SOME CHARACTERISTICS OF COLLISIONS, THE POPULATION OF CAR OCCUPANT CASUALTIES AND THEIR RELEVANCE TO PERFORMANCE TESTING

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SUMMARY

The development of biomechanical performance criteria so far has been directed at assessing specific thresholds for certain injuries, and converting these to numerical values of force and time measured on a dummy in a standard crash. In real life, however, occupants vary greatly in age, size, and tolerance to injury, and collisions vary from the slightest to the most severe. The use of a single size dummy in a single test clearly cannot fully reflect the range of variables present in the real world.

This paper examines some of the data already published on these variables. These are the distributions of severities of impacts, of types of collision, the age, sex, and size of occupants exposed to risk in the three designated seats in the car (driver, front passenger, rear passenger), the variation in injury severity with age and the relation of age to mortality for a given injury.

Some conclusions are drawn on the weightings which might be given to different severities of injuries, and some observations are made on the consequences of "under" and "over" protection. Suggestions for necessary further research projects are outlined briefly.

INTRODUCTION

Historically, the protection afforded by vehicles in collisions has been specified by means of design rules which have controlled the characteristics of certain sub-systems. It has become apparent in recent years, however, that it is impossible to provide optimum protection by the specification of these sub-systems considered separately, and there is now a trend towards the development of a series of whole vehicle tests which will supposedly represent a satisfactory proportion of real-world accidents (Mackay, 1975). Further, each test will specify the performance limits in terms of the forces and the time durations as measured on anthropometric dummies.

Development of biomechanical performance criteria for tests of occupant restraint systems is clearly a promising way forward, but in discussions on this topic, attention has been mainly directed to assessing thresholds for certain injuries of human subjects and the conversion of these to values to be measured on a dummy in a standard crash. It is then perhaps too readily assumed that the task will be completed.

In real life any proposed restraint devices will be used by a wide range of size and age of occupant and the impacts will range from the slightest to the most severe. The aim of the restraint system is to minimise the injuries caused having also appropriate regard to inconvenience or extra expense that may be incurred by the use of the protection. The method of a single severity of impact and a single size of dummy may achieve this minimum but consideration of the populations of impacts and of persons exposed should clarify whether this is so. The following sections discuss some of the distributions and relationships involved.

THE POPULATION OF SEVERITY OF IMPACTS

Minor impacts are much more frequent than the most severe. Many of the minor impacts, however, do not cause injury to the occupants so that the distribution of injury-producing impacts is skewed starting at zero with low impact speeds and rising rapidly to a peak at perhaps 25 km per hour Equivalent Barrier Speed (for frontal impacts) where the increasing risk of injury with increasing E.B.S. combines with the decreasing but still high frequency of impacts at moderate speed to give a maximum (Mackay et al, 1973) see Fig. 1. Similar relationships in terms of velocity change are described by Grime (1977) who also quotes Moreland (1961) and Langwieder (1973); these are illustrated in Figs. 2 to 5.

The effect of choosing a single severity of impact for a test specification is to select a particular value in this distribution, for example, A-A in Fig. 5.

THE DISTRIBUTION OF TYPES OF COLLISIONS

It is important that any test should represent adequately a large proportion of a particular accident type. The impact configuration and speed of each test should be so chosen that it is typical of a moderately severe part of the crash severity spectrum for that class of collision. Tolerance levels should be specified which will firstly provide survival for most people exposed to those conditions, and secondly, but perhaps at a subordinate level, protect against serious injury where possible. These conditions may have to be met at the expense of a number of minor injuries caused in more numerous low speed collisions.

A number of studies have outlined the relative frequency of different collision configurations and objects struck, (Riley and Radley, 1976; Griffiths et al 1976). If frontal and front oblique collisions are considered together, approximately two thirds of those causing serious injury are car to car, the remainder being impacts with trucks or solid objects such as trees and lamp posts. The mechanisms of structural collapse and injury causation are similar in car to car and car to solid object crashes, which together account for over 80%. It is, therefore, reasonable to base a test procedure on these types of accident.

Although it is more convenient to run the car into a solid object, the type of test must be arranged to give results similar to car to car impacts in terms of the extent of the damage, the deceleration pattern and the velocity change, and it must also allow for mass ratio considerations. Over fifty per cent of collisions have a direction of impact which is head-on, and the injuries received by the occupants do not differ much between head-on and oblique impacts, and, therefore, a head-on direction is acceptable for test purposes. More than a third of injury-producing frontal collisions involve overlaps of between a quarter and a half. The amount of overlap of the frontal width is important because for a given speed of impact, this quantity largely controls the level of deceleration and the amount of intrusion into the passenger space. These two criteria, deceleration and intrusion, lead to different types of trauma and require separate evaluation, although it may be possible within a single test to specify both requirements.

