A REVIEW OF RIDERS AND PEDESTRIANS IN TRAFFIC COLLISIONS

by

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ABSTRACT

This paper reviews the information available on the biomechanics of trauma to riders of two-wheeled machines and to pedestrians. Data come from hospital studies, field accident investigations and experimental work. A general description of the trauma received by these groups of road users is given in terms of the frequency and severity of injuries to the main anatomical regions of the body.

Information on the circumstances of collisions is summarised as far as is known, in relation to specific sources of injury, the relative importance of vehicular and ground contacts and the influence of speed on these circumstances. The paper concludes by emphasizing the importance of improved vehicle design in minimising injuries to these classes of road user, an area which has so far received relatively little attention.

INTRODUCTION

The last decade has seen a large research effort concentrated on protecting car occupants. The knowledge acquired is now being translated into vehicle design so that the occupant of a new car can, in the main, expect to be substantially better protected now than would have been the case ten years ago. Improvements in door lock design, windscreens, steering assemblies, compartment integrity and above all in the provision of seat belts, mean that given the occurrence of a crash, the restrained car occupant has a markedly improved chance of avoiding death or serious injury in comparison to the typical crash of the 1950s or early 1960s. One may suggest for example that the introduction of the anti-burst door lock, considered as a public health measure, has probably saved more lives than the vaccination against poliomyelitis.

With compulsory use of seat belts now accepted by most motorised countries of the western world, the importance of the other road users, especially pedestrians and riders of two-wheeled machines, is now being recognised. The conventional wisdom that nothing can be done in the conflict between an 80 kgm. pedestrian and a 1000 kgm. motor car is being questioned, and data are now being generated which should eventually allow the optimum crash performance design for the vehicle exterior to be specified, just as the vehicle interior is now. In many ways the state of knowledge on the biomechanics of trauma to the other road users parallels the work on car occupants of ten years ago. The time scale for the acquisition of new knowledge is likely to be at least as long because the problems are in many ways more complex and the optimisation of the various conflicting requirements will not permit easy solutions.

This review divides into two sections dealing with two-wheeled machines and their riders first, and then pedestrians are discussed.

TWO-WHEELED VEHICLES AND THEIR RIDERS

During the last decade there has been an overall increase in the popularity of the two-wheeled vehicle in many countries. This resurgence has been particularly prominent over the last five years. Injuries and fatalities sustained by users of these vehicles have followed a similar trend.

Two-wheeled vehicles provide an alternative form of transport to the car at low cost. They are fast and convenient, an insubstantial addition to the congestion of high density roads. A world wide fuel shortage and subsequent increase in fuel costs, and the availability of a wide range of machines has increased their attractiveness in recent years.

They are made up of two main vehicle types; pedal cycles and motor vehicles. Pedal cycles are propelled solely by the expenditure of user energy. Two-wheeled motor vehicles include motorscooters, mopeds and motorcycles. Motorscooters are typically characterised by smaller wheels than a conventional motorcycle and include an open frame and platform for feet. Mopeds have an engine capacity not over 50c.c. and are equipped with pedals. Motorcycles are all other two-wheeled motor vehicles or combinations. It is recognised that the design differences of these three groups of motor vehicles may affect their performance in certain situations but as few research reports distinguish between them, for convenience the term "motorcycle" will subsequently refer to all two-wheeled vehicles unless otherwise specified. Pedal cycles will be considered as a separate group.

The two-wheeled vehicle is inherently unstable, therefore by the very nature of their instability one would expect a higher accident rate, especially for single vehicle accidents (Sharp, 1971).

The relative frequency of two-wheeled vehicle accidents is difficult to assess. Statistics are confounded by the differences in reporting procedures both within and between countries and the type and density of the motor vehicle population. For instance, in some European countries - such as France, Belgium, The Netherlands, West Germany, - special bicycle tracks are provided along high-use roads. However the main problem lies in the known high number of injury accidents which are not reported to police authorities. Published statistics which rely solely on police accident statistics are typically an underestimate of the true frequency of two-wheeled vehicle injuries in a community.

Several workers have established that only about a third to a half of all two-wheeled accidents resulting in medically treated injuries are reported or known to the police (Clark and Morton, 1971; Kraus, Riggins, Drysdale, and Franti, 1972).

Bull and Roberts (1973) looked at a sample of 1200 cases attending the Birmingham Accident Hospital, England as a result of road accidents. In their sample of 40 serious and 114 slight cases of injury to pedal cyclists, they found only 14 serious and 22 slight cases were known to the police (35% and 19%). Most of the cases not known to the police were riders who fell off their machines, no other vehicle being involved. It is reasonable to expect that any two-wheeled accident resulting in no or minor injury to the user and/or little damage to the machine or other property will not be reported. The rate of notification for motorcyclists was 85 known to police out of a total of 128 injury cases (66%).

