?	?
Spain	moped	no	no	?	?	-
	motorcycle	outside	outside	?	?	ECE 22
	motorcycle	yes	yes	?	?	ECE 22

Table 2. Helm use and definition

Country Year of statist.	Class of two-wheelers	Accidents with two-wheelers Killed (rider + pass.) with helmet	without helmet	unknow helmet	total	Injured (rider + pass.) with helmet	without helmet	unknow helmet	total	Number of two-wheelers (population) x 1000	Number of killed per 100.000 two-wheelers	Number of injured per 1000 two-wheelers
Belgium	fiets				191				8080	3500	5,5	2,3
1987	bromf. A+B	106	8	4	118	8317	269	634	9220	356	33,1	25,9
	motorcycle	106	8	6	120	2609	65	325	2999	131	91,6	22,9
Denmark	bicycle				87				2283	?		
1986	moped	22	9	2	33	728	315	79	1122	139	23,7	8,1
	motorcycle	29	9	6	44	552	83	11	646	42	104,8	15,4
France	bicycle				401				8565	17000	2,4	0,5
1986	moped	470	186	61	717	23154	3593	1598	28345	2740	26,2	10,3
	moto legere	50	15	5	70	1707	202	75	1984	95	73,7	20,9
	velomoteur	644	120	28	792	16344	1346	1032	18722	739	107,2	25,3
	motocycles	694	135	33	862	18051	1548	1107	20706	834	103,4	24,8
Germany	bicycle				730				40764	46000	1,6	0,9
1987	mofa/moped				163				7853	807	20,2	9,7
	l.kraftrad				48				2962	327	14,7	9,1
	motorrad				876				25969	1391	63,0	18,7
Great	pedalcycle				293				27970	?	??	
Britain	moped				74				10291	3520	2,1	2,9
1987	motorcycle				800				42885	6260	12,8	6,9
Greece	cycle				21				365	?		
1986	motorcycle				122				3977	179	68,2	22,2
	two-wheel				173				3356			
Ireland	cycle				36				410	?		
1985	motorcycle				48				967	?		
Italy	ciclo				473				7168	20000	2,4	0,4
1987	ciclomotori				575				25300	6000	9,6	4,2
	motoveicoli				682				25587	1500	45,5	17,1
Luxem-	cycle				2				44	?		
bourg	bic motor				?				?	2		
1987	motorcycle				21				490	6	350,0	81,7
The	fiets				282				11006	11695	2,4	0,9
Nether	snor/bromf.				120				10880	516	23,3	21,1
lands	motor				62				1745	130	47,7	134,2
1988												
Spain	cycle				104				2157	?		
1987	moped				389				16046	?		
	motorcycle				321				13716	?		

Definition of dead: within 30 days after the accident
exept: Italy 7 days, France 6 days, Greece 3 days, Spain and Portugal 24 hours.

Table 3. Accident rates of two-wheelers and numbers of two-wheelers

Country	Class of two-wheelers (cc)	Accidents with two-wheelers Killed	Injured	Total	Acc. all road users Killed	Injured	Total	perc. two-wheelers Vs all road users Killed	Injured	Total	Year of statistics
Belgium	fiets	191	8080	8271	1922	83856	85778	9,9	9,6	9,6	1987
	< 50	118	9220	9338	1922	83856	85778	6,1	11,0	10,9	
	400	120	2999	3119	1922	83856	85778	6,2	3,6	3,6	
Denmark	cycle	87	2283	2370	713	11790	12503	12,2	19,4	19,0	1986
	< 50	33	1122	1155	713	11790	12503	4,6	9,5	9,2	
	< 400	44	646	690	713	11790	12503	6,2	5,5	5,5	
France	cycle	401	8565	8966	10536	243545	254081	3,8	3,5	3,5	1986
	< 50	717	28345	29062	10536	243545	254081	6,8	11,6	11,4	
	51 80	70	1984	2054	10536	243545	254081	0,7	0,8	0,8	
	81 125	792	18722	19514	10536	243545	254081	7,5	7,7	7,7	
	> 125	862	20706	21568	10536	243545	254081	8,2	8,5	8,5	
Germany	fahrraeder	730	15126	15856	7967	108629	116596	9,2	13,9	13,6	1987
	< 30	163	3459	3622	7967	108629	116596	2,0	3,2	3,1	
	< 50	48	1355	1403	7967	108629	116596	0,6	1,2	1,2	
	> 50	876	13044	13920	7967	108629	116596	11,0	12,0	11,9	
Great Britain	cycle	293	27970	28263	5103	308972	314075	5,7	9,1	9,0	1987
	moped	74	10291	10365	5103	308972	314075	1,5	3,3	3,3	
	motorcycle	800	42885	43685	5103	308972	314075	15,7	13,9	13,9	
Greece	cycle	21	365	386	1502	26478	27980	1,4	1,4	1,4	1986
	< 50	122	3977	4099	1502	26478	27980	8,1	15,0	14,6	
	> 50	173	3356	3529	1502	26478	27980	11,5	12,7	12,6	
Ireland	cycle	36	410	446	387	8323	8710	9,3	4,9	5,1	1985
	< 150	48	967	1015	387	8323	8710	12,4	11,6	11,7	
Italy	cycle	473	7168	7641	6791	218845	225636	7,0	3,3	3,4	1987
	< 50	575	25300	25875	6791	218845	225636	8,5	11,6	11,5	
	> 50	682	25587	26269	6791	218845	225636	10,0	11,7	11,6	
Luxembourg	cycle	2	44	46	84	1863	1947	2,4	2,4	2,4	1987
	> 50	21	490	511	84	1863	1947	25,0	26,3	26,2	
The Netherlands	fiets	282	11006	11288	1366	47981	49347	20,6	22,9	22,9	1988
	< 50	120	10880	11000	1366	47981	49347	8,8	22,7	22,3	
	> 50	62	1745	1807	1366	47981	49347	4,5	3,6	3,7	
Spain	cycle	104	2157	2261	5858	153388	159246	1,8	1,4	1,4	1987
	< 50	389	16046	16435	5858	153388	159246	6,6	10,5	10,3	
	> 50	321	13716	14037	5858	153388	159246	5,5	8,9	8,8	