It is apparent that the perpendicular 30 m.p.h. rigid barrier test which currently specifies steering assembly performance, produces decelerations of the vehicle which are more severe than those which occur in car to car collisions on the road (C.C.M.C. 1975). Conversely at equivalent barrier speeds, the amounts of intrusion seen in car to car collisions are much greater than in the rigid barrier, symmetrical test.

Work is under way which compares the relative merits of offset, perpendicular barrier impacts with varying amounts of overlap with angled barriers set at 60 degrees to the line of travel of the car (Kemp, Neilson and Wall, 1976). An asymmetrical test, however, introduces a number of new problems which still demand evaluation, and at present it is too early to say whether deceleration and intrusion criteria can be measured solely in terms of dummy response, and whether these can both be evaluated in a single crash test.

There is the additional problem of compatibility both in terms of collisions between vehicles of different mass, and between structures which vary in terms of the stiffness of their several components. This is a complex problem because true compatibility involves considerations of collision configurations other than car to car, head-on. Front to side impacts particularly show severe incompatibility between front structures and side structures as they are currently designed. In the future the use of deformable barriers for both frontal and side impact evaluation may well be necessary.

THE POPULATION OF PERSONS EXPOSED

Age

Though the total population which might be exposed has a broad distribution with only slightly decreasing numbers with advancing years up to age 60 and after that a more rapid decline, the actual exposed population differs from this. Proportionately fewer children and fewer old people travel in cars and in the case of drivers there are legal limits to the age range. A further influence is that younger drivers have high accident rates. The data of Tarriere et al (1977) give the distributuion of ages of occupants in injury-producing accidents from sample studies in France. These data are illustrated in Fig. 6.

They show that, as drivers, males predominate in a ratio of 4 to 1. For front seat passengers, however, females outnumber males in a ratio of almost 2 to 1, whilst for rear seat occupants again females predominate in a ratio of 6 to 5. The median age for rear seat occupants is 20, with 25% being less than 12 years of age, and 20% being over 40 years. Occupants in the three sitting areas occur in the ratios of 2.3 to 1.5 to 1 for drivers to front passengers to rear passengers. For both groups of front seat occupants the distribution is skewed with a peak at approximately 25 years. The distributions given in Fig. 6 show that rear seat occupants particularly are different from front seat occupants. The data in Fig. 6 are for occupants present in injury producing collisions. The distributions for collisions with serious and fatal casualties are likely to be different again.

Relation of age to susceptibility to injury for a given impact

Apart from special factors which affect changes of susceptibility through childhood, the major change is an increase of susceptibility with increasing age through adult life. Tissues become more subject to injury for a given severity of impact. Consistent with this is the finding by Schmidt et al (1974) of increasing numbers of rib fractures with advancing age of cadavers when subjected to experimental impacts (Fig. 7). The relationship shows an average increase in rib fractures of about 3.75 or of injury severity of 0.6 AIS per decade above age of 20 years, according to Schmidt.

This implies that when an impact load is applied to the chest of a 25 year old male such that it just begins to produce rib fracture with no displacement, the same load might well generate multiple, life-threatening rib fractures, often associated with damage to the thoracic organs, in a 65 year old.

Age is not the only parameter which influences susceptibility to injury. For example the mineral contents of bone have a considerable effect on both the dynamic and static strength characteristics of the skeleton (Curry 1969).

Relation of age to mortality for a given injury

Studies by Baker et al (1974) and Bull (1975) show a relation of mortality to age for given severities of injury. In Fig. 8 the data are reconstructed to demonstrate this relationship. After the age of 40 mortality from moderately severe injuries rises by 5 - 10% per decade.

In field data of injury and death from traffic accidents there are included both the increasing susceptibility to injury and the increasing mortality for given injuries with advancing years. Hopens (1965) analysed ACIR accident data and compared the injuries of young adults (20 - 39 yrs) with those of older adults (60+ yrs). He showed that after correction for severity of accident and seating position the older car occupants were more frequently injured and their injuries were much more often serious or fatal.

Size and Weight

Standard figures are available for the increase of body weight with age through childhood. For adults there is a correlation between body weight and height (e.g. log height proportional to log weight) and height itself shows an approximately normal distribution. Further anthropometric data are available for specific relevant measurements, e.g. sitting height, though these may need to be separately considered for different ethnic and national groups. Selection of a single size of dummy implies that the tests relate to a single value in the distribution of body height and body weight.

Data from France (Tarriere, 1977) are shown in Fig. 9 for the heights of occupants involved in injury-producing accidents. These data show that rear seat occupants particularly are smaller than front seat occupants, and consideration of mean values only can be misleading.

Within a car, variation in height particularly may lead to changes in the exposure to risk of certain parts of the body. For example, tall people in the front seats have an increased risk of head contacts occurring with the header region or the A pillar in comparison to shorter people, if no restraints are used.