The magnitude of the problem of two-wheeled accidents is certainly much worse than nationally recorded numbers would indicate. So, figures obtained through police records must be used with caution, especially when making comparisons with other classes of road user.

Although the casualty rate per mileage for two-wheeled vehicles is elusive for many countries, the numbers of persons reported injured and killed in many countries is high and increasing (Department of the Environment, 1976 and press notice; Drysdale, Kraus, Franti and Riggins 1975; Bothwell, 1960, 1962, 1963; U.N. Economic Commission for Eruope, 1974).

In general, estimates of accident involvement of different types of vehicles show that the two-wheeled vehicle produces the greatest rate of accident injury relative to mileage performed than any other vehicle type.

Before looking at injury patterns it will be helpful to note some of the characteristics of the two-wheel accident and the user population revealed from an overview of pertinent literature.
Motorcycles: There is a high degree of consistency about the age and sex bias of motorcycle users. The motorcycle operator is predominantly male and under 25 years of age. Data available for motorcycle passengers show a similar trend with a suggestion of more females.

A large number of accidents involve collisions with another moving vehicle. Typically, the other vehicle making a right-angle turn into the intended path of the motorcycle - initially both vehciles are travelling in opposite directions on the same road. The other most significant accident class are single vehicle accidents, involving no other moving vehicles. They predominantly result from loss of control. However, the operation of the aforementioned unreporting bias precludes further comment about the comparative rate of these two main accident classes. It is important to stress that subsequent accident-type figures typically represent only reported accidents and almost certainly do not reflect general accident-involvement trends. There is an over-involvement of motorcycles with more powerful engines. The lower ratio of accident injuries occurs among persons using smaller motorcycles (less than 125 c.c.). Highest observed ratios are for persons using motorcycles with intermediate (250-500 c.c.) or larger engines (500-750 c.c.). Further the more powerful machines are more often involved in serious injury producing accidents.

The large majority of motorcycle collisions with other moving vehicles occur in urban areas, at speeds under 40 m.p.h. Reported single vehicle accidents occur at all speeds, but higher speeds are recorded for rural single vehicle accidents.

PEDAL CYCLES

The population of pedal cyclists is not easy to isolate. Multispeed gearing and improved ligh-weight construction plus their convenience and attractiveness to the environmentalist, has sharply increased the adult user population in recent years. However there remains a high percentage of children and teenagers below the legal driving age and of both sexes. Pedal cycles are used by the very young in an extension of play rather than as a serious means of transport. Most pedal cycles are used on local and residential streets, therefore they are unlikely to be involved in high speed accidents.

Despite the recent increase in adult pedal cyclists, the pedal cycle accident problem predominantly involves children. Male riders are nearly twice as often involved in accidents as females. It has been suggested that there is a greater likelihood of injury when a child is riding a modern 'high-rise' machine (high handle bars and a long seat with a back rest) than when riding conventional models (Craft, Shaw and Cartlidge, 1973). However environmental and rider characteristics may explain this difference.

The concern caused by the increasing casualty rates of two-wheeled vehicle users is reflected in the increasing amount of work in this area. Published reports generally belong to one of three categories: investigations of real accidents; experimental studies; mathematical modelling and computer simulation. A selection of published work considered representative of the overall two-wheeled vehicle accident is reviewed.

STUDIES OF REAL ACCIDENTS

There are two main methods of studying real accidents. 1)A retrospective examination of the accident by use of information available from police, medical, and/or Coroner reports. 2) At-the-scene investigation of accidents. Comparison of the results is difficult, the data source differs, and the criteria for recording and reporting injuries seems to vary considerably. Injury data is summarised in tables 1 to 5. Firstly, studies of the former type will be reviewed with fatal accident studies described at the end.

POLICE AND MEDICAL DATA STUDIES

Aston and Perkins (1954) described the injuries sustained by all road accident cases treated at the Royal Hampshire County Hospital, Winchester, England. There were 268 motorcyclists involved (38% of the total). Not only were they the largest of the various groups reviewed, they also had the highest proportion of severe, but non-fatal injuries (22%). There were 120 cyclists. One feature of pedal cyclists' injuries was the high proportion of upper limb injuries compared with lower limbs. The authors suggest a possible explanation is that pedal cyclists put out their hands to protect themselves when thrown off their bicycles, whereas motorcyclists travelling at greater speeds, do not have time to do this.

