SOME CHARACTERISTICS OF THE POPULATION WHO SUFFER TRAUMA AS PEDESTRIANS WHEN HIT BY CARS AND SOME RESULTING IMPLICATIONS

S.J. Ashton and G.M. Mackay

Accident Research Unit, Department of Transportation and Environmental Planning, University of Birmingham, England.

ABSTRACT

Pedestrian casualties represent a particularly heterogeneous population in terms of their biomechanical characteristics. Age and sex are two measureable parameters which relate to this variation, whilst the circumstances of the accident control the frequency and severity of exposure to certain types of trauma. This paper looks at some of the dominant accident variables. These are the pedestrian's age and stature, the car impact speed and some of the detailed geometrical and physical characteristics of the car exterior. The great importance of leg fractures and head injuries is illustrated and some of the consequences for design are discussed in terms of realistic and appropriate test procedures.

PROTECTION OF THE CAR OCCUPANT, given that a crash is going to occur, has been the concern of the car industry and legislative groups for the last decade. With the provision of improved crash performance, in the form of occupant restraint systems, better windscreen glass, load-limiting steering assemblies and anti-burst door locks, the car occupant has a markedly improved chance of survival. One consequence of this trend is that in many motorised countries pedestrians represent the most important single group of traffic casualties.

In terms of fatalities, pedestrians account for 40% - 50% of the total in many countries, particularly in those parts of the world such as the Middle East where the growth in car ownership has been very rapid over the last ten years. If one takes into account the incomplete data from the developing countries, it is quite possible that pedestrians, worldwide, represent the single largest group of traffic fatalities. Fatalities, however, are only a small part of the problem.

This paper looks at some of the characteristics of the pedestrian population and at some of the vehicle factors influencing pedestrian trauma.

IMPACT SPEED

Figure 1 shows the impact speed distributions for car and car derivatives involved in pedestrian accidents where the pedestrian is struck by the front of the involved vehicle. This figure is derived mainly from data obtained in at-the-scene pedestrian accident studies conducted at the Accident Research Unit, University of Birmingham (1, 2)* with the data weighted to produce the

*Figures in parentheses denote references at the end of the paper.