Body weight itself may well have a considerable influence on injury susceptibility. In a given collision a heavy person wearing a seat belt experiences loads which are concentrated across the shoulder and chest, the pelvis and on the knees. Those loads for a given collision vary in proportion to the body weight of the occupant, but it is unlikely that the tolerance to injury varies proportionately.

DISCUSSION

The aims of good design for crash performance and for legislation which influences design are to minimise deaths and injuries or minimise costs to the community or some combination of both. There may also be a desire to use other criteria. One such would be to minimise "unacceptable" accidents such as coach crashes where large numbers of people are severely injured at the same time, or special "unacceptable" injury situations such as entrappment in a burning vehicle. In a political sense more effort sometimes appears to be appropriate for the prevention of these special situations than is made for more "normal" accidents.

More generally, in the light of what is known of the populations of impacts and variations in individual susceptibilities, we should guard against optimisation of protection at the wrong values, or combinations of levels of the selected variables. For instance, protection should not concentrate too much on severe impacts, which may be fatal by a number of injury mechanisms not all of which can be controlled. There may then be detriment to fuller protection in less severe impacts which would give benefit to more people.

Judgement on these considerations depends partly on:-

1. The relative weightings to be given to prevention of slight, severe or fatal injuries.

2. The role of circumstances of injury other than those modelled by the test procedure, e.g.
    a) Impacts from other directions
    b) Deformation of the passenger compartment, leading to severe injury.

Further analysis of field studies will be necessary to assess these factors.

3. The likely effects of "under protection" and "over protection".
    a) "under protection" will occur with impacts more severe than those tested or with persons heavier or otherwise more susceptible to injury than correspond to the dummy specifications. The resulting injuries will then be more severe.

    b) "Over protection" will occur with less severe impacts and/or lower levels of susceptibility. In these circumstances it is possible that a device such as a more rigid belt might induce more injuries than would a belt which would just protect in the circumstances. If this is valid then more extensive exploration of the interplay of impacts and individual susceptibilities will be necessary to optimise the test specifications.

We suggest that more studies and thought along these lines should precede adoption of standards of the type currently proposed. For example:-

1. A further examination of the optimum velocity changes at which protection is to be provided in frontal and side impacts.

2. An examination of the physical characteristics of the populations sitting in the three designated seats in the car (driver, front passenger and rear seat occupant). Is it appropriate to assume that the same levels of protection should apply to all three positions? In particular it appears that rear seat occupants have different physical characteristics in comparison to front seat occupants.

3. An examination of accident distributions to optimise the consequences of "under" and "over protection".

4. An examination of the consequences of a simple, single-test, pass-fail criterion for the protection level offered by a car. Because of scatter in dummy response under crash conditions, what margin must a manufacturer provide in order to be confident that his design will pass a compliance test? What will be the consequences of that margin and would it be better to introduce some probability element into the compliance specification?

5. Even in those countries where compulsory use of seat belts has resulted in high levels of belt use, when measured in the general traffic stream, it is by no means clear that the level of belt usage in collisions is correspondingly high (McLean and Aust, 1977). It is perhaps premature to act on the premise that all occupants will be using restraint systems and that design should be optimised exclusively for the restrained condition. An examination of the best balance in design for differing proportions of restrained and unrestrained occupants is an immediate requirement before test conditions and protection levels are established.

6. Studies of real accidents and the associated injuries with simulations of the same accidents using instrumented dummies can contribute greatly to the solution of the problems outlined. The findings then need to be interpreted in the context of the suggested distributions of personal and accident variables. Valuable studies on these lines have been made by Lowne and Wall (1976) and are in progress in the co-operative programme on biomechanics at present being conducted in Europe.