Gissane, Bull and Roberts (1970) studies 4,342 road accident casualties who received treatment from Birmingham Accident Hospital, England, during 1961. There were 1116 motorcyclists (924 riders and 192 passengers) of which 328 were treated as inpatients, 26% of the total inpatient accident population. Almost one-third of the motorcycle accidents involved no other vehicles, a similar number resulted from collisions with cars. In collision accidents, femoral fractures were particularly common and most were due to the primary collision impact. Thirteen percent (168) of the inpatient population were pedal cyclists, a further 659 treated as outpatients. About half their accidents involved no other vehicle. Whitaker (1976) describes injuries sustained in 425 motorcycle accidents reported to two divisions of the Thames Valley Police, England during 1974.

In the U.S.A., the motorcycle population and the number of motorcycle accidents has increased most markedly in California, so, not surprisingly, many motorcycle accident studies have been based in this area. (Department of the California Highway Patrol, 1968; Harano and Peck, 1968).

Drysdale et al (1975) using police accident reports and hospital medical records in Sacramento County, California, U.S.A. identified 1,273 motorcycle casualties for 1970. Official police reports were available for only 450 (38.5%) of the accidents. Of these, 63% involved another motor vehicle and accounted for 65% of the serious injuries. Overturning the motorcycle accounted for 26.6% of all accidents and 26.4% of the serious injuries.

Of the total sample of 1,273 injured persons, 18 (1.4%) died, 257 (20.2%) were hospitalized and 293 (23.0%) visited an emergency department for treatment and received outpatient care. These comprised the serious injury group. The average length of stay for all hospitalized persons was 12 days, medium length of stay was 6 days. The bones most frequently injured were in the leg (tibia 16.3%, fibula 11.6%) or the hand/wrist (13.4%). Thirty percent of the tibia fractures were open. Multiple fractures or other serious injuries were common. Serious injuries were limited to one of four main body areas. Most commonly involved were the lower extremities (30.8%), upper extremities (21.7%) and the head (19.0%). The immediate cause of death for 5 of the 18 fatalities was multiple traumatic head injuries without other serious injuries. Helmet use was not reported at the time of the accident.

Motorcycles with more powerful engines (250 c.c. or more) were more often involved in serious injury producing accidents than would be expected from their distribution in the comparison group (Kraus, Riggins, Drysdale and Franti, 1972). The converse was true for motorcycles less than 250 c.c.

A clinical analysis of 127 motorcycle users involved in accidents in Southern

California was carried out by Hight, Seigel and Nahum (1973). The results of their study show definite injury patterns associated with occupant kinematic motion. Based upon the occupant kinematics they divided motorcycle accidents into three primary classifications: non-ejected, ejected, and deflected.

Non-ejected occupants typically came to rest within about 10-15 feet of the impact area. This group generally sustained the most extensive injury pattern, often including severe to fatal lesions to two or three body areas. In a typical frontal impact the non-ejected motorcyclist moves forward in a seated position, the knees contact the steering and upper fork area. Depending on the amount of pitching the motorcyclist's knees will strike the opposing vehicle or object followed by head contact. The upper torso will usually contact the forward surface last.

Ejected occupants were generally airborne along their original direction of travel for more than 10-15 feet. Two principal ejection patterns occurred. Firstly, accidents involving contact with the front or rear wing of the other vehicle. Riders were ejected over the hood or trunk. Overall injury severity appeared dependent on whether the head or other part of the body struck the road surface first. Secondly, accidents when the motorcyclist lost control and the motorcycle was overturned. Generally, the occupant developed less vertical velocity than in the first ejection mode. Although abrasions and road burn injuries were important, these occupants usually received moderate or less overall injuries when the head was not injured.

Deflected occupants included glancing impacts by the motorcycle with the opposing vehicle's front or rear corner or bumper or where the motorcyclist was struck on the side. Severe leg injury was frequent. Head injuries appeared to be lower.

Almost all occupants received injuries to more than one body region, several to most body regions. The most frequently injured part of the body was the head. Persons not wearing a helmet sustained 43% severe head injuries (American Medical Association Abbreviated Injury Scale (A.I.S.) 03-06). In contrast only 2 (11%) of the helmet-wearing group received severe head injuries. This figure excludes five cases of helmet 'failure' during the impact sequence. In four of these cases the strap or strap connector failed. After head injuries, legs were the most frequently injured area. A high incidence of severe leg injuries (70%) was recorded for the deflected group in comparison to about 35% for each of the other two groups. The deflected occupants were subjected to lateral forces which tended to rip or tear the lower leg.