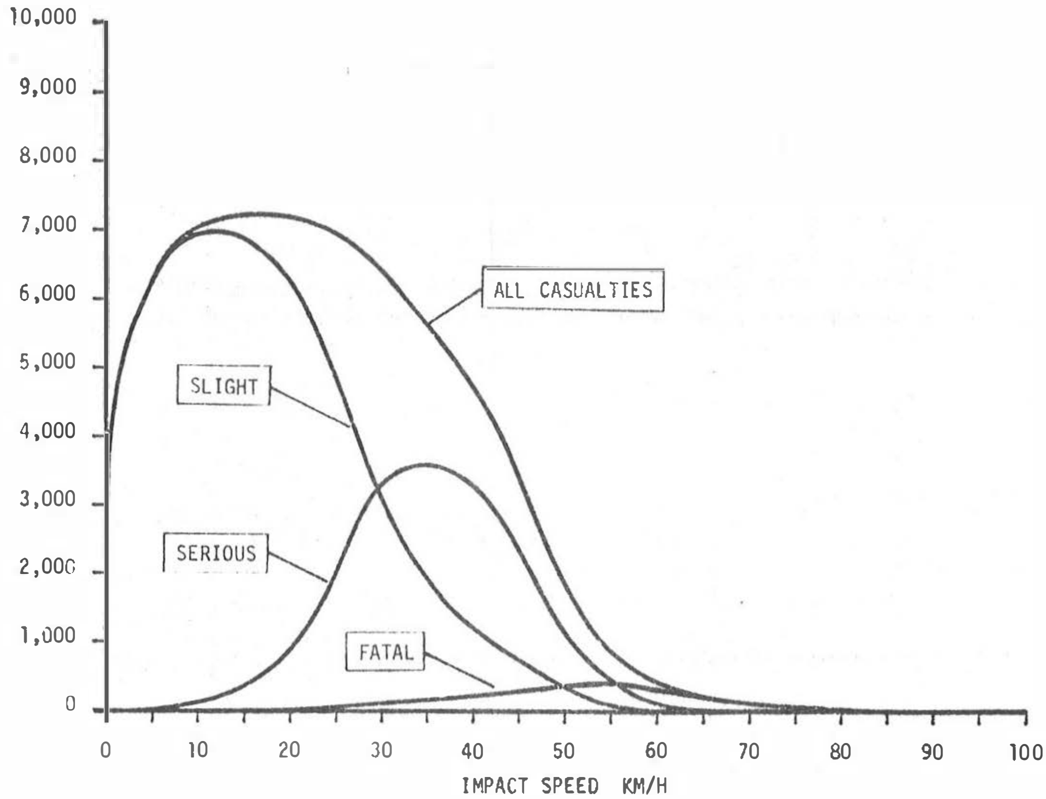

Figure 1 - Impact Speed Distributions for Pedestrians Struck by the Fronts of Cars or Car Derivatives.

same proportions of slight, serious and fatal casualties as occur in the U.K. nationally. With current car designs, pedestrians struck at impact speeds less than 30 km/h sustain predominantly slight (AIS 1) injuries whilst at impact speeds above 30 km/h the injuries are predominantly non-minor ($\geqslant$AIS 2). The change from predominantly survivable injuries to predominantly fatal injuries takes place between 50 km/h and 60 km/h. These results are in agreement with those of other studies (3).

The impact speed distributions are dependent on the severities of the injuries considered. The 50%ile impact speed for all severities of injury is between 20-25km/h. If, however, only non-minor injuries are counted, the 50%ile impact speed rises to approximately 35km/h, and if only fatalities are considered, to 50km/h. The corresponding 90%ile impact speeds are, for all injuries 40km/h, for non-minor injuries 50km/h and for fatalities 65km/h (Figure 2).

It has frequently been reported, and can also be seen from figure 1, that there are considerable variations in the severities of the injuries sustained for a given impact speed; fatalities having been noted at impact speeds less than 20km/h and minor injuries having been noted at impact speeds greater than 40km/h. These variations in injury severity for a given impact speed suggest that variables other than impact speed are important in determining injury severity.