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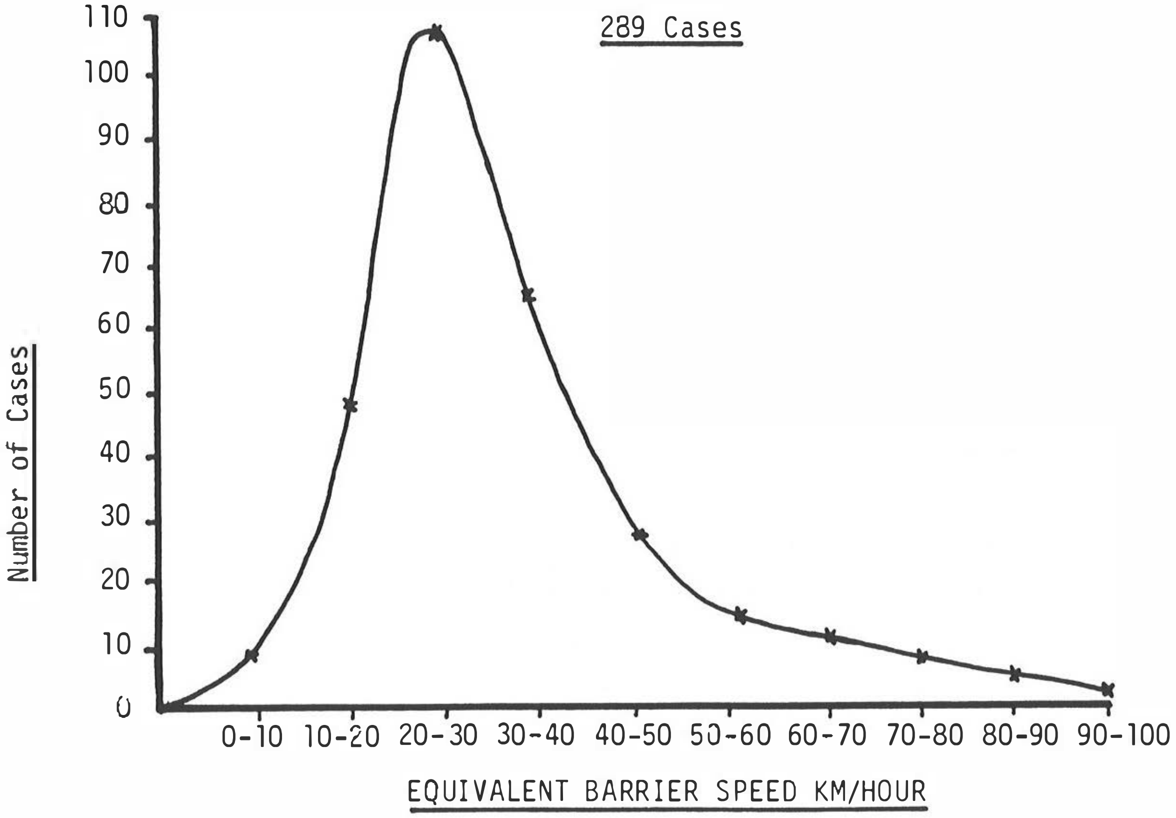

Fig. 1. E.B.S. distribution for injury-producing frontal impacts (Mackay et al 1973)

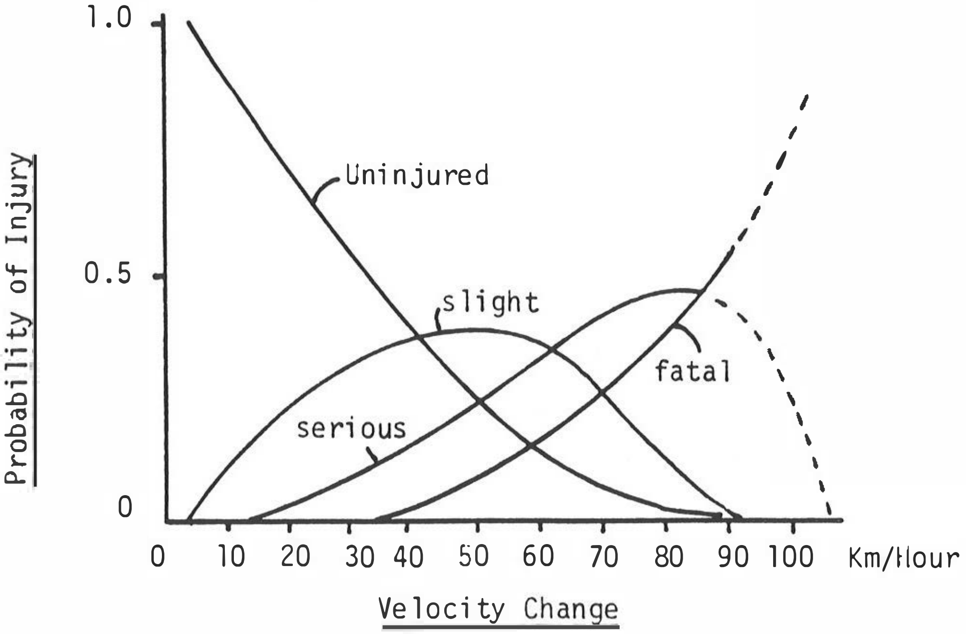

Fig. 2. Severity of injury to drivers in frontal impacts (Grime 1977 after Moreland 1961)