Hight et al compared the injury severity for operators and passengers on the same motorcycle. They found some differences, occasionally passengers fared better in motorcycle frontal collisions because they loaded the operator and were ejected without sustaining primary frontal impact injuries. Where the motorcycle was struck on the side the injury severity was dependent on the velocity of the striking vehicle. In accidents where the motorcyclist has lost control, the passenger has a tendency to be thrown from the motorcycle first. The rider's vertical motion or lateral separation from the machine is limited by holding onto the handlebars.

One further injury described, directly related to motorcycle design, was the genitalia injury sustained by six male operators. Although the numbers are small, the filler cap and the front-fork instrument cluster were important causes of this injury.

In North Carolina, U.S.A., the Highway Safety Research Center's accident files for 1972 were scanned (Griffin, 1974). Of 2,410 motorcycles involved in accidents, 706 (29.3%) were involved in single vehicle accidents, and 1,418 (58.8%) collided with a car. A probably bias through unreported single vehicle accidents is reported. This is one of the few studies reporting estimated motorcycle speeds before the accident.

For single vehicle accidents, 72.6% of the speed estimates lie between 20-59 m.p.h., for motorcycle collisions with cars, 70.1% lie between 10-49 m.p.h.

Campbell, Macbeth, and Ryan (1967) isolated 363 motorcycle accidents from Police records in the Ottawa area, Canada, for 1967. There were 229 injury accidents in which 283 persons were recorded as killed or injured. No other vehicle was involved in only 11.2% of the accidents. Hospital records were available for 180 of the police reported accidents. These were supplemented with 171 motorcycle casualties not known to the police, and the injury distribution reported.

Clark and Morton (1971) reported on 226 motorcycle accidents in Monroe County, New York, U.S.A. in 1969). A simultaneous study of injuries resulting from both pedal cycle and motorcycle accidents was carried out from January 1, 1965 to September 1, 1967 in Wisconsin. In Sweden, Backstrom examined police reported traffic accident injuries in Scanai (excluding Lund city) in 1958. Their sample included 541 motorcyclists and 256 cyclists. Gogler (1962) analysed injury data for inpatients of the Heidelberg Clinic, Germany, from 1952-1958. Bø (1972) described injuries received in all accidents in Oslo and Akenshus County.

Several studies have focused on the nature of injuries to pedal cyclists (Aldman, Thomson and Ashberg, 1969; Chlapecka, 1974; Guichon and Myles, 1975). Wright (1974) reviews some of the U.S. based research in this area. He concludes that about 30-40% of pedal cycle injuries involve the leg, about 20-25% involve the arm, and about 15% are sustained by the head. For more serious injuries, head and facial injuriesaccount for about one-third of the injuries.

McDermott and Wood (1975) studied 613 pedal cycle injuries treated at hospitals in the greater Seattle-King County area, U.S.A. over a one year period. Most fatal injuries were of the head, but injuries to the shoulder were considered unique to the pedal cycle.

FATAL ACCIDENTS

Slatis (1962) examined 349 cases of traffic accident fatalities in Helsinki, Finland during 1956-1960. The series includes 45 motorcyclists and 56 pedal cyclists. For both groups head injuries predominated but simultaneous injuries to several gross body areas were recorded for 55.5%. They found the number and distribution of injuries for motorcyclists seemed to depend on the type of accident. The number of injuries sustained was higher for accidents involving another vehicle (2.2 injuries/case) than for single vehicle accidents (1.4 injuries/case).

Gissane and Bull (1961) studied 149 persons who died as the result of road accidents in Birmingham during 1960 and an additional 34 involved in fatal road accidents outside the city. Of the total 34 motorcycle deaths, 26 were ejected from the machine, and subsequently 7 were run-over by other road vehicles. Seven of the 22 pedal cyclists were run over. Head injuries predominated, and simultaneous injuries in several body areas was also high. Of the 15 motorcyclists wearing crash helmets, 8 sustained some degree of brain injury. However Gissane and Bull report that even in fatal accidents fewer head injuries occur to motorcyclists wearing crash helmets.

Sevitt (1968) studied material from 250 necropsied road users in Birmingham during 1961-1966. A later analysis of 254 road deaths in Birmingham during 1969 and 1970 was carried out (Sevitt, 1972). Only the injuries known to have caused or contributed to death were recorded.

All available documents relating to 219 motorcycle accidents which occurred in the Metropolitan Police District, England during 1970, 1971 and 1972 were examined (Renton, 1973). There were 284 users involved, of these 226 were killed. The accidents comprised 62 (28%) single vehicle accidents, but in 46 (74%) of these the motorcycle collided with something else. Only 23% (50) of the riders and 12% (8) of the passengers were believed to have received their most serious injuries from other vehicles, however all but 3 of these were fatal. Thirty-five percent (76) of the riders and 51% (33) of the passengers were most seriously injured by the road surface, of these 72 were fatally injured.

