

Seat Belts and Other Devices to Reduce Injuries from Traffic Accidents

Report on a WHO Technical Group

Meknès
26-28 June 1979

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WHO TECHNICAL GROUP ON PROTECTIVE DEVICES AND RESTRAINT SYSTEMS TO MINIMIZE INJURIES CAUSED BY ROAD TRAFFIC ACCIDENTS

Meknès, 26-28 June 1979

1. INTRODUCTION

The Regional Office for Europe of the World Health Organization, in collaboration with the Government of Morocco, convened a meeting of a Technical Group to discuss protective devices and restraint systems to minimize injuries caused by road traffic accidents at Meknès from 26 to 28 June 1979. It was one of a series of meetings of technical groups concerned with different aspects of road accident prevention, which are called to review the major scientific findings in this field and which provide an input to the WHO global programme on road accident prevention, for which the Regional Office for Europe is responsible, in accordance with the priority attached to this field (1).

In the industrialized countries road traffic accidents are a major public health problem, which has grown over the last 50 years along with the growth of vehicle ownership. Levels of ownership stabilize at one vehicle for between two and three persons; at that point road traffic accidents rank fourth in most industrialized countries as a cause of death, after heart disease, neoplasms and respiratory infections (2).

In the short term of the next 5 to 10 years in the industrialized countries, little change in accident rates can be expected from changes in road-user behaviour and improvements in the traffic environment. Past experience of behavioural change programmes indicates that improvements in road-user behaviour occur slowly over a long time. Similarly, the long period — many decades — over which large investments have been made in the environmental infrastructure means that any short-term changes in the traffic environment are necessarily of limited impact. Hence it is important to accept that collisions will continue to occur, in the developed countries, at approximately the same rates as at present for at least the next decade. Consequently, all measures to minimize the severity of the trauma resulting from those collisions need to be considered.

In the developing countries vehicle ownership rates are in general rising fast. It is not uncommon for ownership levels to double in five years. As a result, road traffic accidents are becoming a major problem, with some distinct differences from accidents in the industrialized countries. Even with

the still relatively low levels of vehicle ownership in developing countries the consequences of road accidents are severe. It has been estimated that approximately 1% of the gross national product (GNP) is consumed in the effects of road accidents in many of the developing countries (3). Since they still have relatively few vehicles, they should introduce without delay protective devices and policies that mitigate trauma so that they can avoid the mistakes and omissions of the industrialized countries and take early advantage of new knowledge with regard to crash performance.

The scope and purposes of the meeting of this Technical Group reflected these problems and needs. The Group was given the following objectives:

- to examine injury patterns of the different groups of road users;
- to review crash protection measures and data, particularly from hospitals, that could provide indicators of the efficiency of such measures;
- to identify major problems for which successful solutions had been found and to recommend specific action in respect of them;
- to identify the major problems for which there are no obvious solutions and which need further research (in this respect, the Group was asked to discuss the role of biomedical research in crash studies and crash protection research, and to make recommendations for a more structured and rational use of medical research in this field);
- to review international collaboration especially in research, information and standardization.

The Group consisted of temporary advisers from 14 countries, including Nigeria and Tunisia, and a WHO staff member (see Annex V for list of participants). The disciplines represented were engineering, epidemiology, medicine, public health, and surgery. Five national road-traffic safety research institutes were represented.

To aid the Group in its discussions five working papers had been made available as well as three background documents.

The meeting was opened by the Minister of Health, Dr Rahal Rahhali and the Minister of Transport, Mr Mohand Nacer, who welcomed the participants and referred to the close cooperation between Morocco and WHO in respect of the organization of emergency services, and to the strengthening of road safety activities in Morocco. The Group was also welcomed by Mr Tayeb Bencheikh, Secretary of State for the Plan and for Regional Development, and Mr Doubi Mohamed Kadmiri, Governor of the Province of Meknès.

Dr Leo A. Kaprio, WHO Regional Director for Europe, was represented by Dr C.J. Romer, Regional Officer for Accident Prevention. In thanking the Government of Morocco for acting as host to the meeting, he referred to the active collaboration between WHO and Morocco, especially in regard to the

organization of emergency services. The experience already gained in Morocco would provide the Group with important information, especially about the specific problems of countries at a similar level of socioeconomic development.

Professor A. Belmahi and Mr M. Feraa were elected Chairmen and Dr G.M. Mackay Rapporteur.

2. THE EPIDEMIOLOGY OF ROAD TRAFFIC INJURIES

2.1 Deaths

Although figures are not readily available from several sizeable countries (e.g., Argentina, China, Egypt, India and the USSR) it is clear that there are almost 300 000 deaths from road accidents annually in the world and that total casualties number up to 10 million.

The most recent statistics are shown by geographic regions in Annex III, but those numbers are minima since only certain countries furnish such statistics regularly.

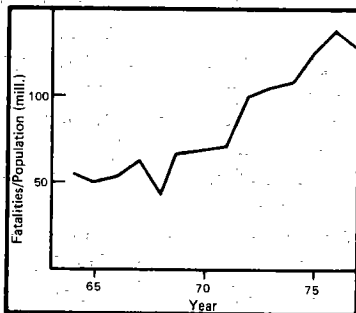
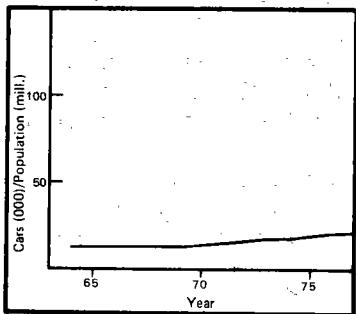
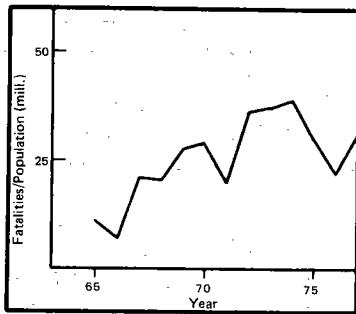
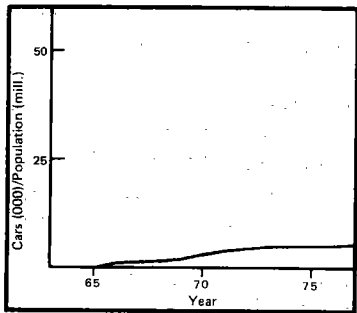
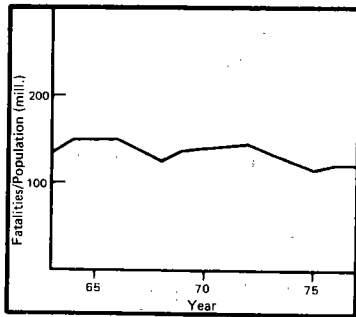
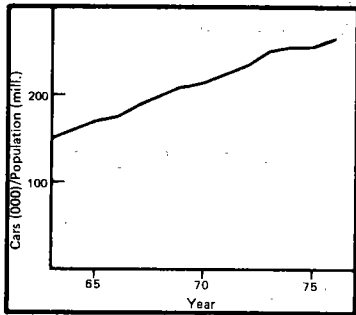
Much of the variation in road deaths between different countries and at different times in the same country can be explained in terms of population size (P) and numbers of vehicles (V). Smeed (4) found that the best fit for annual road deaths was $0.0003 (V \cdot P^2)^{1/3}$, and it is remarkable how widely this formula is applicable. An important concept is the degree of motorization or vehicles per head of population (V/P). With increasing vehicle ownership road deaths rise, but less than might be expected, so that deaths per vehicle fall as V/P rises. Presumably, this is a general measure of many changes such as improved roads, better vehicles, changes in driving behaviour and better medical care of casualties.

In the industrialized countries these adaptations to road transport have been spread over 70 years or more. However, in many developing countries changes have been much more rapid, and the statistical relationship of Smeed does not apply to them for certain periods of time. With a very rapid development of motorization the death rate per vehicle can rise with an increasing level of vehicle ownership.

One consequence in some developing countries is that although relatively few people own vehicles, the risks of accident may become so high over a short period that road deaths per head of population may exceed those of industrialized countries (Fig. 1).

Jacobs (3) has proposed alternative relationships between traffic deaths, population and vehicle ownership for the developing countries, and he has also shown that the proportion of fatalities to total casualties is closely affected by both the proportion of motorcycles to total vehicles and the quality of medical facilities available.

Fig. 1. Cars/population rates versus fatalities/population rates in countries at different stages of motorization



Sources: 1. *Demographic year book, 1963-1967*. New York, United Nations, 1964-1968. 2. *World health statistics annual, 1964 & 1965*. Geneva, World Health Organization, 1967/68 & 1968/69. 3. Transport Road Research Laboratory, Crowthorne, United Kingdom.

Further analyses of the industrialized countries show that, in spite of a general fit with the Smeed formula, persistent differences remain between some countries so that the same ones are always above or below the expected values. For example, with similar levels of vehicle ownership, the risk of road death in France or the Federal Republic of Germany is about double that of Great Britain or Sweden (5).

2.2 Categories of road user

Most road vehicles are cars and most road injuries are sustained by car occupants or pedestrians struck by cars. In spite of great changes in numbers of vehicles, pedestrian fatalities per million population tend to remain steady, but the rates differ between countries. In developed countries pedestrian casualties account for 15% to 40% of total road deaths and deaths of vehicle occupants for 40% to 60%. In the same countries deaths of vehicle occupants per thousand vehicles have fallen with time and with increasing numbers of vehicles. In Great Britain, for instance, the rate fell from 0.48 deaths per thousand vehicles in 1966 to 0.18 in 1976; the corresponding figures for the Federal Republic of Germany were 1.07 and 0.36.

These risks are very much lower than those for motorcycle riders (e.g., in the United Kingdom in 1976 there were 1.1 deaths per thousand machines). On an average, motorcyclists travel only about 25% as far as the average car driver, so that their risk of death per mile travelled is about 20 times as high as that for car drivers. Mopeds also present special problems in several European countries, where their number has increased rapidly.

Pedal-cyclists share with pedestrians almost total exposure to the violence of motor vehicles. Numbers of deaths vary with the popularity of bicycles. It has been estimated that the risk of death per mile travelled by cyclists in Great Britain is about half that for motorcyclists. Statistics of numbers of cycles are not normally available, so that comparable risks per thousand vehicles are unobtainable. It would be of interest to compare rates for countries such as the United Kingdom and the USA, where few special facilities are provided, with rates for the Netherlands where there are special cycle tracks, and with rates for countries such as China where there are many cycles but few cars.

2.3 Personal factors

For each category of road user there is a marked change of road-accident rate with age. The main factors in this are exposure and competence. As soon as children can walk, they are liable to have pedestrian accidents. The age-specific risk per exposure is very high in the early years but falls as competence improves. A peak occurs at about the age of 7, after which exposure increases markedly but is more than outweighed by the improved competence

associated with experience. The same sequence can be seen with pedal cyclists (peak-rate age 10), motorcyclists (peak-rate age 19) and car drivers (peak-rate age 21). In other countries with different regulations and traffic customs these peak rates may be at slightly different ages.

The lowest rates are found in mid-adult life, after which competence again seems to regress with the impaired motor and sensory abilities of advancing years; new high rates per exposure are again found at 65 years and above. It is disputed whether sex as such has an important effect: Rates per exposure are usually higher in females but experience of traffic is commonly less. However, there are potentially important differences of exposure within categories; one is that a higher proportion of females ride as car passengers than as drivers. This may have implications for protection from injury.

Apart from obvious severe disabilities, medical conditions have little bearing on accident risk. It seems that, as with many aged persons, the moderately disabled commonly select relatively safe traffic conditions and so avoid the high accident rates that would otherwise be expected. An example of disability which is much more prevalent than the common physical disabilities is that due to alcohol consumption; for example, almost half of the young drivers fatally injured in the United Kingdom have blood alcohol levels higher than the permitted level of 80 mg%.