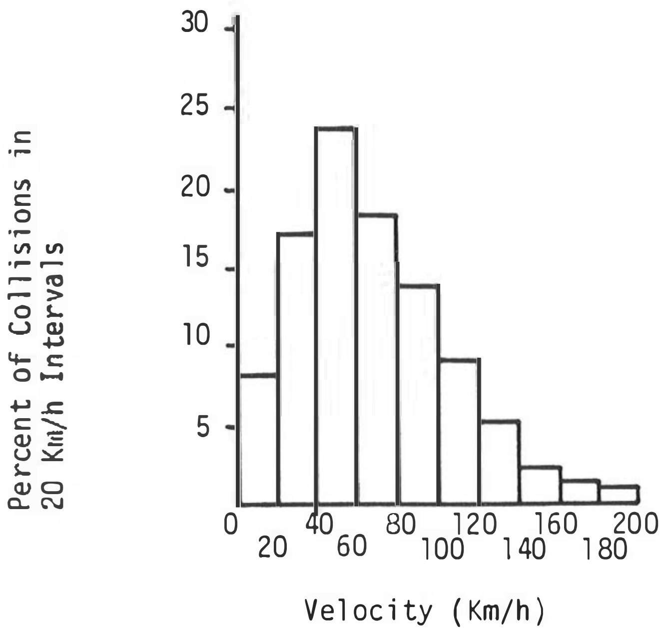

Fig. 3. Distribution of relative velocity in car/car head on collisions (Grime 1977 after Langwieder 1973) (relative velocity approximates to twice velocity change)

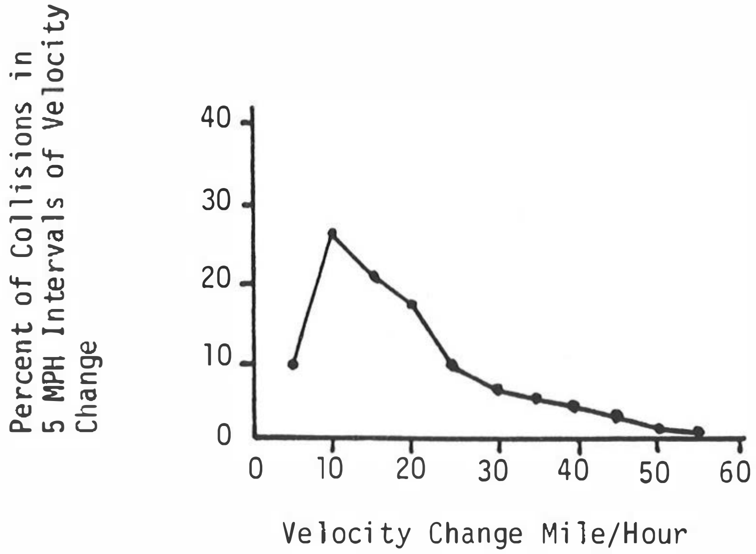

Fig. 4. Distribution of velocity changes in frontal collisions (excluding damage only collisions) (Grime 1977 after Mackay 1973)