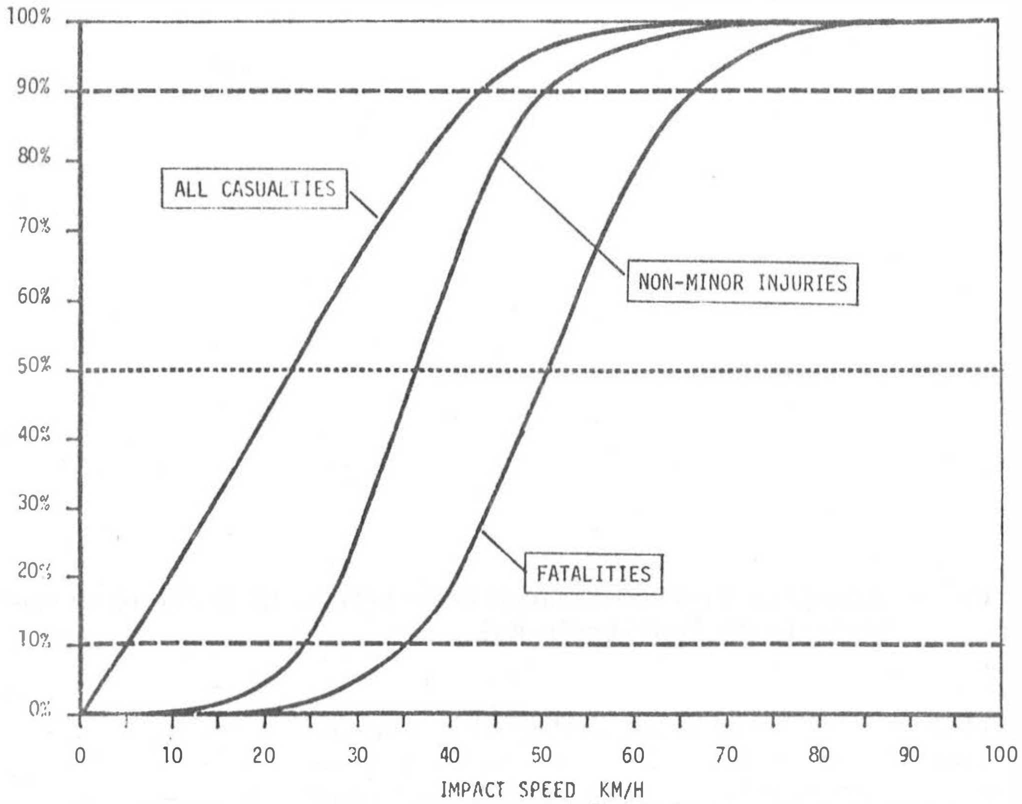

Figure 2 - Cumulative Impact Speed Distributions for Pedestrians Struck by the Fronts of Cars or Car Derivatives.

AGE

Age influences pedestrian injuries in two ways. Firstly height and weight are related to age and consequently a child will experience different impact conditions to an adult if both are struck at the same speed by similar vehicles. If the pedestrian is an adult the bumper typically strikes the lower leg and the front of the bonnet strikes the upper leg or pelvis. If, however, the pedestrian is a 6 year old child the bumper would strike the upper leg and the bonnet would strike the chest or abdomen.

Secondly, injury tolerance is a function of age. The bones of young children (< 10 yr.) are more resilient than the bones of adults (4). The elderly generally tend to be more susceptible to injury than other age groups due to their decreased bone strength and, once injured, are more likely to die from injuries of a given severity.

The effects of age can be shown by considering the frequency of injuries of different severity by age of pedestrian (Figure 3). In the 5-15 year age group approximately 5% of those sustaining a serious or fatal injury die, while for the 61-70 year age group the figure is 15%, rising to over 25% for those aged over 80 years. The proportional increase in serious and fatal injuries with age is, at least partly explained by the lowering of injury tolerance to impact with age and by the increased susceptibility with age to die once injured (5), and may also be partly explained by differences in impact conditions with age (7).

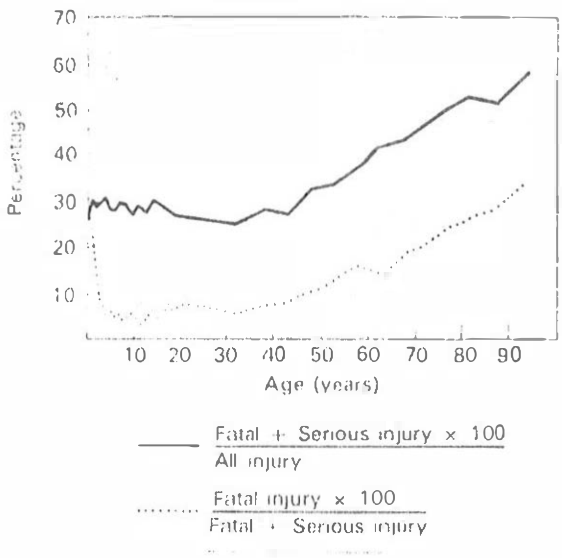

Figure 3 - Susceptibility of Injured Pedestrians to Different Levels of Injury Severity by Pedestrian Age.

It will be noted from Figure 3 that the very young child (≤ 2 years old) is more likely to be killed than the older child when involved in a pedestrian accident. Fortunately, however, their involvement rate is low. Less than 1% of all child pedestrians struck by cars are less than 3 years old (7).

The effects of age can also be seen in the pattern of the injuries sustained. For instance there is a lower incidence of non-minor pelvic and leg injuries, and a higher incidence of non-minor head injuries in the young than in the elderly. Figure 4 shows the percentage sustaining an injury to a particular body area by age. It can be seen that, whilst there were no non-minor pelvic injuries sustained by children aged 0 - 4 years old, 10% of adults aged 30 - 44 years old and 53% of elderly adults aged over 75 years sustaining AIS 2 - 3 injuries sustained a non-minor pelvic injury.