2.4 Patterns of injury

When dealing with descriptions of patterns of injuries sustained by the several categories of road user, it is important to be clear about what boundary conditions apply to various sample studies. In addition there are no uniform definitions for the descriptions of anatomical parts, so that comparisons need to be made with caution. For example, the thoracic spine is often included with the chest as one zone, and occasionally the head and cervical spine are similarly combined. There are numerous studies of patterns of injuries amongst both fatally injured and survivors. A detailed review of these data is beyond the scope of this report but the following conclusions are relevant.

1. For pedestrians the main cause of death is head injury from car contacts. For surviving pedestrians both serious head and serious lower-limb injuries are typical.
2. For motorcycle riders the main cause of death is also head injury, but severe injuries to the chest and abdomen are common. A feature of motorcycle fatalities is both the multiplicity and the great severity of the trauma sustained. For surviving motorcycle riders injuries to the extremities occur with great frequency; those to the legs often cause significant long-term disabilities.

A feature of motorcycle casualties in industrialized countries in particular is a very significant proportion of survivors with serious brain damage. Rehabilitation prospects for these casualties are poor and the cost of health care for them, because they are predominantly young, is extremely high.

3. For bicycle riders head injuries predominate amongst both fatal casualties and survivors. Lower-limb injuries are fairly frequent, and a specific problem of foot injuries to child cyclists from spokes has been identified.

4. For car occupants, in fatal cases, both head and chest injuries are of almost equal importance; among survivors lower-limb injuries are a frequent cause of disability. The use of seat belts by car occupants reduces the risk of all types of injury. Amongst car occupants who are injured, the use of seat belts changes the anatomical distribution of injuries and also, for collisions of equivalent impact severity, reduces markedly the risk of specific injuries (6). For unbelted occupants ejection is still identified as an important mechanism of injury, although it has been reduced with the introduction of anti-burst lock designs in car doors.

5. For occupants of light vans, patterns of injury vary significantly from those of car occupants. Ejection is a more important mechanism of injury, and lower-leg injuries occur more frequently; chest and head injuries occur less frequently (7). In lateral collisions vans appear to have some substantial advantages over cars.

6. For occupants of trucks, patterns of injury differ substantially from those of car occupants. Severe injuries to the lower leg are particularly prominent amongst serious casualties, and chest and head injuries are relatively less frequent. Fatal injuries are strongly associated with massive intrusion of the cab structure or with ejection of the occupants (8).

A useful epidemiological survey of road users treated in a casualty department at Odense, Denmark, is illustrated in Annex I (fig. 1). Those data show the frequency with which the more common categories of road user receive injuries of various severities (9). The absence of coherent data such as these for other countries, particularly from the developing world, is an important gap in our knowledge. Without such data it is difficult for countries to establish priorities for action programmes or to monitor the effectiveness of changes as they are introduced.

For most countries the statistics of nonfatal injuries are unsatisfactory. Studies in Great Britain and Sweden have shown deficiencies in notification of serious injuries of 20% or more; these deficiencies vary for different categories of road user. Notifications of slight injuries are even more unsatisfactory. However, special efforts have been made in Denmark to obtain full information, and in Australia road injuries have recently become medically notifiable.

For some developing countries, there is evidence to suggest that even fatalities may be under-reported by 30% or more, and the absence of simple reporting procedures is an important deficiency in documenting the extent of the problems in many areas.

2.5 Control data

As well as the fragmentary reporting of information on road traffic injuries, the almost total absence of control data is a major difficulty. Without exposure data and basic control information the evaluation of many problems becomes impossible. The planning of new studies should incorporate more provision for the collection of such material.

3. ACCIDENT STUDY METHODS

In reviewing problems of methodology the Technical Group recognized the need for different levels at which accident data should be acquired. Typically, most countries require three levels: the first, a basic, continuous national scheme; the second, broad-based epidemiological samples; and the third, periodic in-depth investigations. The experimentalists also need the information thus obtained when they come to designing protective devices and specifying, for purposes of legislation, crash-performance requirements.

3.1 Basic national accident data

Most industrialized countries have some national reporting scheme; many developing countries do not. The practicalities of reporting through both hospital and police channels produce many difficulties. A number of national schemes do not run satisfactorily because the requirements are too complex for the persons who are expected to report the information to do so accurately and regularly. There is a need for a simple, factual *pro forma* scheme which would give annually the statistics of road accidents in a given country, and it should be tailored to the abilities of the reporting personnel.

3.2 Second level: representative sample data

More detail is needed in descriptions of specific road accident problems. Such studies are usually hospital-based, but often they need the cooperation of transport ministries and police. Again, it is important to recognize the limitations of information that is not collected primarily for purposes of research or evaluation. Hospital-based data have a number of pitfalls, particularly for

evaluating the effectiveness of such measures as seat belts and crash helmets. Almost by definition, any hospital-based study examines only those patients who have not been protected entirely satisfactorily by some protective device. In general, studies of the effectiveness of crash protective measures require careful experimental design, and the design must provide for the assessment of circumstances that do not result in injury as well as the circumstances that produce injury.

3.3 Third level: in-depth studies

This technique has been used with considerable success in some industrialized countries where specialized multidisciplinary teams of engineers and doctors carry out small-scale, in-depth sample studies. Such an approach permits a detailed evaluation of the causes of specific injuries; for example, lower-leg trauma to pedestrians in relation to the characteristics of car bumpers, or the effectiveness of full-face crash helmets compared to open-face ones. However, such in-depth studies are expensive and require special skills that are not widely available. Also, sampling problems and geographic limitations can limit their general validity.

In general, medical data collected by hospital accident departments that do not participate in accident studies are not useful because they include little or no information on the types of collision in which the victims have been involved. This may lead to simplistic or even harmful uses of the data, e.g., alarmist reports on the supposed risks to the cervical vertebrae from safety belts.

Such information is detrimental to safety, since it causes the public to doubt the validity of decisions which call for their collaboration, such as the wearing of helmets and safety belts.

However, medical records that do not cover the technical aspects of accidents could well be used to connect each type of injury and each representative clinical picture with some of the economic consequences of such injuries, e.g., total duration of temporary disability and rate of permanent partial disability. These indices should be related to the occupation, age and sex of accident victims. Such use calls for the cooperation of insurance companies. So far, little has been done in this field. Nevertheless, information of this kind would supplement the medical data obtained from surveys of accidents and would make it possible to determine more precisely the priority action needed with regard to road safety and the benefits to be expected.

In addition, these in-depth studies, which are part of what is being called accidentology, cannot identify all mechanisms observed. Some of them (e.g., visceral and cerebral lesions) need to be explained by experiments. In this context, the international collaboration that has been established should help to bring about rapid advances in knowledge aimed at optimizing protective measures and determining adequate criteria for injuries.

A major practical difficulty in introducing protective measures and evaluating their effectiveness is that responsibilities for doing so are divided between different governmental sectors. Better cooperation between health ministries and transport ministries in particular appears to be a prerequisite for effective investigation procedures and successful action programmes.

4. EFFECTIVENESS OF CURRENT CRASH PROTECTIVE MEASURES

The last decade has seen great advances in the adoption of crash protective design and restraint systems. From the stage, in the early 1960s, when such devices were considered mere accessories, the field has progressed to the present position where crash performance is a basic design criterion that influences fundamentally many aspects of a vehicle. Broadly speaking, the measures can be classified into "passive" or "active" according to whether the road user must actively use the device or not. The following section summarizes the Group's discussions on this point.

4.1 Anti-burst door latches

Despite popular belief, being thrown from a car during a collision increases the risk of death and serious injury by a factor of from 5 to 10. Anti-burst latches were introduced into cars in the mid-1950s, almost a decade prior to any legislative requirements. Studies of rural accidents in the USA (10) and a subsequent study of urban and rural accidents in Great Britain (11) showed that with the introduction of anti-burst designs door-opening rates fell from 44% to 29% in the USA and from 28% to 8% in Great Britain. This small change in vehicle design has been one of the most successful and least recognized improvements in collision performance in recent years. In some parts of the world, particularly with light vans and trucks, anti-burst latch design is not used, and ejection as a cause of death is still a frequent occurrence.

4.2 Steering assembly

The specification of the steering wheel and column is a good example of the need for the better use of medical knowledge from hospital experience by the technical sections of organizations responsible for drafting regulations that control the design of the steering assembly.

Current regulations are supposed to specify two factors, viz. the rearward motion of the steering assembly into the passenger compartment, which is limited in a controlled experimental crash, and the nature of the

chest contact, which is specified on the basis of contact between the assembly and a hard rubber body block. This simulation of a driver's chest contact is too simple and, besides, the intention of the original specification was to replicate the conditions of a driver wearing a lap belt. When the regulations were drafted in the USA lap belts were the most frequent type of restraint system. No account was taken of how the anterior chest wall is loaded in terms of the contact area between the wheel-and-spoke system and the chest.

Subsequent studies of injuries in both North America and Europe have shown that present systems, especially in small cars, are not functioning as intended. Although regulations related to the anti-intrusion factor may have some benefits, those based on studies of chest contact remain unsatisfactory because of the relatively small contact area through which crash loads are transmitted.

4.3 Windscreen glass

Two quite different solutions to the problem of injuries from glass have been arrived at in different parts of the world. Laminated glass has come into use in North America, Scandinavia and Italy, and toughened glass in most other countries that produce cars. Improvements in laminated glass occurred from 1966 onwards with the introduction of high penetration resistance (HPR) glass. Comparative studies both in the laboratory and with hospital-based data have shown that HPR glass causes fewer and less severe soft-tissue injuries than does toughened glass. Injuries from glass are seldom life-threatening, but lacerations from toughened glass contacts are frequently severe and disfiguring. In addition, approximately 5% of seriously injured occupants of cars with toughened glass windscreens suffer eye trauma.

4.4 Structural integrity

Beyond the specific items of passive protection summarized above, vehicle design is taking greater account of findings from actual, as distinct from simulated, collisions. Reinforcing the doors of cars is a requirement in some countries, and ways of strengthening car bodies to protect occupants in lateral collisions are under consideration. Under-run guards on trucks are recognized as an important need, particularly in countries where heavy commercial vehicles are a high proportion of total vehicles.

4.5 Exterior design

Pedestrians and other unprotected road users are the majority of serious traffic casualties in many countries. Recent research has shown that car exteriors differ markedly in their potential for causing injury. There is

undoubtedly an optimum exterior design with appropriate geometrical and mechanical properties which will minimize pedestrian trauma. However, the problem is difficult because what may be best for an adult at one speed, for example, may not be the best for a child at another speed. It is clear that the design of bumpers ought to take account of the fact that perhaps 5% of all cars will at some time strike and injure lower limbs. Also, the recognition of the zones of the car most likely to cause serious head injury, a major problem for pedestrians, should result in improved mechanical properties so that some passive protection can be given to road users other than vehicle occupants.

4.6 Specification of vehicle design

Basic vehicle design is conducted in only a handful of industrialized countries. Also, vehicle design in general, and passive protection in particular, are based exclusively on biomedical studies in those few countries. There is a need for a greater recognition by the car-producing countries of the requirements of the rest of the world, where a very high proportion of cars are used. This need applies to the specifics of design, but must also be taken into account by those international agencies which control, by means of legislative requirements, many characteristics of present-day vehicles.

4.7 Seat belts

Fundamental to the protection of the occupant is a restraint system that prevents him from striking any part of the interior of the car and at the same time attaches him firmly to the car structure, so that he can slide forward towards the frontal crush zone of the car, with the consequent attenuation of the forces applied by the restraint system.

Bohlin in Sweden (12) showed that the use of seat belts reduces the number of fatalities and non-fatal injuries by approximately half each. To achieve these potential benefits a number of governments have made the use of seat belts compulsory. Australia was the first to do so, in 1970-71, and the effects have been outstanding. Car-occupant fatalities in Australia have been reduced by approximately 25% with the change from voluntary to compulsory use of belts, and that effect has been maintained for nine years. Scandinavia has had a similar success, but it is too early to measure the consequences of compulsory use in the other European countries. The Group identified 25 countries in all where the use of seat belts at least in the front seats of cars has been made compulsory (Table 1).