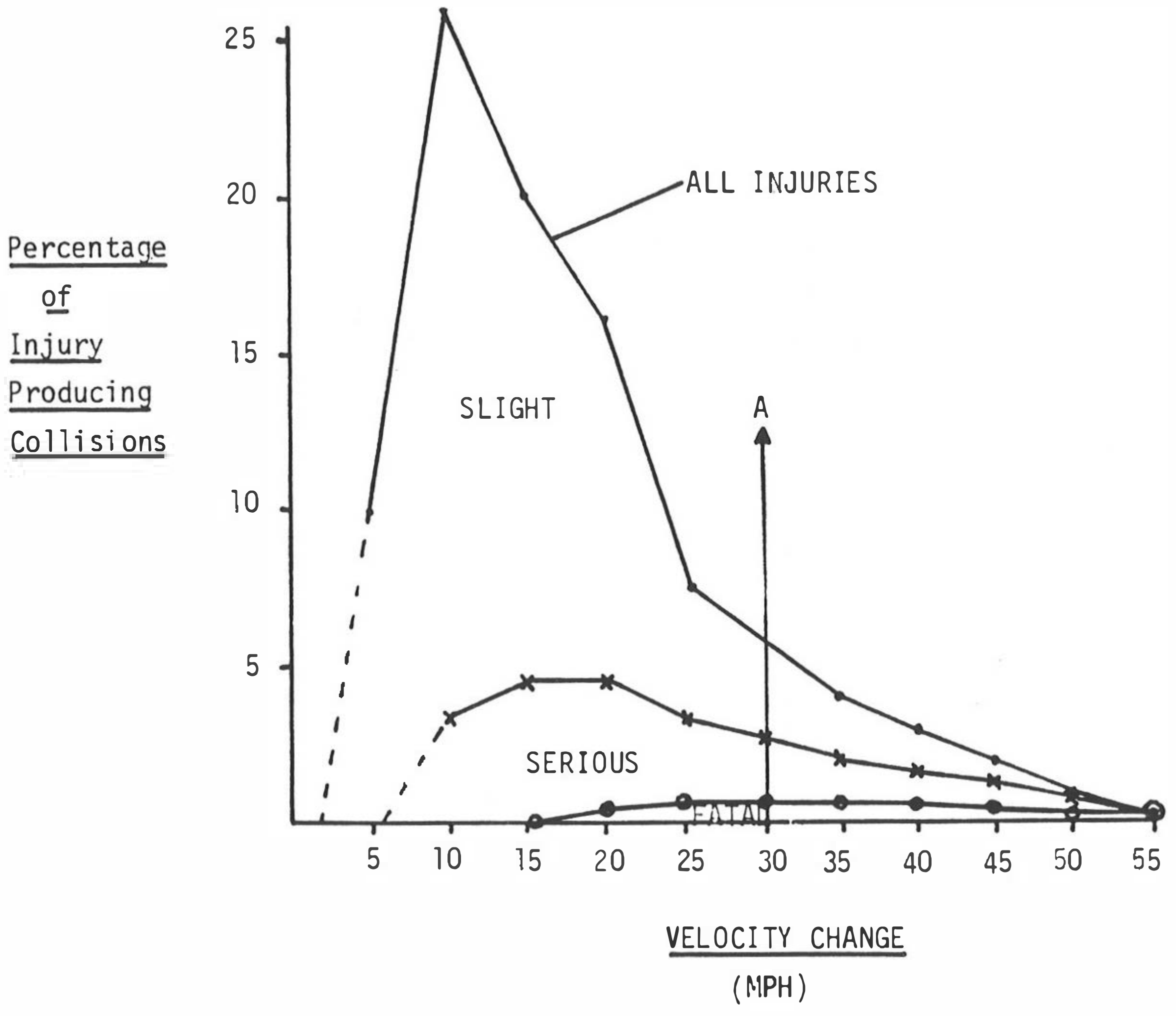

Fig. 5. Data of Fig. 4 partitioned in accordance with Fig. 2. to show approximate distribution of velocity changes in impacts causing different severities of injury.