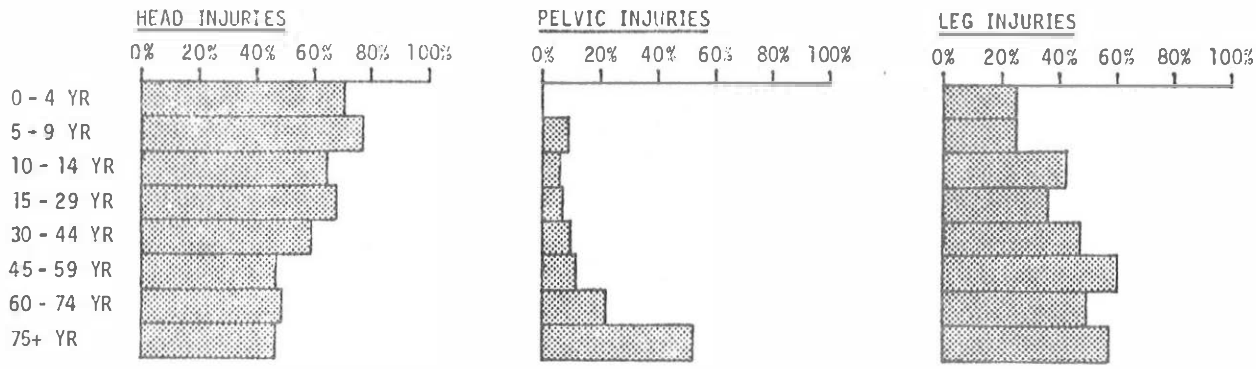

Figure 4 - Incidence of Non-Minor Head, Pelvic and Leg Injuries by Age for 739 Pedestrians Sustaining AIS 2 - 3 Injuries.

Changes in the nature of the injuries sustained with age have been considered in more detail elsewhere (6,8). These differences in injury patterns between the different age groups are due to variations in exposure of the different body areas to injury between children and adults as a result of differences in stature, and as a result of the differences in injury tolerance that occur with age. Whilst adults and elderly adults are likely to have the same exposure to pelvic and leg contacts, the reduced injury tolerance of the elderly makes them more likely to be injured.

PATTERNS OF INJURY

Head, leg and arm injuries are the most frequent injuries sustained by pedestrians struck by the fronts of cars. Data obtained from existing police and hospital records have been used to describe the injuries sustained by pedestrians (8) and it has been found that the pattern of injury varies with age, overall injury severity and with the severity of the injuries counted.

The effect of overall injury severity on the pattern of injury can be seen in Figure 5 which shows the distribution of injuries sustained by adults aged 15 - 59 years by overall injury severity. Leg injuries were sustained more frequently than head injuries by those sustaining only minor injuries. For those receiving non-minor injuries head injuries were the most frequent injuries and leg injuries the second most frequent injuries sustained. In general the likelihood of injury to any particular body area increased with increasing overall injury severity - for example head injuries were received by 54% of the survivors sustaining minor injuries, 79% of the survivors with non-minor injuries and 95% of the fatalities. Corresponding figures for leg injuries were 76%, 75% and 88%, and for arm injuries 37%, 45% and 57% respectively.

The severity of the injuries counted in describing the pattern of injury also has an effect on the pattern of injury. For example, although head injuries were sustained by 79% and leg injuries by 75% of the adult survivors with non-minor injuries, only 60% sustained non-minor head injuries and 48% sustained non-minor leg injuries.

Many of the injuries sustained by survivors with non-minor injuries are surface injuries or brief periods of unconsciousness (AIS 2 internal head injuries with no skull fracture). If these injuries are not considered as 'serious' injuries the relative importance of head and leg injuries changes, leg injuries becoming the most frequent injuries sustained - head injuries being sustained by 38% and leg injuries by 66% (Figure 6).

GENERAL CAUSES OF INJURY

In depth at-the-scene accident studies have enabled the specific causes of pedestrian injuries to be identified and the relative importance of different mechanisms of injury established (3). Contact with the car has been shown to be the main cause of non-minor injuries, and it has also been shown that the severity of these injuries is dependent on the speed of the vehicle at impact. In contrast the injuries resulting from contact with the ground appear to be virtually independent of impact speed, although there may be some masking of the ground contact injuries by vehicle contact injuries.