It appeared to the Group that the successful results of seat belt laws in Scandinavia and Australia could not be expected to occur automatically from similar laws in other countries. Good conformity with such legislation requires a good understanding of the problem by drivers. In developing countries

Table 1. Countries where seat belt use is compulsory
(with date of introduction)

Australia (1972)	Ivory Coast (1970)
Austria (1975, indirectly)	Japan (1971)
Belgium (1975)	Luxembourg (1975)
Brazil (1977)	Malaysia (1978)
Bulgaria (1974)	Netherlands (1975)
Canada (Ontario, Quebec, 1976)	New Zealand (1972)
Czechoslovakia (1974)	Norway (1975)
Denmark (1976)	Puerto Rico (1974)
Finland (1975)	South Africa (1978)
France (1975, staged)	Spain (1975)
Germany, Fed. Rep. of (1976)	Sweden (1975)
Hungary (1976)	Switzerland (1976, repealed 1978)
Israel (1975)	USSR (1976)

in particular there is a general disregard of many traffic regulations, especially in remote regions. The Group considered that legislation must be coupled with effective education campaigns and that local and regional health authorities should play a leading role in them.

The use of seat belts is by far the most effective short-term way of reducing traffic casualties, and the Group was unanimous in recommending the immediate promotion by both legislative and educational means of the fitting of seat belts in all cars and their use.

Most countries that have required the fitting of seat belts for front-seat occupants are now making rear-seat belts obligatory as well. One of the major limitations on the protection that seat belts provide to front-seat occupants is the frequent absence of seat belts for rear-seat passengers. Not only does this put rear-seat passengers themselves at risk but also it substantially increases the risk of serious injury to restrained occupants in the front. The Group recommended strongly the widespread fitting of rear belts and the development of associated health education programmes.

The alternative approach of passive restraint is being promoted heavily in North America by health and transport authorities, particularly the use of airbags. Although the airbag is an interesting solution, field studies of accidents show that if the use of seat belts can reach a level of about 75% their compulsory use should, in most environments, be more beneficial than the use of airbags (13). It is doubtful if highly technical and complex systems which have not been proven to be reliable should be widely recommended or imposed. They cannot be expected to function properly in a crash when they have been subjected, perhaps for many years, to the harsh conditions of many parts of the world.

The Group considered passive belt systems to be a more attractive solution and one which can be applied at the same time as compulsory belt use. With compulsory usage, many drivers may well choose a passive belt so as to conform with the law without any effort on their part.

4.8 Child restraint systems

Although in industrialized countries there are relatively few casualties among children as occupants of vehicles, the extensive use of special restraint systems for children has much to recommend it. This is because parents are likely to be more willing to use an "active" system to protect their children than they are to use one for themselves. Health education that makes use of this motivation is vital because it is likely to persuade concerned parents to use an active system once its benefits are understood. In respect of the use of restraint systems acceptability and easy daily use are much more important than a very high level of crash protection.

A few countries have introduced laws which require that children of under 12 or 15 years in cars be in the rear seats. Although this requirement may be desirable, in theory it is difficult to apply because it demands quite significant behavioural changes. Better information, from health education, appears to be a better approach than introducing a law which is widely disregarded.

4.9 Head restraints

A number of countries have made it a requirement to fit head restraints to car seats to minimize the occurrence of hyperextension injuries to the cervical spine in rear-end collisions. The details of the legal requirements are of note because they ignore the realities of human behaviour and have resulted in relatively ineffective designs. Vertical adjustment of the head restraint on the seat is allowed in most countries. Data from both accidents and surveys show that approximately 80% of head restraints are not adjusted correctly, most being in the fully "down" position. Accident studies have demonstrated only very minor benefits from head restraints. This illustrates the limitation of an "active" solution; a preferable design is a "passive" one where the head restraint is permanently fixed at the correct height. Approximately 10% of collisions that produce injury are rear-end ones, but the nature of whiplash injury may well mean that it is significantly under-reported in most countries.

5. PROTECTION OF USERS OF TWO-WHEELED VEHICLES

Two-wheeled vehicles provide cheap transport and popular forms of sport and recreation. They have consequently become increasingly plentiful

in many countries over the last 10 or 20 years, and in view of the present energy shortage this trend is likely to continue over the next decade or so. Compared with cars, two-wheelers are unstable and provide little protection for their riders in accidents. Therefore from the point of view of injury prevention this group of road users needs special attention. Accident statistics support this view.

In recent years an increase in two-wheeler accidents has been reported from several parts of the world. At present in some countries more than one-third of all traffic deaths occur among users of two-wheeled vehicles, a large proportion of them bicycle and moped riders. Between 30% and 50% of cyclists who are killed are below the age of 20, and 20–30% are between 10 and 14 years of age. Older cyclists are also heavily represented among bicycle deaths. A similar pattern is seen in moped riders. With regard to motorcycle drivers and passengers, fatalities are highly concentrated in the younger age groups, 50–70% being between 15 and 25 years of age.

5.1 Legal aspects

Legislation concerning two-wheelers varies considerably from one country to another. In general no licence is required for cyclists; some countries have prescribed a minimum age for cycling on public roads. In some countries the carrying of passengers depends on the age of the rider; most countries permit child passengers to be carried but some require suitable equipment to be fitted for this purpose.

Most countries require motorcycle drivers to have a licence. In many countries both drivers and passengers must wear crash helmets. Apart from a passenger seat and foot rests there seem to be few restrictions on the carrying of passengers. Motorcycles are usually subject to the same speed limits and priority rules as motorcars.

Mopeds in many respects form a group between bicycles and motorcycles and the definition of “moped” varies considerably from country to country. It is usually a two-wheeled vehicle fitted with a motor so constructed that it cannot exceed a given speed. This speed varies a great deal. Some countries require mopeds to be fitted with pedals for propulsion. A driving licence, valid for mopeds only, is required in a few countries. The minimum authorized age for moped users varies from 14 to 16 years. A passenger may generally be carried provided the moped is fitted with a passenger seat and foot rests. Some countries require both driver and passenger to wear a crash helmet.

Each type of two-wheeler covers a wide range of vehicles with regard to wheel size, frame design, engine capacity for motorcycles, number of speeds for bicycles, etc. In addition there are some categories of motorized vehicles that do not fit into this general pattern.

5.2 Accident trends

The problem of two-wheeler accident and casualty risk is difficult to describe in global perspective, mainly because exposure data are often lacking. Such data are urgently needed. However, there are indications that mopeds and motorcycles carry much higher risks of accidents with casualties than cars. The risk for bicycles is possibly somewhat lower than for mopeds but still higher than for cars.

The characteristics of accidents with two-wheelers have been described in a number of studies devoted to a detailed analysis of two-wheeler accident statistics. In-depth studies have also been performed in some places. It is difficult to compare the results from different countries because traffic mix and travelling patterns are different. Some useful information can, however, be extracted concerning the most common vehicle movements in the most frequent accident types for two-wheelers in the countries of study:

- the two-wheeler and the other vehicle carry straight on, but intersect each other's paths;
- one vehicle turns left (in countries where traffic travels on the right-hand side) while the other comes from the opposite direction;
- one vehicle turns left while the other comes from the left;
- on the nearside of a straight road a two-wheeler has a single-vehicle accident.

Most two-wheeler accidents occur in urban areas, where the traffic density is far higher than in rural areas; the speed of traffic much lower, and the traffic picture more complex. The intersection accidents are more serious than accidents occurring on street sections. Heavy traffic volumes and lack of space for evading manoeuvres are some characteristics which may influence these accidents.

Two-wheeled vehicles are very vulnerable to bad road conditions such as loose materials, holes, studs, horizontal markings and drain covers. However, the vast majority of accidents seem to occur when the two-wheeler has been in a stable condition before the crash. In rural areas there are relatively fewer accidents – they usually involve a car or a lorry – and they are more severe than accidents in urban areas.

Fatality rates per mile ridden vary markedly with the type of machine. Data from some countries indicate that the risk per mile goes up in roughly the same proportion as the engine capacity, so that a 1000 cc machine is involved in a fatal accident 10 times more frequently than a 100 cc machine. Some countries are so concerned with the high fatality rates of large motorcycles that they are considering restricting their use by legislation. Japan prohibits machines of over 750 cc and there are proposals in Europe to prohibit machines with a power output of more than 100 bhp.

5.3 Injury patterns

These have been touched on in a previous section. To a great extent the injury patterns are similar for all three main types of two-wheeler. The probable explanation for this is that most accidents occur at relatively low speed and often involve a collision with another vehicle. In general this implies that the most frequently injured parts of the body are the extremities and the head. The riders of the slower bicycles and mopeds tend to have a slightly higher frequency of injuries to the upper extremity than the riders of motorcycles, but the lower extremity is more frequently injured in both groups. The probable explanation for the high frequency of lower-limb injury is that the leg is often squeezed between the rider's own vehicle and the striking vehicle or the ground. These injuries can be quite severe but are not often life-threatening. The leading causes of death in two-wheeler accidents are, among pedal cyclists, injuries to the head, and among motorcyclists injuries to the head and chest. Serious abdominal injuries are sometimes seen in children after bicycle accidents. These injuries occur when the child falls against the free end of the handlebar. Other soft-tissue injuries seen in riders of two-wheeled vehicles are caused by protruding objects on a motorcycle, on the other vehicle, or on the ground.

The most serious injuries occur usually in accidents that involve the highest rate of change in the velocity of the rider. Most accidents in rural areas fall within this category. In urban areas the most serious accidents are those that cause a significant change in the trajectory of the rider. This happens when the two-wheeler collides with another vehicle or a stationary object large enough to change the path of travel of the rider. If the object is low enough for the rider to pass over it, the trajectory will not change significantly but the rider will usually continue in the original direction until he hits the ground, or some other object, at some distance from the site of the collision. This distance is determined mainly by his original speed and is longer for motorcycle riders than for moped riders and cyclists. While airborne the rider may tumble and therefore it is not possible to predict his position at impact with the ground.

5.4 Injury protection

Compared with occupants of other vehicles riders of two-wheeled vehicles are virtually unprotected in the event of an accident. Efforts to reduce casualties that involve changes in vehicle design come up against a particular problem in respect of the pedal cycle since such changes tend to increase its weight to an unacceptable level. For mopeds and motorcycles this restriction is not so evident, and some studies have been performed on the possibility of reducing the risk of injury to their riders by changes in vehicle design. The elimination of protruding details that can cause injury, and efficient roll-bars,

are the most significant attempts in this direction. For all three classes of rider improvements in acceptable protective clothing would also help to reduce the number and severity of injuries.

There are similarities between the causes of injury to riders of two-wheeled machines and the causes of pedestrians' injuries. Improvements in car exteriors will not only help pedestrians but will also have benefits for motorcyclists and moped riders.

5.5 Crash helmets

Without doubt, the most important item of equipment for reducing the severity of two-wheeler accidents is the crash helmet. To date the use of helmets has been seriously considered only for riders of motorcycles and mopeds. However, some work has been done on a cyclist helmet. The main factor here is that the cyclist needs very nearly the same protection as the motorcyclist because head impact occurs in similar ways for both.

There have been several studies on the effectiveness of crash helmets. These are difficult to compare with one another not only because of differences in exposure data but also because the design of helmets has changed over the years. In early helmets only the top of the head was covered by a rigid shell. Later the shell was extended over the sides of the head and a shock-absorbing lining was introduced. Recently the full-face integral helmet has become very popular. It extends the protection to cover more of the head and face of the wearer and also it has an improved shock-absorbing capacity.

It appears that the use of a helmet reduces the risk of sustaining a head injury by 30% on average, and the risk of being killed by up to 40%. The introduction of the crash helmet has brought about a change in the type of severe head injury caused by two-wheeler accidents. Before helmets were used the type of injury often seen was an open linear or depressed fracture of the forehead under a severely lacerated scalp; often it was smeared with dirt from the road and there was rather localized brain damage. With helmets fractures more often occur at the base of the skull, the brain damage is more diffuse, and scalp lacerations are less frequent.

Crash helmets prevent laceration of the scalp to a great extent. They also reduce the incidence of skull fractures and brain damage. In the more severe accidents helmets are probably less effective, and special attention should be given to the lateral impacts common in intersection collisions. Data from some studies indicate that most injuries, of all degrees of severity, occur with frontal impact but that most of those that occur with lateral impact are in the more severe category. Impacts to the rear and to the top of the helmet are quite rare.