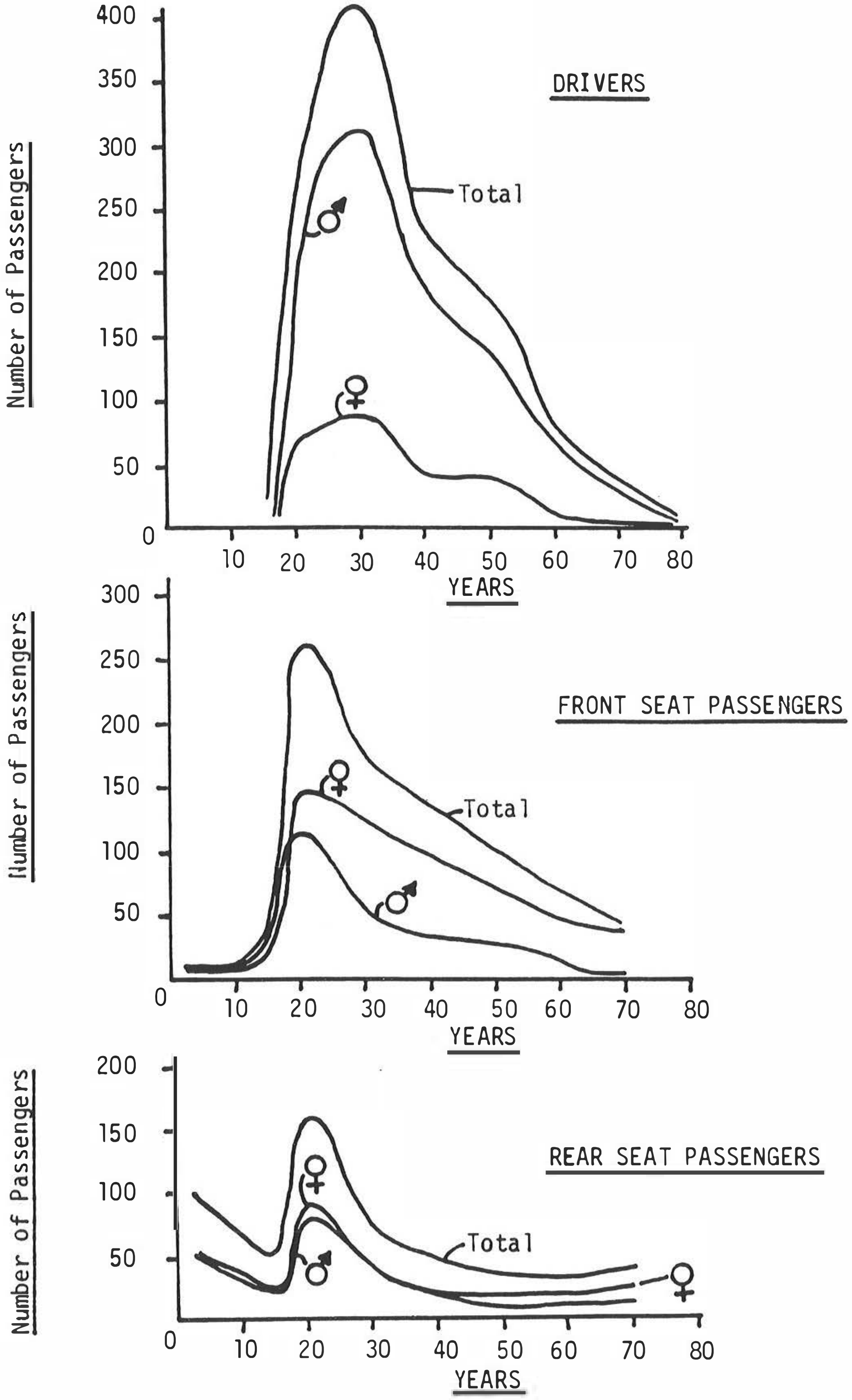

Fig. 6. Age Distributions of Car Occupants in Crashes (after Tarriere 1977)

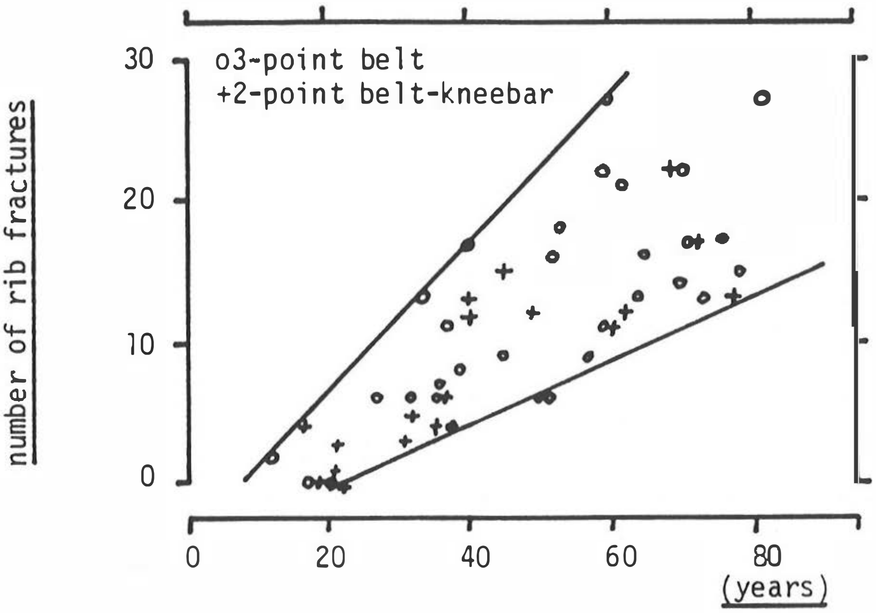

Fig. 7. No. of rib fractures in cadavers of different ages subjected to experimental impacts (Schmidt et al).