Table 4. Accident rates of two-wheelers and of other users

Location injuries	1971 %	1972 %	1973 %	1974 %	1975 %	1976 %
Cyclists						
- head	50,5	50,7	51,4	49,9	50,2	51,7
- trunk + arms	23,8	23,5	24,6	24,4	24,2	25,7
- legs	25,7	25,7	24,0	25,7	25,7	22,6
	100	100	100	100	100	100
Mopedists						
- head	57,1	54,2	53,2	51,8	43,5	41,0
- trunk + arms	16,7	20,0	20,9	21,7	25,3	26,5
- legs	26,2	25,8	25,9	26,5	31,3	32,5
	100	100	100	100	100	100
Car occupants						
- head	43,3	49,7	49,6	50,0	47,9	47,5
- trunk + arms	35,7	32,4	33,2	33,4	35,7	36,8
- legs	20,9	17,8	17,2	16,6	16,4	15,7
	100	100	100	100	100	100
Pedestrians						
- head	46,5	48,3	44,7	45,1	44,4	43,9
- trunk + arms	24,3	23,4	24,4	25,7	25,5	26,1
- legs	29,2	28,3	30,9	29,4	30,0	30,0
	100	100	100	100	100	100

Table 5. Location of injuries of traffic casualties, The Netherlands 1971-1976 (SWOV, 1978).

Country: ....

		DEFINITION OF TWO-WHEELER					
No.	**Questions**	**BICYCLE**	**MOTO. 1**	**MOTO. 2**	**MOTO. 3**	**MOTO. 4**	**MOTO. 5**
1.0	Name of class	X					
2.0	Piston displacement [cc]	X					
3.0	Speed limit inside built up areas [km/h]						
3.1	Speed limit outside built up areas [km/h]						
4.0	Minimal age rider [years]						
5.0	Driving licence rider						

No.	Questions	BICYCLE	MOTO. 1	MOTO. 2	MOTO. 3	MOTO. 4	MOTO. 5
		HELMET USE AND DEFINITION					
6.0	Helmet compulsory for rider since [mm-dd-yy]*1						
6.1	Helmet compulsory for pass. since [mm-dd-yy]*1						
7.0	Helmet standard *2						
8.0	% helmet use inside built up areas *3						
8.1	% helmet use ouside built up areas *3						

* 1 If not are there plans to adopt legislation. When? Are there any restrictions of the law? e.g. only outside built-up areas. If so, what restrictions. Please send a copy of the relevant provisions.

* 2 If not ECE 22 please send a copy of this standard.

* 3 Is there more information about use e.g. use of the helmet by age or by rider or passenger, or information on proper use of the retention system in your country? Please send this information.

No.	Questions	STATISTICS *4 BICYCLE	MOTO. 1	MOTO. 2	MOTO. 3	MOTO. 4	MOTO. 5
9.0	Number of vehicles						
9.1	Year of statistics						
10.0	Number killed in road accidents *5						
10.1	Number killed in road acc. with helmet						
10.2	Number killed in road acc. without helmet						
11.0	All injured in road acc.						
11.1	All injured with helmet						
11.2	All injured without helm.						
11.3	Year of statistics						

* 4 Supply the most recent information.
* 5 Give a definition of a killed road user.

12.0 Total number of killed road users in the same year (11.3): ....

12.2 Total number of injured road users in the same year (11.3): ....

13.0 Number of cars: .... **Year:** *4

If there is any information in your country about:

1) **Differences in injury severity or in injury distributions by the use of a helmet.**
2) **Effects of the use of a helmet on risk of being killed or injured.**

Please send us this information.

This questionaire was filled in by:

NAME:

INSTITUTE:

ADRESS:

TELEPHONE:

TELEFAX:

SWOV '89