Another aspect which has not been examined very much until recently is what actually happens in cases of head impact. For a long time it has been taken for granted that the head usually strikes the other vehicle or the

ground perpendicularly and is consequently subjected to linear acceleration. Standard test methods used in approval tests are simulated accordingly and the requirements also apply to this kind of impact. The high frequency of intersection collisions and the fact that the rider is often thrown some distance before his impact with the ground indicate that many head impacts may well be oblique rather than perpendicular, and may therefore subject the rider's head to angular as well as linear accelerations. Research on this question is in progress in some countries. Angular head accelerations are likely to result in tearing of the bridging veins and diffuse rather than localized brain lesions.

The extended protection offered by the helmet to the sides of the head, as in the so-called jet-type helmets and the full-face helmet, seems to be an improvement but such helmets have disadvantages which must be considered. These include increased weight, the hearing loss that occurs when the ears are covered, and the possible build-up of carbon dioxide inside a full-face helmet. However, the reduced severity of injury which follows from their use far outweighs any disadvantages. A number of studies are in progress to improve the helmet design.

Visors do not appear to be a significant cause of injury, and undoubtedly they sometimes prevent facial damage. There is some evidence that heavily tinted visors cause accidents, particularly at night, because they reduce the transmission of light. Also, in some countries insects are so numerous that they can very quickly render a visor unusable.

Since the most common injury of cyclists is head injury, there is a good case for an acceptable light cyclists' helmet.

Leather clothing reduces the risk of extensive superficial soft-tissue injury. It also seems to reduce the tendency of the body to tumble and gives it a smoother motion when it slides over the road surface in an accident. Leather boots can, to some extent, protect the lower legs and feet and their use should therefore be encouraged.

6. PROBLEMS SPECIFIC TO DEVELOPING COUNTRIES

In general, basic data on traffic accidents in developing countries are fragmentary but they permit a number of conclusions to be drawn. Road casualties have increased spectacularly in the oil-rich countries. In Nigeria for instance, despite probable gross under-reporting, reported road deaths have doubled in the last six years. The increases have been less abrupt in developing countries without oil. In general it is likely that most of the world is now entering a period of very rapid and sustained growth of vehicle ownership. Experience from the industrialized countries shows that vehicle ownership with time follows a classical 'S' curve. It appears that many countries are

reaching the point on the lower part of the 'S' curve where growth rates take off from very low levels and increase linearly for a number of years. Particularly if oil is available, the growth rates are likely to be very much faster than they were in the industrialized world.

Developing countries are very different from the industrialized countries with regard to the environment and the mix of vehicles in the traffic stream. The following are the more important differences.

1. Large numbers of pedestrians share the roadway with vehicles, and many have little appreciation of the limitations of road vehicles in their ability to stop and turn. There is almost no segregation of pedestrians from wheeled traffic.
2. There are large numbers of old, poorly maintained vehicles. With high growth rates of vehicle ownership, the people have no mechanical knowledge or aptitude. Economic restrictions result in low standards of maintenance. The proportion of accidents caused by defects in vehicles is probably several times higher in developing countries than in the industrialized world.
3. Low levels of driving performance are found. In many of these countries unlicensed drivers are a major difficulty, and driving standards are low. Some countries do not require any driving tests.
4. There are large numbers of motorcycles. Because of their cheapness and usefulness, motorcycles represent the first step in individual powered transport in many places. Their riders are very vulnerable, particularly if they are untrained and self-taught.
5. There are large numbers of buses and trucks carrying many people, and they are often overloaded. Single accidents involving 50 or more casualties are not uncommon. In Colombia in 1977, for example, 128 people were killed in one accident.
6. There is a widespread disregard of traffic rules. Particularly in isolated districts, there is little appreciation of the need for traffic regulations and they are rarely enforced. There is usually no education in traffic matters.
7. Some oil-rich countries have large numbers of new cars, many of them high-performance cars, on very inadequate roads.
8. The people at greatest risk as car occupants in some countries are those who are most valuable to the community. The casualties include doctors and other professionals, senior civil servants and technicians – those people most useful to the economic development of a country.

9. In some developing countries special kinds of vehicle are constructed, not seen elsewhere. For example, in Asia scooter-taxis are common, and in parts of Latin America truck chassis are used for locally constructed buses, often made of wood and therefore extremely vulnerable in collisions. In general, these cheap and functional special vehicles are built with no regard to crash performance.

10. There is a lack of information about the extent and nature of the traffic accident problem. Data collection systems are often rudimentary or non-existent. Often they exist in theory, but in practice gross under-reporting and inaccurate reporting are commonplace.

11. Government authorities — local, regional and national — often lack an adequate understanding of the problem. Since traffic accidents are a relatively new problem in many countries, official agencies often do not know how to deal with them. This is compounded by confusion about areas of responsibility between health and transport authorities, police and, in some countries, the military, who may be in operational charge of many civil policing functions.

7. ROLE OF BIOMEDICAL RESEARCH

The Group identified the following topics on which knowledge is inadequate.

Mechanisms of injuries and human tolerance levels

To specify the correct characteristics which vehicles should exhibit under crash conditions, more biomedical research is required to establish optimal levels for the various physical parameters that influence the nature and severity of injuries. Enough is known for the basic requirements for some standardized crash conditions, but a greater understanding of tolerance to impact is needed before optimal designs can be produced.

Population variability

The population of road users extends from the young child to the mature adult and to the old and the infirm. Little is known about the consequences of such a heterogeneous population on the appropriate values which should be used in crash protective design. Allied to this question are the unknowns associated with the different exposures to risk of the varying sections of the road-user population.

Long-term disabilities

Most reporting of road accidents takes place within a 30-day period. A number of sample studies have shown that long-term disability is common in seriously injured traffic casualties. Brain damage, spinal injuries, lameness and blindness can all have long-term consequences which have not been identified adequately. Follow-up studies over a 5- or 7-year period are necessary, and such work is worthwhile because these types of trauma carry very high social and often economic costs.

The social costs of minor injuries

Minor injuries, which are usually treated in outpatient services and by general practitioners, are probably under-rated in importance, particularly with regard to their social costs.

Traffic injury in developing countries

Very little work has been done on the epidemiology of traffic injury in the developing world. Thus, the dimensions of this mechanical disease are largely unknown and the disease itself is accepted as inevitable. An initial prerequisite of any effective disease control programme is an understanding of its characteristics, and road accidents are no exception.

In general the Group recognized that much is already understood about road traffic accidents. Although the above areas of research were identified as being of great importance for future programmes, enough is already known for many effective remedial measures to be introduced immediately with the likelihood of very large gains. Public health programmes in this area probably represent one of the most effective returns on the efforts made, compared to many other claims on resources.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 General

The introduction and use of protective devices and restraint systems are regarded as crucial public health issues for many countries at present. Because of the effectiveness of crash protective measures, and the great drain on community resources which road accidents represent, the cost-benefit of introducing these measures is likely to be considerable. In general, the cost of road accidents represents roughly 1% of the gross national product in most countries, whether industrialized or still developing.

8.2 Methodology and epidemiology

1. Data collection systems are needed to identify high-risk groups of road users in countries, such as riders of large-capacity motorcycles in the United Kingdom.
2. Data are required on certain high-risk environments such as the transnational highway in Yugoslavia, carrying large numbers of foreign vehicles making long journeys, and — in developing countries — rural trunk roads used at night with little traffic but high accident rates, and large cities with relatively few cars but high rates of vehicle involvement in accidents.
3. The effectiveness of given measures in reducing mortality and morbidity needs further study, and the findings should be communicated more widely among countries.
4. Improved reporting of non-fatal accidents is a basic need in most parts of the world.
5. Control data on exposure to risk for specific road users, vehicle types and environments are largely absent, thus reducing the usefulness of accident statistics. The collection of such data should be considered as important as accident recording.
6. The criteria should be further standardized, particularly for classification of severity of injuries, severity of collisions, types of accident and configurations of accidents.
7. For the purpose of studies in the field of accidentology, defined as “the objective study of accidental phenomena as to both causes and effects”, a research package should be established showing the minimum requirements of a developing country for accident data, control data and assessment of the effectiveness of measures.
8. As few countries can afford high-level, multidisciplinary accident investigation teams, the transfer of routine accident data and specific research findings should be encouraged. Because of the limited resources of developing countries, better dissemination of knowledge from the industrialized world is particularly important.
9. The problem of road accidents falls between the jurisdiction of transport and health ministries. This division of responsibility is reflected in several international bodies concerned with crash protection. As WHO is inadequately represented in the deliberations of such bodies, arrangements for

improved collaboration should be discussed bearing in mind the public health role and global capabilities of WHO and the needs of countries not normally represented in ECE, EEC, OECD, CMEA and other groups.

10. As legislation in itself does not ensure conformity of behaviour, particularly in developing countries, it is essential to undertake public health education programmes in parallel with the introduction of new measures.

8.3 Vehicle occupants

1. The provision and use of front lap/diagonal seat belts should be encouraged at all times, in all circumstances.
2. The provision and use of rear seat belts should likewise be encouraged.
3. The fitting of high penetration resistance laminated glass windscreens in all vehicles should be encouraged.
4. Steps should be taken to ensure greater availability and wider use of child restraint systems in cars.
5. The fitting and correct use of head restraints in cars should be encouraged.
6. Basic vehicle design and production control legislation depend largely on the decisions of a few industrialized countries. Greater account should be taken of the needs of the developing world in this respect.
7. Exterior vehicle design should be such as to minimize the severity of trauma to all unprotected road users, i.e., pedestrians and riders of two-wheelers, as well as car occupants.
8. Differences in the working lifespan of vehicles, and the relatively large numbers of small commercial vehicles in developing countries, should be recognized as important factors in framing legislation which controls vehicle design worldwide.

8.4 Two-wheeled vehicles

1. Risk exposure and accident data on two-wheelers are still fragmentary. However, the available information shows very high levels of risk associated with large-capacity motorcycles. There is a good case for limiting the engine size of such vehicles (as in Japan where the capacity may not exceed 750 cc) and, where possible, special road facilities should be developed to limit conflicts with other types of traffic.

2. Steps should be taken to ensure the wearing of crash helmets by motorcycle and moped riders worldwide, coupled with health education programmes to explain their benefits and correct use. Studies for the evaluation of effectiveness should be coupled with these measures.
3. Technical development of helmets should be encouraged, with particular reference to comfort and function in extreme climates, and conditions where there are many insects in the atmosphere.
4. Special cheap helmets acceptable to bicycle riders should be developed and their use encouraged.
5. Motorcycle design should be improved to give better protection to the legs of riders.
6. The use of protective clothing by motorcycle riders should be encouraged.
7. The problem of foot injuries to child cyclists requires attention.
8. Comprehensive health education programmes relating to active and passive protective measures for two-wheelers should be instituted.

8.5 Biomedical research

1. Problems still requiring solutions include questions of tolerance to impact loads, the consequences of physiological variations throughout the population at risk on the roads, and the mechanisms of certain types of trauma.
2. Further investigations are needed on the social cost of allegedly minor injuries, which has been grossly underestimated, and the long-term consequences of very serious injuries resulting in brain damage, blindness and spinal trauma.

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Annex I

PATTERNS OF INJURY FROM ROAD ACCIDENTS, VARIATIONS WITH CLASS OF ROAD USER AND METHODOLOGICAL PROBLEMS

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Injury pattern and categories of accident

When dealing with descriptive statistics on the pattern of injuries sustained in road traffic accidents (RTA) it is important to note the sampling frame used. There are significant differences between the patterns of injuries found among fatalities, surviving hospital inpatients, and outpatients. Dalggaard et al. (1) have described typical syndromes for fatally injured car riders, two-wheelers and pedestrians according to accident situation. Severe head lesions were found in about two-thirds of the injured, and truncal injuries formed the remaining one-third of the causes of death for all groups. In addition to the lesions directly leading to death, car riders showed characteristic facial lesions, and unprotected road users had characteristic bumper lesions on the legs.