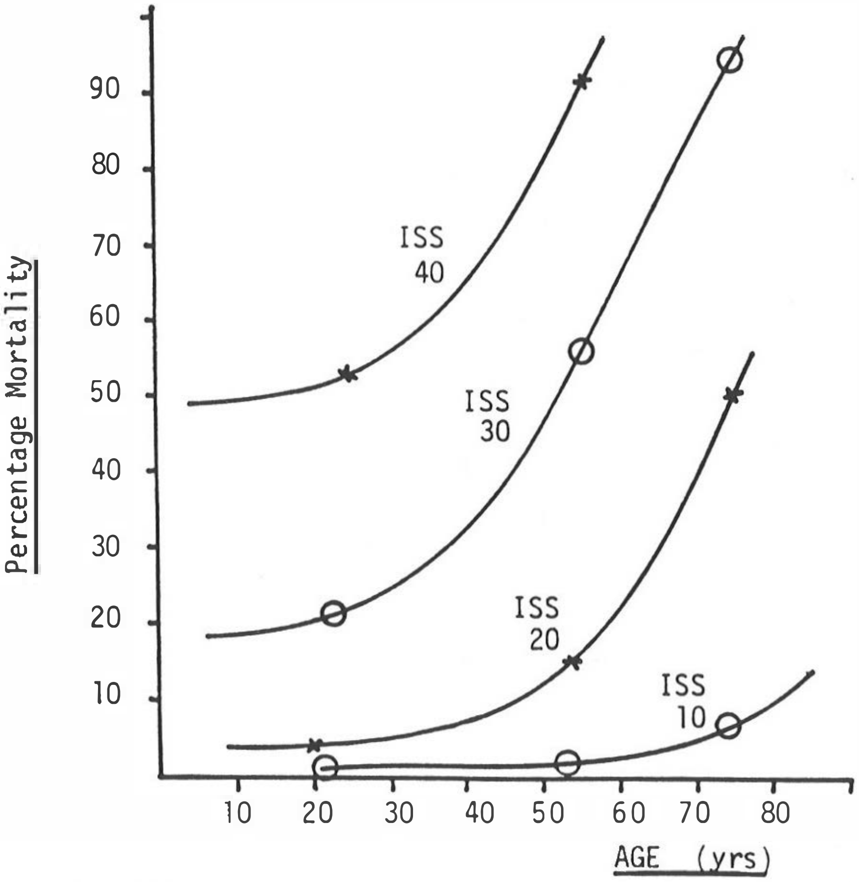

Fig. 8. Mortality at different ages for injuries of standard severities (Bull 1975).

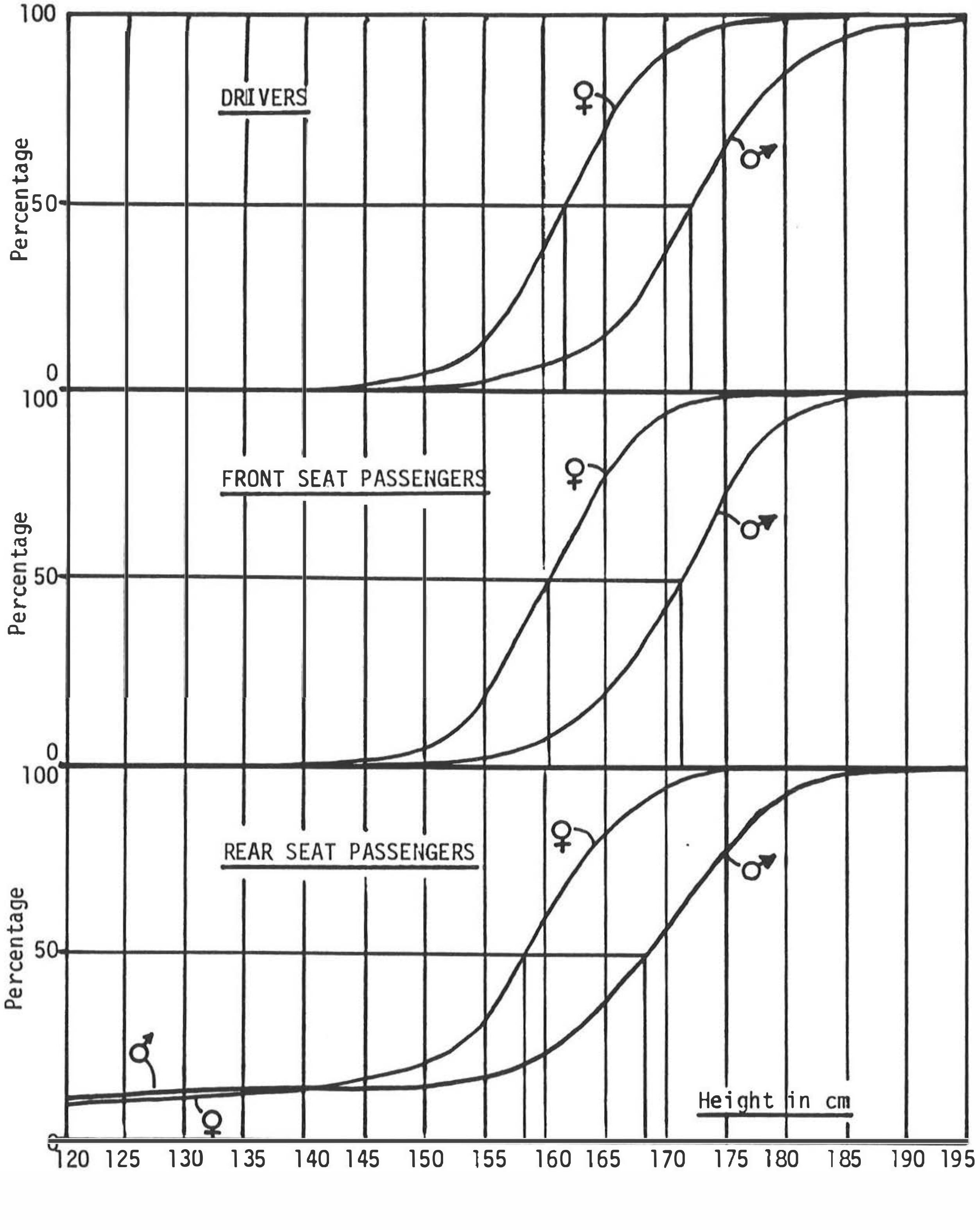

Fig. 9. Cumulative Frequency Curves for Heights of Car Occupants in Crashes (after Tarriere 1977)