Tonge, O'Reilly and Davison (1964) analysed data on 2214 traffic accident fatalities occurring in Brisbane, Australia, during 1935-1963. Brain damage occurred in 85.3% of total motorcycle casualties and 80.1% of all pedal cyclists. In 70.3% motorcyclists and 71.3% pedal cyclists there was an associated skull fracture. The incidence of crash helmet wearing was not reported. A continuation of this study was carried out for 1963-1968. (Tonge, O'Reilly, Davison and Johnston, 1972). There was no change in proportion of head fractures, but there was a decrease in the occurrence of brain damage. Only 4 motorcyclists were known to be wearing a crash helmet.

Jamieson and Tait (1960) report an investigation of 1000 consecutive admissions to hospitals on deaths due to traffic accident injury in Brisbane during 1962-1963. There were 151 motorcyclists and 70 pedal cyclists. Injury distribution for motorscooter riders, pillion passengers, and other two-wheeled motor vehicle users were similar. However there was a greater incidence of severe multiple injuries in the latter group. Injury patterns of pillion passengers suggest they are protected by the rider from the initial frontal contact injury.

Hodge (1962) reported an investigation of injuries for 174 road accident deaths in the Adelaide metropolitan area during 1959-1961. Twnety-eight motorcyclists were killed, 24 sustaining fractured skulls.

Henderson (1970) examined police records for 120 motorcycle accident fatalities in New South Wales, Australia, during 1970. Although the data source did not provide detailed injury data, in 72.5% of the sample head and /or neck injury was reported as a major cause of death.

Graham (1969) looked at autopsy reports for 324 of 352 motorcycle fatalities in Los Angeles, California from 1962-1966.

AT-THE-SCENE INVESTIGATION

Jamieson, Duggan, Tweddell, Pope and Zvirbulis (1971) report on 218 accidents attended Brisbane during 1963. Only 14 were motorcycles, involving 18 persons, and there were 9 pedal cyclists. Although the numbers are small they found that the severe motorcyclist injuries resulted from vehicle contact.

An at-the-scene investigation of injury producing traffic accidents was carried out in Adelaide, Australia in 1963 and 1964 (Robertson, McLean, and Ryan 1966; Ryan, 1967). The 408 accidents investigated included 74 motorcyclists and 45 pedal cyclists. About one-third of all two-wheeled vehicle accidents involved collision with cars or trucks. Fractures of the lower half of the tibia and fibula were common, attributed to contact with the car bumper. When the side of a motorcycle is hit by the front of a car, the legs of the rider are exposed to direct impact from the front of the car, particularly the bumper bar. Although the bumper height varies with vehicle make, at the time of this study, the authors recorded the bumper bar generally about 6-12 inches above the foot-rest of the cycle. They also concluded that fractures of the small bones of the hand were typically caused as the motorcycle handgrip swung against the car. The road was reported the most common cause of head injuries. However, overall, injuries sustained through vehicle contact were more severe.

Kolbuszewski, Mackay, Fonseka, Blair and Clayton (1969) describe at-the-scene investigation of 425 road accidents in Birmingham during 1965 and 1966, and 210 in Worcestershire 1967-1968. The proportion of motorcyclists who were concussed was higher in frontal impact collisions. Side impacts resulted in a higher proportion of leg fractures (McLean and Mackay, 1970). The injuries received by 17 riders were compared with that of their passengers. The riders received more lower leg and arm fractures, though there was no difference in the incidence of concussion.

Newman and Webster (1974) describe an at-the-scene investigation of 133 motorcycle accidents in Ottawa, Canada during 1973. Over 65% of the 100 accidents reported to the police involed another vehicle. Single vehicle accidents predominantly resulted from loss of control. The largest proportion of all accidents (20.6%) occurred at an intersection. In an analysis of the injury mechanics of the motorcycle accidents, Newman and Webster are in general in agreement with Hight et al.

Notwithstanding the difference in study methodology there is general agreement that the overall pattern of injury sustained by users of two-wheeled vehicles, is one of severity and multiplicity. Head injuries predominate, followed by lower limb injuries and then injuries to the upper arm.