Patterns of injury among survivors have been described in numerous investigations. Fig. 1 from a casualty room survey performed by the Accident Analysis Group at Odense illustrates the pattern of injury according to injured region, severity of injury, use of seat belts and helmets, and age group for selected important accident situations (2). The predominance of head injuries in all situations is obvious. Cyclists involved in single accidents sustain a high number of upper extremity lesions of medium severity, mainly fractures. All unprotected road users sustain a high number of medium to severe lower leg injuries when colliding with cars. Fatality rates and severity of lesions are considerably higher in the elderly age groups.

Comparison of these findings (abstracted above) with findings from other research groups reveals only minor differences.

Fig. 2 shows the distribution of injury severity according to the Abbreviated Injury Scale (AIS) in four typical collision situations. There is a significant difference between pedestrians hit by cars and the other groups. However, the three other groups do not differ significantly from one another. This observation may be explained partly by a relative over-representation of small children and elderly persons in the pedestrian group.

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Methodological problems

Monitoring and analysis of road traffic accidents in relation to background observations, exposure, sampling conditions and stratification of materials pose many problems.

From a scientific viewpoint – especially when using epidemiological techniques – a major drawback to the majority of RTA studies is that background information is often very scarce or of limited validity and relevance. First, the population in the area under study may not be known, and the fraction of transients may often be very roughly estimated. Second, the fraction of this population which theoretically should form the population at risk is hard to estimate. Third, the population exposed in accident situations – and hence subjected to biomechanical forces – is usually underestimated, since most monitoring systems will catch only a fraction of the persons injured in the accidents, usually the fraction seeking medical care at a larger hospital unit. Only special programmes will allow an estimation of the number of people actually injured in RTAs.

These three drawbacks are of paramount importance in studies aimed at evaluating the effectiveness of protective devices. Relative risk or cross-product ratios for various categories of road user (using and not using protective devices) may become impossible to calculate.

Even within the monitoring site itself, there are numerous problems related to the establishment of the validity of the internal and external data collected. Some standardization in injury description has been achieved by means of the WHO N-codes. The XVIIth section (accidents, poisoning and violence) of the 8th Revision of the *International Classification of Diseases (ICD)* has a dual classification according to external cause (E) and to nature of injury (N). However, the detailed description of lesions is normally of minor importance in analyses aimed at setting up preventive action programmes. On the other hand, it is extremely important that injuries be divided into at least two well-defined severity groups, the use of these definitions being stable over periods and comparable between different monitoring centres.

As examples of different systems for stratification of severity one may use: patient disposition, estimation of duration of incapacity, actual measurement of the sociomedical consequences (a rather time-consuming and expensive approach), and AIS scaling. The latter method is in widespread international use and is very useful, especially in biomechanical studies. However, the use of AIS scaling is somewhat time-consuming in epidemiological studies.

Information about the accident circumstances, i.e., biomechanical circumstances in the crash period and factors influencing the pre-crash period, are of utmost interest. A rough description of these factors can usually be obtained from victims or witnesses, or from the police if they

recognize the accident. Such anamnestic information, however, must be supplemented by on-the-spot investigations and in-depth studies for further penetration into the nature, frequency and preventability of the mechanisms that cause accidents and injury.

In broader large-scale epidemiological studies computer techniques and modern statistical methods have been shown to be not only very useful but even indispensable. Such techniques should preferably be closely linked to the further development of the concepts of risk and exposure/liability applied to RTA studies.

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Fig. 1. Distribution of most disabling lesion

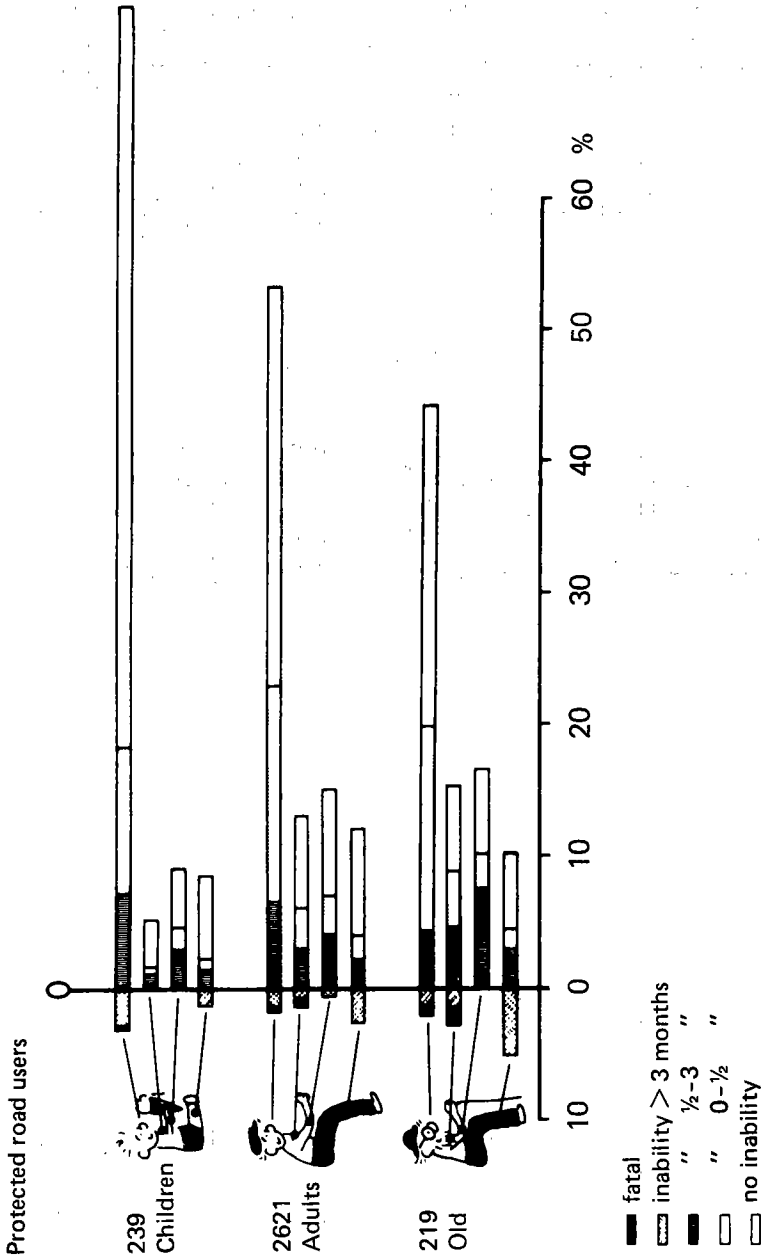


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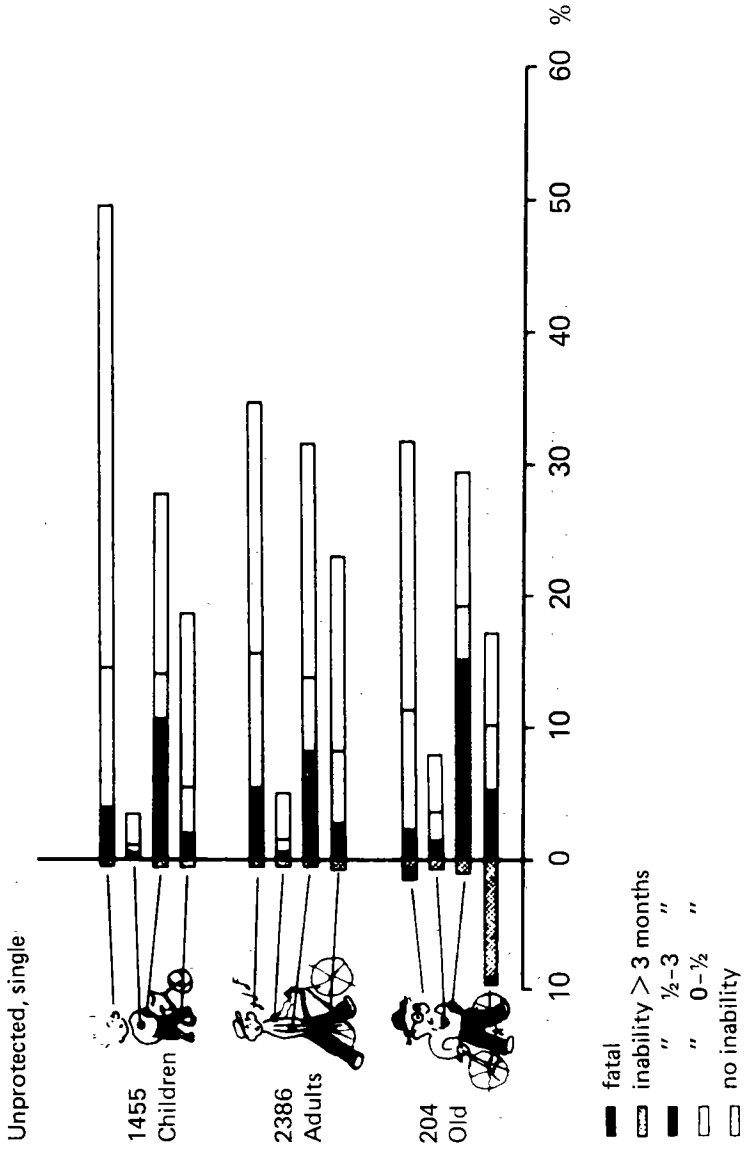


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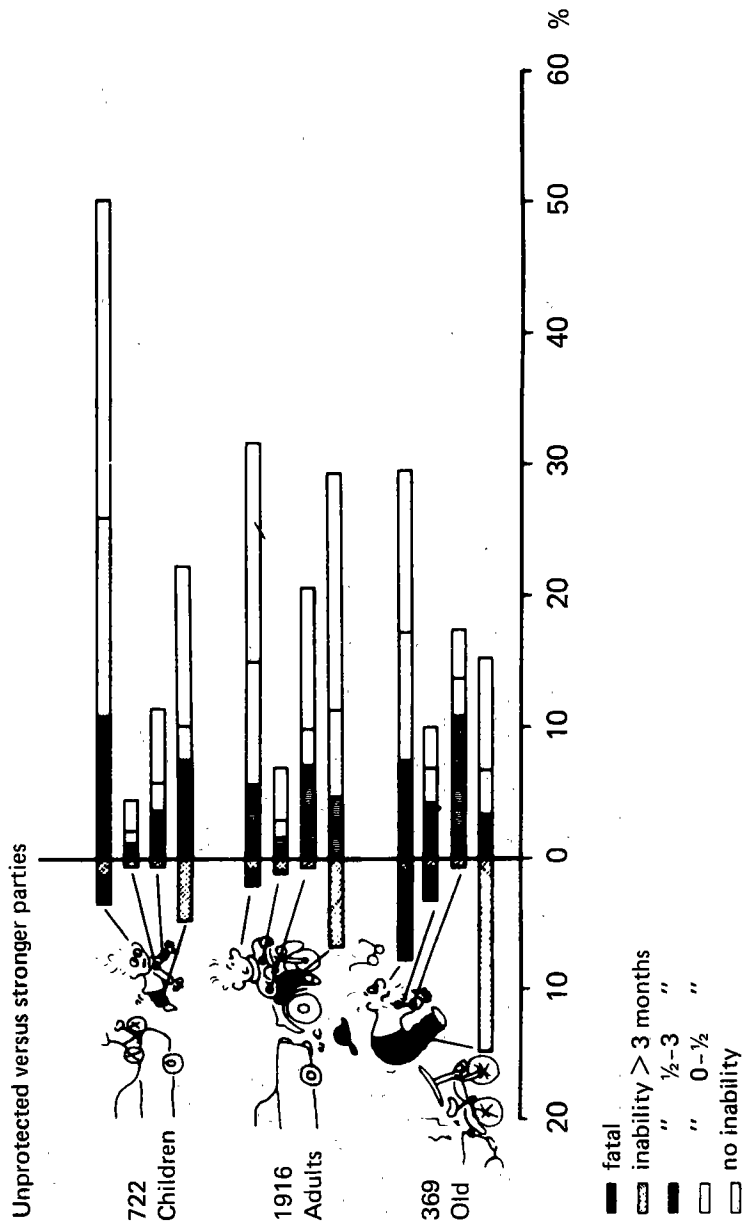