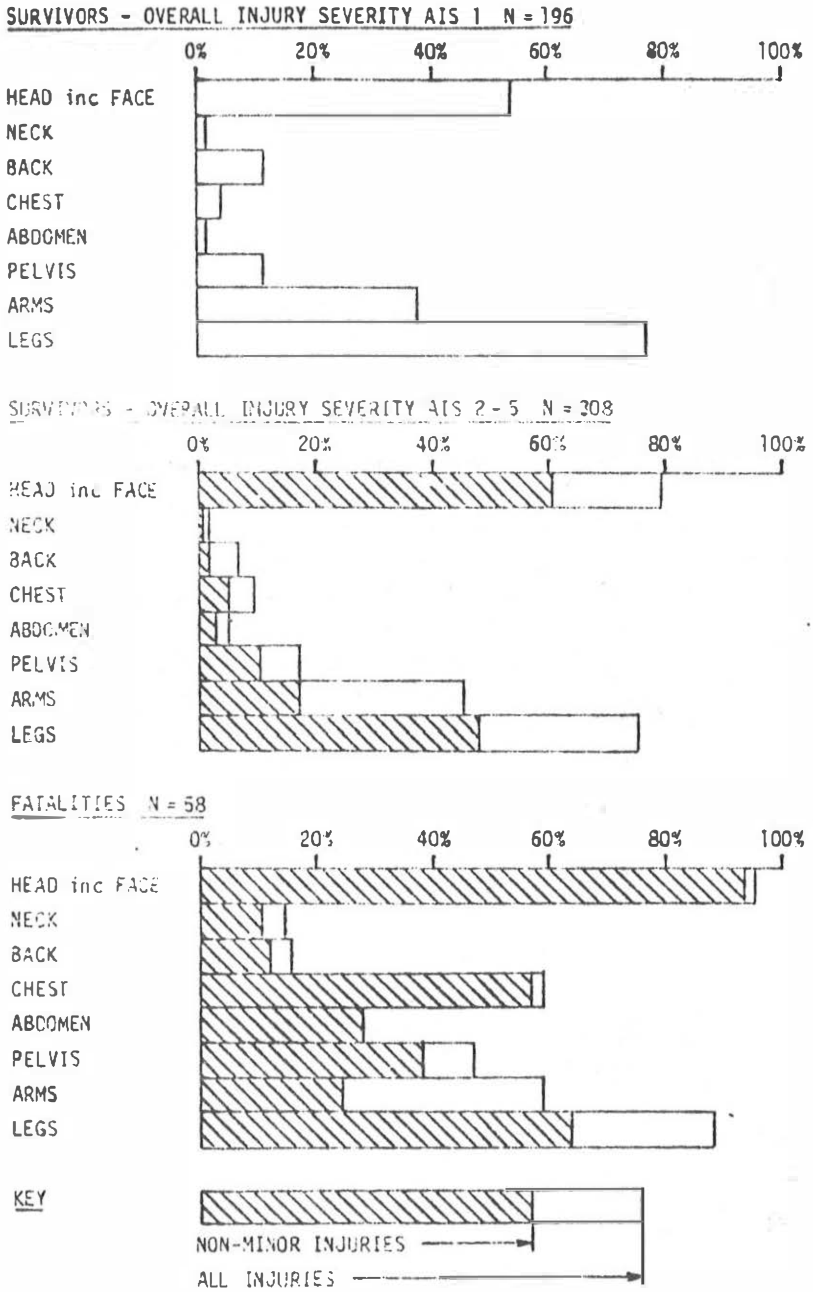

Figure 5 - Pattern of Injury for Adults Aged 15 - 59 Years Struck by the Fronts of Cars or Car Derivatives by Overall Injury Severity and Severity of Injuries Counted.

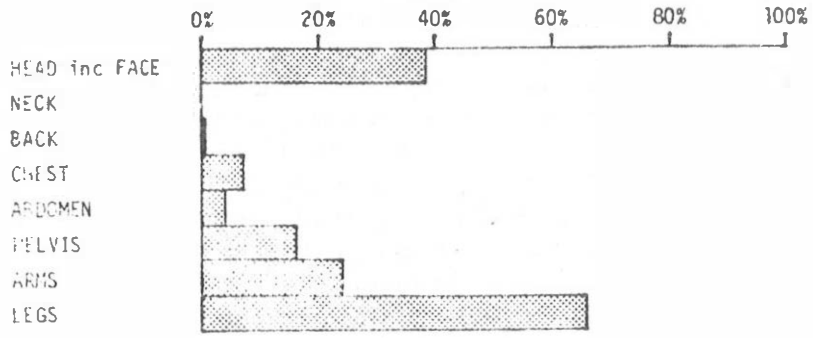

Figure 6 - Pattern of Injury for Adults Aged 15 - 59 Years, Excluding Surface Injuries and Moderate Concussion, for Pedestrians Struck by the Fronts of Cars or Car Derivatives and who Sustained Non-Minor Non-Fatal Injuries.