Injuries sustained come from three primary sources - the machine, the object struck,and the road surface. Typically two-wheeled vehicles are involved in two types of accidents. 1) Collision with another vehicle. The occupant is protected from the machine, sometimes receiving injuries as he/she passes over the handlebars. However the major trauma are sustained during the primary impact with the other vehicle. The occupant then falls to the ground where additional injuries may be received from the road surface or other intervening objects. The machine is usually badly damaged, front wheel and front fork distortion is typical. In more severe accidents distortion may extend to the frame. 2) Single vehicle accidents as the rider looses control of the machine. As the machine overturns the rider usually slides along the road surface independent of the bike. The rider strikes whatever objects may be in his/her path. There is little damage to the machine.

EXPERIMENTAL WORK

Severy, Brink and Blaisdell (1970) report on 7 collision experiments between a motorcycle and rider striking the side of a passenger car. Independent variables studied were speed at impact, size of motorcycle, position impacted along the side of the passenger car. Methodology, including apparatus and dummy specifications is described.

At impact the 'rider' slides forward maintaining a normal seated position until its knees impact an opposing structure. The knee contact causes the torso to undergo a jackknife action frequently accompanied by torso elevation over the handlebars and into or rotating over the car. Damage to the motorcycles was confined almost exclusively to the front wheel suspension system. In general motorcycle collapse was complete 40-60 ms following contact, after maximum collapse the rear of the motorcycle elevates, then returns.

The sequential nature of the motorcycle collapse produces a continuous deceleration pattern. Considering this and the extended distance available for the motorcyclists to decelerate before impact they suggest a passive restraint system for the legs and torso would allow the rider to decelerate in a much safer manner. Protection would be given during primary impact without significantly reducing the handling characteristics of the motorcycle.

A series of 41 motorcycle tests were run at the Motor Industries Research Association Crash Test Facility, Nuneaton, England (Peterson and Bothwell, 1973). They were the beginnings of a programme initiated by the University of Denver Research Institute to establish the role of the various aspects of motorcycle design in producing injuries and so to provide safety performance standards. The tests simulated a representative group of traffic accidents.

Several hazards in perpendicular impacts were identified, i.e. the fire hazard created by 'flip-top' filler caps and fibreglass fuel tanks from the initial pelvic impact on the fuel-tank; leg/pelvis impact with handlebars/steering head and other body contacts on sharp projections on the motorcycle.

Taneda (1973) reports on initial experiments in Japan on the simulation of motorcycle collisions with a fixed or moving barrier.

COMPUTER SIMULATION

Three digital computer programmes have been developed by the University of Denver - Denver Research Institute (Peterson and Bothwell, 1973). Firstly, a two-dimensional ten degree-of-freedom model of the motorcycle and rider was developed. The second programme is a modified version of the first. The third programme is a digital computer simulation of the three-dimensional notion of a nine degree-of-freedom model of the motorcycle.

Work is currently underway to modify the CALSPAN 3D-Occupant-Simulation for use as a model for the 3D notion of the motorcycle user (Fleck, Butler and Vogel, 1974).

COUNTERMEASURES

Except for the advent of the protective helmet, there has been no significant injury protection device for users of two-wheeled vehicles.

Crash helmets

The high incidence of head injuries for all types of two-wheeled traffic accidents is well established. Cairns (1941) reported on the significance of the crash helmet in the reduction of head injuries. Crash helmets have improved a great deal since then, and present day helmets are manufactured according to more rigorous design specifications. Available research literature shows that the use of protective helmets is an effective means of reducing the occurrence and severity of head injuries in accidents (Chandler and Thompson, 1957;Foldvary and Lane, 1964; Honda Overseas Driving Safety Promotion Committee, 1972).

Several studies report that the presence or absence of crash helmets have little effect on the incidence of head injuries. However, such conclusions are usually ill-founded. There is a typical sample bias - only motorcycle accidents resulting in injury sufficient to cause death or require hospital treatment are included. It seems highly likely that on occasions where a helmet effectively prevented any head injury, no assistance was needed, and so the accident was not reported.

Crash helmet 'failure' has been reported. Frequently failure of the fastening device to adequately retain the helmet in position for the duration of the accident (Renton, 1973).

It seems obvious from reported injury patterns, that head protection should extend to the pedal cyclists. Lewicki and Newman (1975) discuss this need and outline specific requirements of such a helmet.

Efforts have not only been directed at improving the performance of protective helmets. Improvements in motorcycle design is the subject of an increasing number of published reports (Second International Congress, Bartol, Livers and Hirsch, 1973). The structural safety measures can be divided into two main categories. Firstly, accident prevention safety measures. These include anti-skid devices, improved steering/handling characteristics, improved tyre performance, increased machine visibility, etc. Secondly, safety measures for the reduction of the severity of occupant injury.