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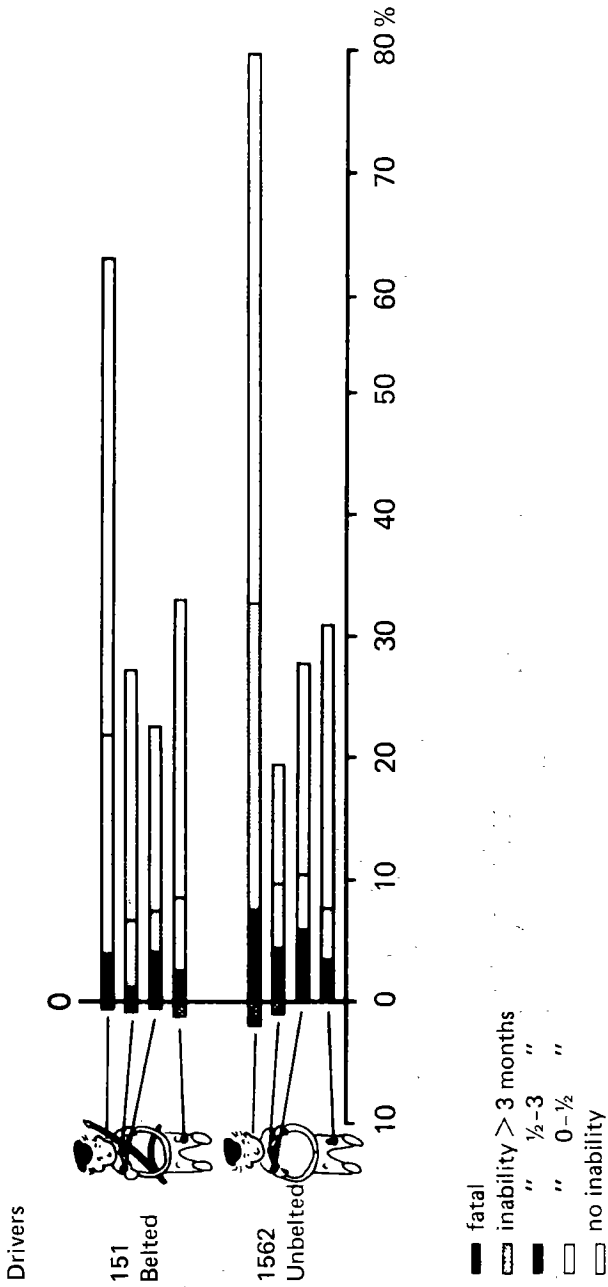


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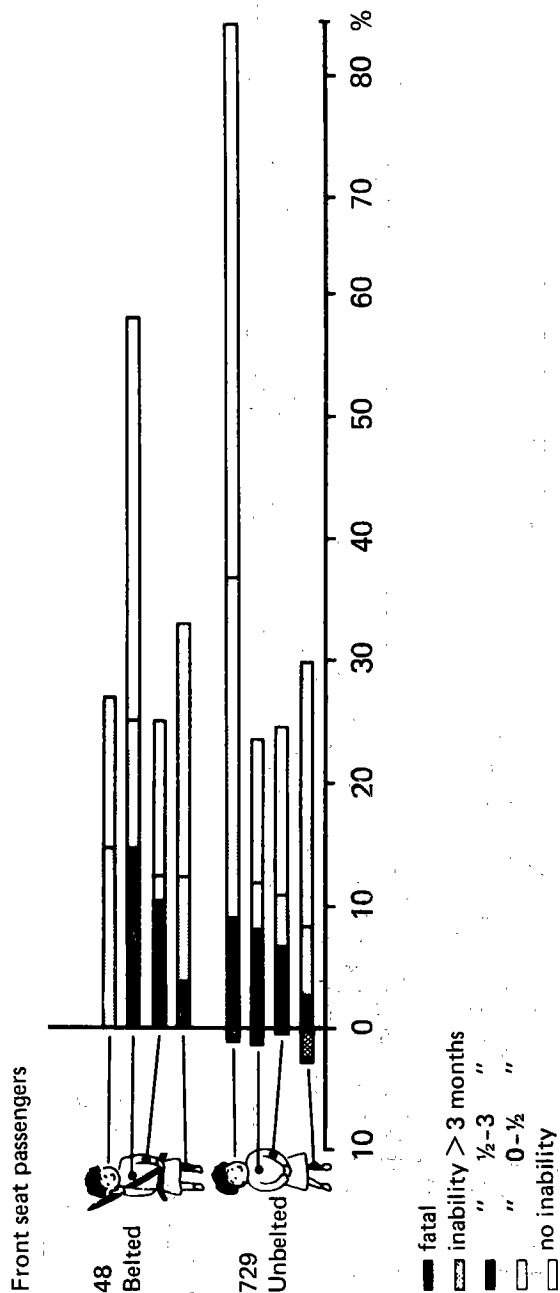


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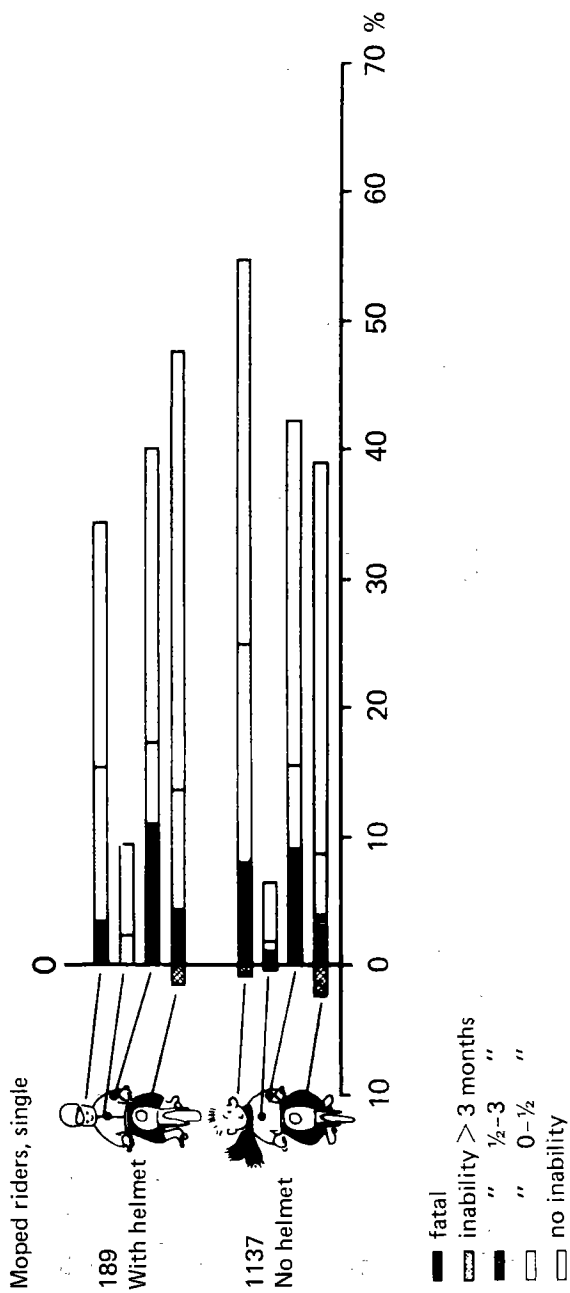


Fig. 1 (contd)

Moped riders versus stronger parties

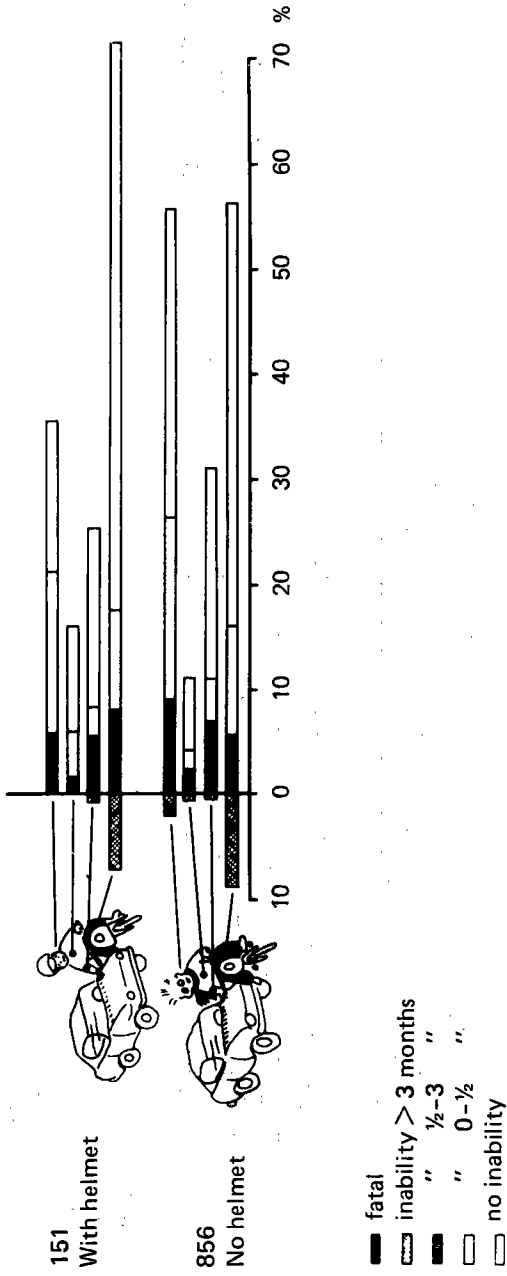


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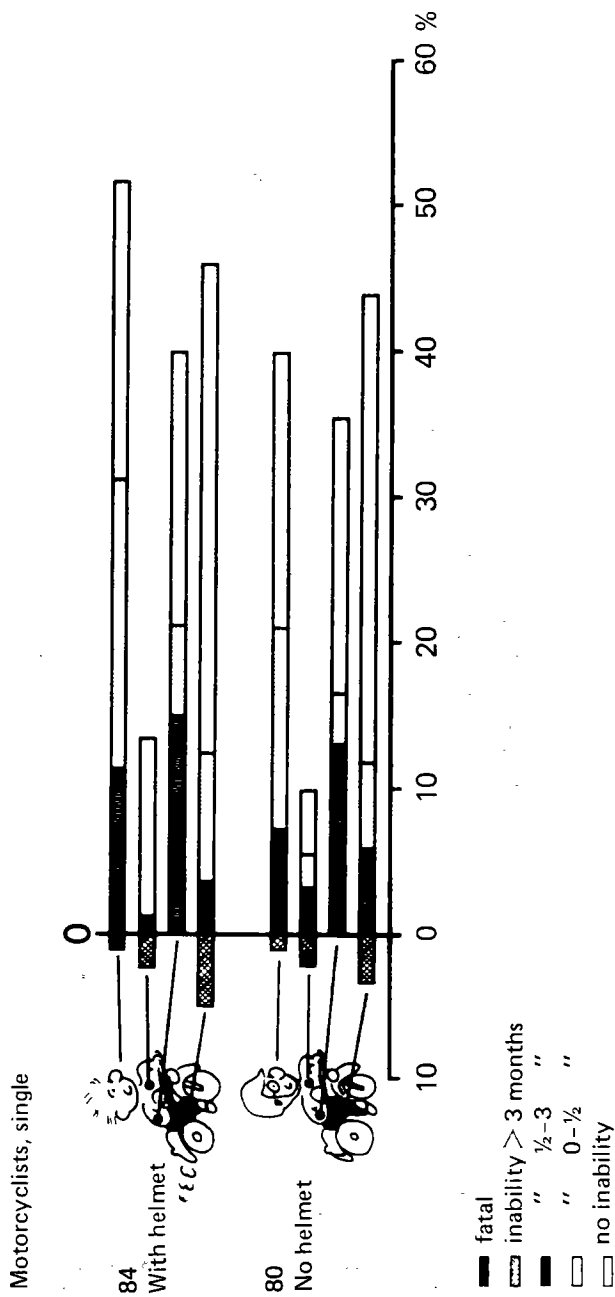


Fig. 1 (contd)