VEHICLE CONTACT INJURIES

Research into actual pedestrian accidents (1, 6, 9) has shown that, for current relatively stiff structures, design of the vehicle front structure can influence the location and severity of the pelvic and leg injuries sustained by pedestrians. The location of the bumper not only determines the location of the fracture but also appears to influence the likelihood of a fracture occurring as a result of bumper contact, the lower the bumper the less likely a fracture to occur. Pelvic fractures occur more frequently with vehicles having short bumper leads than with vehicles having long bumper leads. However vehicles with short bumper leads appear to be associated with a lower overall incidence of pelvic and leg fractures than vehicles with long bumper leads. The optimal design is thus a compromise between different conflicting requirements.

The accident data suggest, however, that there are some benefits from short bumper leads in that the application of the impact forces at two points along the leg rather than at one increases the fracture threshold. Taking this concept to its conclusion suggests that the vehicle front structure should be a smooth structure applying a distributed loading to the pedestrians lower limbs rather than have a separate bumper and leading edge which apply two concentrated loads. Whilst shape has an effect on the injuries sustained, experimental tests (10-13) have shown that compliance is likely to have more effect on the injuries than shape, and that measureable reductions in the numbers of pedestrians with serious pelvic and leg injuries will result from the introduction of compliant 'pro-pedestrian' front structures.

At-the-scene studies have also shown that contact with the vehicle is responsible for a higher proportion of life-threatening or fatal head injuries than contact with the gorund, and that contact with the windscreen frame is more likely to result in serious head injury than contact with the windscreen glass or top surface of the bonnet. Thus, if the vehicle exterior could be designed to reduce the incidence of head contacts to the relatively stiff windscreen frame, a reduction in the incidence of serious head injuries could be expected. However, the actual reduction in the severity of the head injuries sustained may not be as great as expected due to the possible masking of ground contact head injuries by vehicle contact head injuries in this study.

At present the location of the head contact is influenced by pedestrian height, vehicle shape, vehicle impact speed and deceleration; the distance from the front of the vehicle to the head contact increasing with increasing pedestrian height, decreasing bonnet height, increasing impact speed and decreasing vehicle deceleration. The introduction of compliant 'pro-pedestrian' front structures designed to reduce pedestrian pelvic and leg injuries is likely to alter the location of the head contact on the vehicle, the 'Wrap Around Distance' to the head contact becoming equal to the pedestrian height as the increased friction between the compliant front structure and the pedestrian's legs reduces the 'slip' between the pedestrian and the vehicle exterior to zero (14). A reduction in the 'Wrap Around Distance' to the head contact will result in fewer head contacts with the windscreen and windscreen frame and more head contacts with the bonnet. The bonnet, therefore, should be designed to provide a tolerable head contact. This, in conjunction with a 'pro-pedestrian' front structure would result in a vehicle less likely than present designs to cause serious or fatal injury to pedestrians.

THE SPECIFICATION OF THE CAR EXTERIOR

The current state of knowledge shows that pedestrian injuries are extremely numerous, that cars vary considerably in their potential for causing injury, that the bumper and the front edge of the bonnet are important sources of leg injuries, and that severe head injuries are frequent following windscreen frame contact.

In developing test procedures it is necessary to consider what happens in real accidents and to ensure that the procedures adopted reflect real accident circumstances. If this is not done there is a possibility that the test procedures will fail to discriminate between effective and ineffective designs. Accident studies have shown that there are considerable variations in virtually all accident parameters. The heights, weights, pre-impact orientation and injury tolerance of the involved pedestrians vary considerably, as do the impact speeds and locations of the contacts of the vehicles involved. Thus a single test under one set of standardized conditions, can only test one point of the accident continuum. The use of a single test is therefore not sufficient.