Severy et al (1970) suggest that substantial injury reduction in motorcycle/automobile collisions can be accomplished by modification of motorcycle design. They consider it would be impractical to improve the sides of cars so as to attenuate the force of impact for the motorcyclists.

The recognition of the high incidence of lower limb injuries is reflected in the availability of crash bars and leg shields. However their current design is inadequate. Accident cases have been reported where these leg 'guards' have folded back, and trapped the leg against the rest of the machine (Kolbuszewski et al, 1969; Japanese Council of Traffic Safety, 1971).

Bothwell (1962) suggested that the best protection to the motorcyclist would be gained by a combination of some sort of retentive harness and suitably shaped roll-bars.

Wescott (1975) extends this concept. Using scaled models he describes rather extreme design modifications to ensure motorcyclist retention and protection during accidents.

INTRODUCTION TO PEDESTRIAN INJURY STUDY

Three distinct methods of studying the problem of injury causation to pedestrians are used; they are the investigation of real accidents, the reproduction of accidents by experimental tests and the simulation of accidents by mathematical modelling. Accident studies can be based on the data that are routinely noted by the police or the hospitals, or on data collected by specific accident studies.

The first studies of pedestrian accidents described the injuries sustained by pedestrians and compared them with other road user casualties. These studies based on medical data, whilst describing the nature and location of the injuries provided no information about the accident circumstances or the cause of the injury

The use of police data enables the general overall features of accidents to be described, for example factors such as the age and sex of the casualties, the total number of casualties, the time and date of the accident and the vehicles involved can be adequately considered. However data on the injuries sustained is limited due to the methods used for noting injury. In Great Britain the following injury classifications are used:

'Slight Injury'	- an injury of a minor character such as a sprain, bruise or a cut or laceration not judged to be severe.
'Serious Injury'	- an injury for which a person is detained in hospital as an 'inpatient' or any of the following injuries whether or not he is detained in hospital: fractures, concussion, internal injuries, crushings, severe cuts and lacerations, severe general shock requiring medical treatment.
'Killed'	- died within 30 days of an accident.

By combining police and medical records the maximum amount of information can be gleaned from the data that are routinely noted. Differences in injury patterns between different types of accidents can be examined and given large enough samples it is possible that differences in injury patterns between different vehicle types can be shown. The usefulness of this data is limited by the information available; the police rarely note the exact location and nature of the pedestrian contacts on the vehicle, or ascertain the speed of the vehicle at impact.

When it is required that the cause of injury be determined it is necessary to carry out accident studies with this as one of the objectives; this type of study normally requires an at-the-scene investigation by skilled accident investigators. A number of studies have been made throughout the world, the majority of which have considered all road users not just pedestrians.

Experimental work ranges from the testing of various sections of the vehicle structure, for example the stiffness of the bonnet, to the reproduction of real accidents using anthropometric dummies and cadavers. Most of the experimental test work performed has used anthropometric dummies and has been concerned with investigating the variations in pedestrian dynamics with changes in vehicle shape and impact velocity. Tests have been performed using real vehicles and test vehicles in which the vehicle shape parameters can be easily altered. One important aspect of cadaver work has been the determination of human tolerances.

Another approach to understanding the dynamics of pedestrian accidents is the use of mathematical models and computer simulation, the accuracy of the simulation depending on the sophistication of the model.

The use of anthropometric dummies in experimental tests and mathematical models in computer simulations has led to the development of methods to predict the severity of injuries that could be expected in similar real accident situations, so that comparisons between different designs can be made.

In the following pages a brief review of the published work on pedestrian injuries and vehicle design will be made.

REAL ACCIDENT STUDIES

INJURY STUDIES

The various medical studies that have described pedestrian injuries can be divided into two main groups; those which described the injuries sustained by fatally injured pedestrians and those which reported on all casualties. Studies of the latter type will be considered first.

Aston and Perkins (1954) reported on all road accident casualties treated at the Royal Hampshire Hospital, Winchester, England in 1951 and 1952. Gissane, Bull and Roberts (1970) described the injuries sustained by one year's admissions, 1961, to the Birmingham Accident Hospital, and the long term consequences of those injuries. In Germany Gogler (1962) considered in-patients treated in Heidelburg clinic between 1952 and 1958. In Scandinavia Backstrom (1963) described the injuries received in traffic accidents in Scania, South Sweden, excluding the city of Lund, for the year 1958. Bø (1972) described injuries received in all accidents around Oslo, Norway. In both these studies all severities of injury were taken. McNicol-Smith and Letheren (1961) reported on one years admissions, from April 1 1959 to March 31 1960, to Alfred Hospital, Melbourne, Australia. Jamieson and Tait (1966) considered 1000 consecutive hospital admissions or fatalities resulting from accidents in the city of Brisbane.