Motorcyclists versus stronger parties

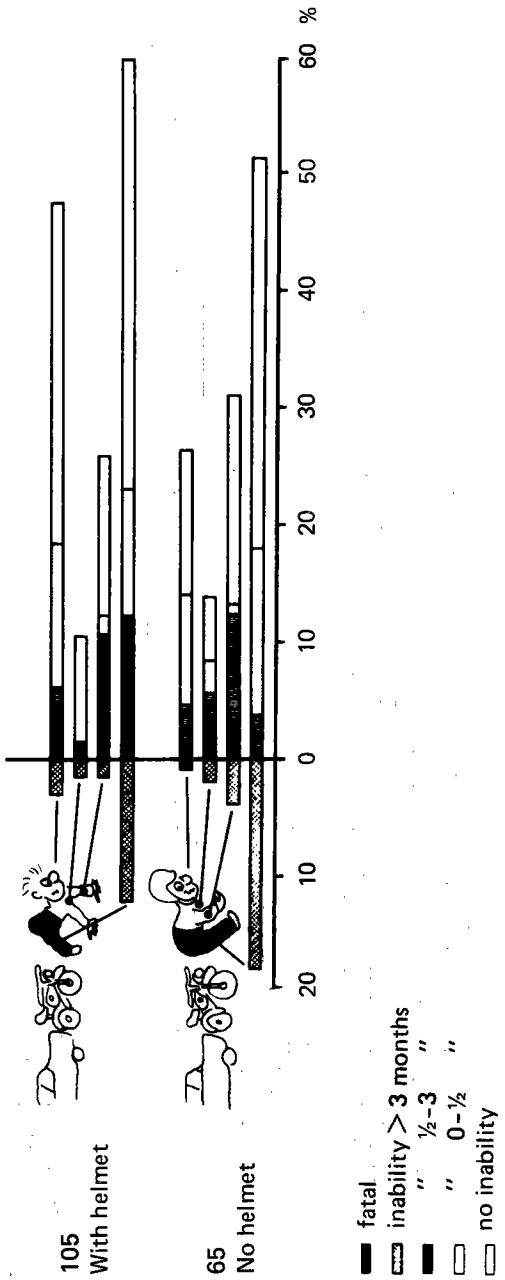
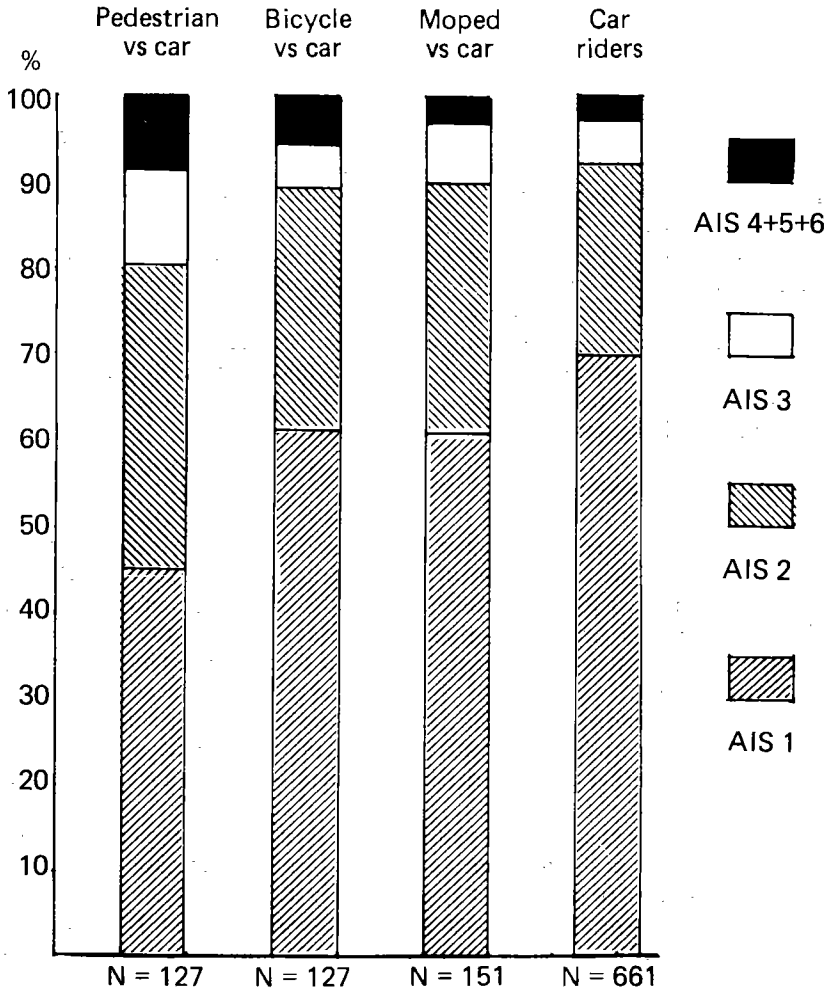


Fig. 2. Severity of lesions by road user category



Annex II

CURRENT PROBLEMS AND PRIORITIES IN VEHICLE OCCUPANT PROTECTION

Dr G.M. Mackay^a

Over the last 15 years the potential benefits from improved collision protection have become widely acknowledged, and cooperation between engineers and doctors has shown that this is a valid and effective form of preventive medicine.

Improvements to the collision phase of a crash reduce the forces and accelerations that act on a vehicle's occupants, and consequently death and morbidity rates. There are active solutions, which require the road user to take some action such as wearing a seat belt, and passive solutions, where the design of the vehicle is changed so that the loads applied to the occupants are lessened or certain exposures to risk are reduced; for example, anti-burst door lock designs, which minimize the risk of ejection.

Active crash protection

Seat belts. Fundamental to the protection of occupants is the prevention of ejection and the elimination of localized high-energy contacts with the interior of the vehicle. A seat belt provides this protection and also couples the user to the car structure so that he can "ride down" on the crush zone at the front of the car with an attenuation of the forces applied by the restraint system. Bohlin (1) showed that the use of seat belts reduced the number of fatalities by approximately half, and non-fatal injuries by a similar amount. Many subsequent studies have confirmed this, and the advantages of seat belts are so enormous that 23 countries have enacted legislation making their use compulsory (2).

A major uncertainty at present is the level of usage that can be achieved by such legislation. In developed countries, without legislation, voluntary usage rates appear to stabilize at approximately 30% (this figure is influenced greatly by the environment, ranging from 10% in cities to 60% on expressways). Propaganda campaigns have marginal and only temporary effects on these levels. With compulsory legislation, usage rates in the general traffic stream rise to between 70% and 85%, after a learning period. However, this

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experience is restricted to countries with a somewhat sophisticated driving population, and in developing countries it is doubtful whether the same effects would be produced.

Recent Australian data (3) suggest that car occupants involved in reported accidents use seat belts significantly less than car occupants in general. In other words, the people most likely to have collisions are those who are most resistant to a compulsory belt-use law.

However, the benefits of seat belts are so great that even partially successful legislation should probably have first priority in any effort to protect car occupants in crashes. Belt use applies to all sitting positions in the car, and it is therefore important to encourage both the fitting and the use of rear-seat belts in those countries that have omitted to do so.

Child restraints. Although, in developed countries, the number of child casualties among car occupants is not great, the possibilities of the extensive use of special restraint systems for children are considerable, because parents are perhaps more willing to use an active system to protect their offspring than they are to use one themselves. In this area, acceptability and therefore daily usage are probably much more important than a very high level of crash protection. A number of countries have specified that children in cars must sit only in the rear seat. This is undoubtedly a reasonable short-term measure.

Head restraints. In the USA, early requirements for head restraints allowed them to be adjustable vertically. Surveys showed that approximately 80% of head restraints were in the fully down position, rendering them ineffective in preventing hyperextension of the neck in a rear-end collision (4). This illustrates the limitation of an active solution; a preferable design is one fixed at the correct height, and if necessary hollow, to minimize vision restrictions. Approximately 10% of collisions that produce injury are rear-end, but the nature of whiplash injury may well mean that these cases are significantly under-reported.

Passive crash protection

Approximately 10% of all cars cause serious injury or death to a road user before they are scrapped (5). In developing countries that figure may well be several times greater. Hence crashworthiness is a normal and important design criterion to be considered. Over the last decade many of the basic aspects of car design have come under legislative control and this trend is likely to continue. Because work on the basic design of cars is conducted in a very small number of developed countries it is important that the legislation which controls design should take account of more than just the specific needs of those countries.

In the past, major improvements in injury reduction have been achieved with the introduction of anti-burst door locks (6), laminated windscreens (7), energy-absorbing instrument panels and anti-intrusion steering assemblies (8).

Recent work has shown that none of these improvements have been optimal solutions. There is a basic need to evaluate continually, in studies of actual injury, the consequences of design changes and associated legislation, to ensure that the reality of collision circumstances and associated injuries is reflected in the controlling legislation.

Future priorities in occupant crash protection

The following topics, in order of priority, are suggested as the most important for future action:

- provision and use of front-seat lap/diagonal belts;
- provision and use of rear-seat belts;
- fitting of laminated windscreens;
- improvements in passenger compartment integrity;
- improvements in side-impact protection;
- greater adoption of restraint systems for children;
- greater adoption of head restraints; and
- prevention of fires following collisions.

International cooperation

Many national and a few international agencies are working on crash-protective design of vehicles. Preventive medicine has contributed little so far, and more medical and public health knowledge is needed. Not enough attention has been paid to physiological variations among the population at risk, nor to the particular needs of the young and the old, in basic research or in action programmes.

Joint international action is the most efficient way to use limited resources to reach solutions to problems that are common to many countries.

Engineers and doctors contribute equally to crash protection. Administratively it is a problem for ministries of health and of transport, and public health authorities could contribute substantially by encouraging both ministries to cooperate with each other.

Developing countries

Vehicle ownership is entering a period of very rapid and probably sustained growth in many developing countries, and it is therefore important while ownership levels are still low to institute preventive measures which are not difficult to introduce, such as the fitting and use of seat belts.

Action in developing countries needs the knowledge gained in the highly motorized countries in both its technical and administrative aspects. Since the proportion of light vans and buses to cars is much greater in some developing countries than in Europe, crash protection for these vehicles deserves particular attention. With the knowledge already available developing countries could avoid problems that highly motorized societies have only recently recognized.

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Annex III

EPIDEMIOLOGICAL FEATURES OF ROAD TRAFFIC INJURIES

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In developed and many developing countries road traffic accidents are now a main cause of death and disability, particularly among young adults. World statistics are incomplete but are sufficient to give an outline of this man-made twentieth century epidemic (1, 2).

Though figures are not readily available for several countries (e.g., Argentina, China, Egypt, India and USSR) world annual road deaths probably approach 250 000 and total casualties perhaps 10 million.

The most recent road traffic accident statistics show the following distribution according to geographic regions, although it must be borne in mind that the figures are underestimates, since only certain countries furnish such statistics regularly.

The main known contributors to annual road deaths are:

Europe	80K	(Federal Republic of Germany 15K, France 14K, Italy 9.8K, Great Britain 6.6K)
The Americas	60K	(USA 46.6K, Canada 5.2K, Brazil 3.3K)
Africa	23K	(Nigeria 8K, South Africa 6.4K)
Asia	21K	(Japan 9K, Republic of Korea 3.5K)
Oceania	4.3K	(Australia 3.7K).

K = per 1000 population

Satisfactory international figures for nonfatal injuries are not available but some illustrative examples from individual countries are mentioned later.

The following paragraphs outline international comparisons, trends, the contribution of different categories of road user, severity of injury, personal factors and some lessons for prevention.

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International comparisons

As Smeed (3) showed 30 years ago, much of the variation in road deaths between different countries and at different times in the same country can be explained in terms of population size (P) and numbers of vehicles (V). Smeed found the best fit was: road deaths = $0.0003 (V \cdot P^2)^{1/3}$, and it is remarkable that this continues to be valid for developed countries (4). A key concept is the degree of motorization, or vehicles per head (V/P). With increase in V road deaths rise but less than might be expected; there seems to be a developing sophistication in vehicle use so that deaths per vehicle fall as V/P rises. This sophistication covers many changes such as improved roads, better vehicles and fewer pedestrians, as well as improvements in driving behaviour and in medical care of casualties.