These conditions suggest that there are three parts to the testing of the pedestrian protection properties of the vehicle front structures:-

1. testing of the dynamic stiffness of the vehicle front structure, probably by an impactor, the maximum stiffness of specified zones being determined from consideration of the impact speed and injury tolerance distributions of vehicles and pedestrians involved in real accidents.

2. identification of the location of the head impact zone for the particular vehicle by conducting full scale behicle dummy impact tests. The limits of the zone being determined from an impact test at, possibly, 30 km/h with a 6 yr. old child dummy and an impact test at, possibly, 50 km/h with a 95% adult male dummy.

3. testing the stiffness of points within the head impact zone, again probably with an impactor the maximum stiffness of the zone being specified.

Of these three proposals, the front compliance test is perhaps most important because the provision of a 'pro-pedestrian' compliant front structure will not only reduce pelvic and leg injuries but also have a beneficial effect on head injuries.

Arguably, the introduction of compliant front structures will produce benefits, in terms of injury mitigation quite comparable to the effects that have resulted for car occupants from the introduction of seat belts.

ACKNOWLEDGEMENTS

Financial support for this research has been provided by the Transport and Road Research Laboratory of the United Kingdom and the Insurance Institute for Highway Safety in the U.S.A., for which the authors are greatly indebted. The views expressed in this paper are entirely those of the authors and do not reflect any official policies of the Department of the Environment.

REFERENCES

1. ASHTON S.J., PEDDER J.B. and MACKAY G.M. "Pedestrian injuries and the Car Exterior". S.A.E., Warrendale. Paper 770092.

2. ASHTON S.J. "Pedestrian Injuries and the Car Exterior". University of Birmingham Ph.D. Thesis, Feb. 1978.

3. ASHTON S.J. and MACKAY G.M. "A Review of Real World Studies of Pedestrian Injury". Unfall-und Sicherheitsforschung Strassenverkehr. Heft 21, 1979.

4. CRAWFORD ADAMS J. "Outline of Fractures". 6th ed. Churchill-Livingstone, Edinburgh, 1972.

5. BULL J.B. and MACKAY G.M. "Some Characteristics of Collisions. The Population of Car Occupant Casualties and Their Relevance to Performance Testing" in 'Proc. 3rd Int. Meeting on the Simulation and Reconstruction of Impacts in Collisions". IRCOBI, Lyon 1978.

6. ASHTON S.J., PEDDER J.B. and MACKAY G.M. "Influence of Vehicle Design on Pedestrian Leg Injuries". "Proc. 22nd Conf. AAAM", AAAM, Morton Grove, Illinois, 1978.

7. ASHTON S.J. "Some Factors Influencing the Injuries Sustained by Child Pedestrians Struck by the Fronts of Cars". Proc 23rd Stapp Car Crash Conference., SAE, Warrendale, 1979.

8. ASHTON S.J., BIMSON S. and DRISCOLL C. "Patterns of Injury in Pedestrian Accidents". Proc 23rd Conf AAAM. AAAM, Morton Grove, Illinois, 1979.

9. ASHTON S.J., PEDDER J.B. and MACKAY G.M. "Pedestrian Leg Injuries, the Bumper and Other Front Structures" in "Proc. 3rd Int. Conf. on Impact Trauma". I.R.C.O.B.I. 1977.

10. PRITZ H.B. "A Preliminary Assessment of the Pedestrian Injury Reduction Performance of the Calspan R.S.V." in "Proc. 6th Int. Tech. Conf. on Experimental Safety Vehicles" D.O.T., Washington, 1976.

11. PRITZ H.B. "Vehicle Design for Pedestrian Protection" in "Proc. 7th Int. Tech. Conf. on Experimental Safety Vehicles" D.O.T., Washington 1979.

12. HARRIS J. and RADLEY C.P. "Safer Cars for Pedestrians" in "Proc. 7th Int. Tech. Conf. on Experimental Safety Vehicles", D.O.T. Washington 1979.

13. KUHNEL A. and APPEL H. "First Step to a Pedestrian Safety Car". "Proc. 22nd Stapp Car Crash Conference". S.A.E., Warrendale, 1978.

14. PRITZ H.B. "Experimental Investigation of Pedestrian Injury Minimization Through Vehicle Design". S.A.E. Warrendale, Paper 770095, 1977.