In the developed countries these adaptations to road transport have been spread over 70 years or more. In certain developing countries changes have been much more rapid, and studies show both a different statistical relationship and, in some cases, rates per vehicle rising rather than falling, with very rapid motorization (e.g., Zambia and Nigeria) (5). Other countries have figures comparable to those of earlier times in Europe.

Further analysis of data from developed countries shows that in spite of the general fit with the Smeed formula there are persistent differences between countries: the same ones continue to be above or below the expected values. Thus, for similar degrees of motorization the risk of road deaths in, say, France or the Federal Republic of Germany is about twice as high as in Great Britain or Sweden (6, 7).

Trends

In the 1950s and 1960s road deaths in most countries increased in step with the increase in vehicles. In some (e.g., Great Britain) the numbers then became nearly constant. This corresponded to a balance between a diminished use of motorcycles and an increase in cars.

The next major change in trend dates from the 1973 oil crisis. In many oil-importing countries voluntary restriction of travel related to rising fuel prices combined with statutory speed restrictions to cause a drop of about 15% in road accidents and deaths. Some countries made further changes (e.g., banning of large motorcycles in Japan) which further accentuated the fall. In most developed countries the initial fall has now levelled out and total deaths are again beginning to rise. In several countries the number of motorcycles has recently increased, with a marked rise in deaths and injuries to their riders.

In the oil-rich developing countries road casualties have increased spectacularly. Reliable statistics are not easily obtained but road deaths in Nigeria, for instance, have doubled since 1973, and at 8000 a year are more than the figure for Great Britain, and are the highest notified in any African country.

In other developing countries increases have been less abrupt, but there are many special problems in the introduction of motorized transport in a less developed background. For instance the scooter-based three-wheeled taxis of Indian cities have numerous accidents, as have also the overloaded and antiquated trucks and buses of many poor tropical countries. Studies show that urban road death rates can be eight times those of European cities (8); further studies are needed to obtain an accurate picture of the numbers of casualties and circumstances of accidents in such communities.

Contribution of different categories of road user

Most road vehicles are cars and the majority of road injuries are to car occupants or to pedestrians struck by cars. In spite of great changes in numbers of vehicles, pedestrian fatalities per million population tend to remain steady, though the rates differ between countries. In developed countries pedestrian casualties account for 15% to 30% of total road deaths. They shared the fall in numbers related to the fuel crisis but are now tending to increase again. Deaths of vehicle occupants account for 40% to 60% of the total, and in developed countries the deaths of vehicle occupants per thousand vehicles have fallen with time and with increasing numbers of vehicles. In Great Britain, for instance, in 1966 it was 0.48 and in 1976, 0.18; corresponding figures for the Federal Republic of Germany were 1.07 and 0.36.

These risks are very much lower than those for motorcycle riders (United Kingdom 1976, 1.1); on an average, motorcyclists travel only about one quarter the distance of the average car so that the risk of death per mile travelled is about 20 times as high. Mopeds also give special problems in countries such as France where they are numerous.

Pedal cyclists share with pedestrians the role of almost passive exposure to the violence of motor vehicles. Numbers of deaths vary with the popularity of bicycles. It has been estimated that the risk of death per mile travelled in the United Kingdom is about half that of motorcycles. Statistics of numbers of cycles are not normally available so that comparable risks per thousand vehicles are unobtainable. It would be of interest to compare rates for such countries as the United Kingdom and the United States, where few special facilities are provided, with the Netherlands, where there are special cycle tracks, and with countries such as China where there are many cycles but few cars.

Injury severity

For most countries the statistics of nonfatal injuries are unsatisfactory. Studies in Great Britain and Sweden have shown deficiencies in notification of serious injuries of 20% or more, these deficiencies varying for different categories of road user. Notifications of slight injuries are even more unsatisfactory. However, special efforts have been made in Denmark to obtain full information, and in Australia road injuries have recently become medically notifiable.

The usual national statistics fail particularly to distinguish the numbers and circumstances of the more severe and permanently disabling injuries. Research series based on hospital cases show the importance of accidents to vehicle occupants, pedestrians and motorcyclists as causes of severe head injuries, and to motorcyclists in causing severe leg fractures. In these types of research the increasing use of severity scores such as the Abbreviated Injury Score and the Injury Severity Score is helping to give comparability.

Another approach has been to survey specific injuries, e.g., head injuries (9) (of which two thirds of fatal cases and one half of hospitalized cases were found to be from road accidents) and spinal cord injuries (10) (about one half of which were caused by road accidents). More work on these lines is needed to define the circumstances in which prevention is most required.

Personal factors

For each category of road user there is a marked change of road accident rate with age. The main factors in this are exposure and competence. As soon as children can walk they are liable to have pedestrian accidents. The age-specific risk per exposure is very high in the early years but falls as competence improves. A peak occurs at about the age of 7 (United Kingdom), after which exposure increases markedly but is more than outweighed by the improved competence associated with experience. The same sequence can be seen with pedal cyclists (peak rate age 10), motorcyclists (peak rate age 19) and car drivers (peak rate age 21). In other countries with different regulations and traffic customs these peak rates may be at slightly different ages.

The lowest rates are found in mid-adult life, then competence again seems to regress with the impaired motor and sensory abilities of advancing years; new high rates per exposure are again found at the age of 65 years and above. It is disputed whether sex as such has an important effect. Rates per exposure are usually higher in females but experience of traffic is commonly less. There are, however, potentially important differences of exposure within categories, e.g., a higher proportion of females ride as passengers in cars than as drivers. This may have implications for injury protection.

Apart from obvious severe disabilities, medical conditions have rather little bearing on accident risk. It seems that, as with many aged persons, the moderately disabled commonly select relatively safe traffic conditions and so avoid the high accident rates that might have been expected. Another cause of disability which is much more prevalent is that due to alcohol; for example, almost half of the young drivers fatally injured in the United Kingdom have blood-alcohol levels higher than the permitted level.

A major interest has been the personal and psychological factors that may determine accidents. There have been many country studies which have pointed to an association with other crimes and antisocial attitudes. Whitlock (11) made a major international study which aimed to identify psychological

causes for the disparity of accident rates from those expected by the Smeed formula. More recently the topic has been reviewed by Benjamin (7).

Lessons for prevention

The epidemiological approach can identify certain areas of particular importance, e.g., motorcyclists, young drivers and alcohol.

In some of these areas improved training may help. However, many past efforts to alter behaviour have been disappointing, and, however successful such efforts are, accidents will continue to happen. There are also areas that need clearer definition, e.g., causes of disabling injury, and the special problems of developing countries.

An approach which avoids too great an emphasis on behavioural aspects is that of Haddon (12). He described ten strategies to prevent injury. These cover ways of avoiding accumulation of energy, e.g., reduction of speed; of avoiding exposure to the energy, e.g., pedestrian precincts; and of mitigating the exposure, e.g., occupant restraint systems. These are fundamentally physical approaches, however, and it must be borne in mind that mitigation of the effects of dangerous exposure to energy requires epidemiological and medical as well as engineering research to make it productive.

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Annex IV

ACCIDENT STUDY METHODS – HOSPITAL AND OTHER DATA SOURCES

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During the last decade or so, substantial progress has been made in accident studies involving the collaboration of physicians and engineers. Their objectives and methods, described briefly below, are well defined and hardly call for comment. However, the use made of them does not meet certain requirements and may give rise to hasty interpretations on the part of organizations which keep medical data separate from accident-related data. This is a shortcoming which needs to be corrected.

Summary of the objectives of accident study

The study of accidents has the following objectives:

- to classify accidents by category, each being distinguished from the others by the protective measures appropriate to it (frontal impact, lateral impact, etc.), and to determine the frequency and severity of each;
- to assign to each accident category and to each degree of impact force a degree of risk in relation to the various parts of the body of those involved; this means designating parts of the body which have to be protected in each impact situation and establishing the maximum impact force for which protective systems should be effective in order to save a given proportion of road users;
- to quantify the effectiveness of existing protective measures (helmets, safety belts, etc.);
- to evaluate the injurious or protective effect, direct or indirect, of the various components of vehicles and to calculate the frequency of their involvement in each of the accident categories listed.

Methodological principles

To achieve these objectives, accident studies observe certain essential methodological principles:

- the information gathered must be absolutely reliable;

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- the acquisition of information must be exhaustive, so as to provide all data which might in the future have uses that were not originally foreseen;
- technical information and medical information are complementary; where either is lacking, uses are very limited and may result in error;
- the classifications adopted for grouping technical and medical data should conform with internationally agreed definitions: definition of lateral impact, definition of “slight injury”, or, in more detail: VDI (Vehicle Deformation Index), AIS (Abbreviated Injuries Scale), for example.

This standardization makes it possible to compare one country's results with those of another and to benefit from the experience gained by each country.

Selection of accidents to be studied

The major methodological problem is that of the selection of accidents to be studied. In the light of the objectives mentioned above, it would appear justifiable to take as the selection criteria for studies the hospitalization of at least one injured person. In this case, it should not be forgotten that the possibilities for generalizing results obtained during a given period of observation are relatively limited. For instance, it will not be possible to calculate correctly, by the number of victims, the benefit achieved by introducing or improving a given safety measure: this is a matter beyond the scope of accident studies.

Some teams choose to analyse any accident where there is a need to tow away the vehicle involved, or which gives rise to material repairs costing over a certain sum. By selecting these criteria a large number of cases are obtained. One must then have available a very large team, unless one reduces considerably the limits of the area surveyed; however, there is then the risk of only including a limited number of types of accident, specific to the section of the road network under consideration. It is better to cover a fairly wide area and to base the survey on only a sample (1/3, 1/5 or even 1/10) of the accidents reported. This criterion, based on the material damage, has the great advantage of covering a range of accidents which can be used for statistical purposes. In particular, it makes it possible to determine trends in physical risks associated with accidents and to assess the influence of any safety measure on these risks more adequately than can be done with national statistics, which only cover accidents which result in victims. However, this criterion should be adopted only in those countries where there is a high level of motor traffic.

Data utilization

Insufficient stress has been placed on the use of medical data gathered over a number of years by accident study teams. There is a need to draw up

detailed lists which record specific lesions and lesion patterns for each category of road user, and the main types of accident sustained, specifying the protective systems used. Admittedly some countries, including France, only in exceptional cases carry out autopsies of persons killed in road accidents, thus greatly diminishing the usefulness of medical records. Such lists would make it possible, *inter alia*, to verify the validity of certain calculations, e.g., that relating to the increase in the number of persons with multiple injuries.^a

It would be incorrect to think that useful information can be derived directly from medical data collected by hospital accident departments which do not participate in accident studies. Generally speaking, there is very little or no knowledge of the types of collision in which these victims have been involved, and this may lead to simplistic or even harmful uses. Thus, one can encounter alarmist publications circulating in France on the supposed risks to the cervical vertebrae from safety belts.

Such information, in short, is detrimental to safety, in so far as it causes the public to doubt the validity of decisions which call for their collaboration, such as the wearing of helmets and safety belts.

On the other hand, medical records which do not cover the technical aspects of accidents could well be used to connect each type of injury and each representative clinical picture with some of the economic consequences of such injuries, namely, total duration of temporary disability and rate of permanent partial disability. These indices should be related to the profession, age and sex of accident victims. This use calls for the cooperation of insurance companies. So far, little has been done in this field. Nevertheless, information of this kind would supplement the medical data obtained by accident study surveys and would make it possible to determine more precisely the priority action needed with regard to road safety and the benefits to be expected.

Mechanism of injuries — biomechanical research

The study of accidents is not in a position to identify all the injury mechanisms observed. Some of them (e.g., visceral and cerebral lesions) call for experiments to be conducted with a view to explaining them. In this context, the international collaboration that has been established should help to bring about rapid advances in knowledge aimed at optimizing protective measures and determining adequate criteria for injuries.

^a See: WHO Regional Office for Europe. *Ad Hoc Technical Group on Road Traffic Accident Statistics, Prague, 26-28 September 1978*. Summary report (doc. ICP/ADR 007 (S)).

Annex V

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