In all these studies pedestrians formed only a small proportion of the total study. The study by McNicol-Smith and Letheren was based on all accidents whilst the other studies reported solely on road accidents.

Direct comparisons between the results of these studies are not possible due to the differences in definitions and selection criteria. Aston and Perkins, Backstrom and Bø described all severities of injury, whilst the other studies considered only hospital inpatients. The descriptions of injuries varied throughout the studies, for example Aston and Perkins divided the body into head and neck, trunk, arms and legs; the arms and legs being further subdivided into left or right, and above or below the elbow: Gogler split the body into head, spine, chest, abdomen, pelvis, upper limbs and lower limbs. Table 6 gives details of these studies.

Not withstanding the differences between the studies there is general agreement that head injuries predominate, followed by injuries to the lower limbs. Injuries to the upper limbs ranked third.

Table 7 summarizes the results of the various studies of fatal pedestrian accidents. Again direct comparisons between the studies are not possible due to differences in the description and severity of injuries noted. Tonge et al (1969, 1972) in describing leg injuries have divided the legs into left and right side and upper and lower leg. Other authors have considered all leg injuries together. However general conclusions about the pattern of injury can be made, there being general agreement that the head is the area most frequently injured followed by the lower limbs including the pelvis, the thorax, the abdomen and finally the upper limbs.

POLICE DATA STUDIES

Hutchinson (1974i, 1974ii) at University College London has analysed national police statistics to investigate the differences in injury severity sustained by pedestrians struck by different vehicle types. He used as a measure of severity the ratio of severe injuries (serious and fatal injuries) to all injuries and, in order to minimize the effect of speed, only accidents occurring in areas subject to a 30 mph ($\simeq$50 km/h) speed limit were considered. He found small but statistically significant differences between the severity of injuries for different car types but was unable to relate the differences to variations in vehicle shape.

Vaughan (1972) in a study in Sydney Australia supplied special forms for police officers to complete on pedestrian accidents so that more data than that routinely noted could be obtained. He considered the first location of the contact on the vehicle, the action of the pedestrian and the speed of the vehicle at impact. The sample consisted of 119 pedestrians of whom 19 were killed. At least 16 of the 19 fatalities had head injuries, in the other 3 cases exact details of the injuries were not known. Fifty two persons had injuries classified as severe and 18 (34.6%) of those pedestrians had head injuries. There was no significant difference between the mean impact speed of the fatal and severely injured pedestrians but there was a difference between the mean impact speed of those groups and the moderately injured pedestrians.

McLean (1972) in New York used data collected by the police to investigate the differences in injury severity sustained by pedestrians struck by Cadillacs and Volkswagens. He supplemented the police data by questionnaires to pedestrians and drivers. From an initial sample of 535 Cadillacs and 584 Volkswagens, the exclusion of cases where the contact was not frontal, where no estimate of impact speed could be made and where there was insufficient information to determine the injury severity, limited the final analysis to 152 Cadillacs of which 9 involved fatalities and 166 Volkswagens of which 7 involved fatalites. It was from this sample that the conclusions that

> "A pedestrian is more likely to be killed if he is struck by the front of a Cadillac rather than by a Volkswagen"

and

> "half of the pedestrian fatalities occurring in collisions with the fronts of Cadillacs may be able to be eliminated by redesigning the shape of the front of the car"

were made. The small number of fatalities in each group makes the reliability of the conclusions questionable as the differences could have arisen due to variations in injury susceptibility due to age differences and injury tolerance differences. Indeed at one stage in the analysis it was noted that

> "Cadillacs have a higher case fatality rate but Volkswagens have a higher rate of severe injuries"

A study of one year's pedestrian accidents in New South Wales (Fisher and Hall, 1972) used routine police data. A description of the injuries sustained by the injured and killed was given using the injury data noted by the police officer, but it was noted that this was the least reliable data in the study. Nevertheless the reported pattern of injuries was in general agreement with that reported in other studies. The influence of frontal design on injuries was considered by grouping the vehicle makes into three groups, each having different frontal shapes; these shapes were a) high square front consisting of Ford Falcon and Fairmont, b) low square front consisting of Morris Mini and 1100 and c) low sloping front consisting of Volkswagen Beetle. No significant difference in the number of injuries per accident was found but there was a significant difference in the fatality rates, fatalities being over-represented for the Volkswagen Beetle and under-represented for the Ford group. It must be noted that the number of fatalities involved were small being 7, 8 and 12 for the three shapes respectively and the reservations noted to McLean's study apply. It was found that head injuries were more frequent (64.6%) in the Volkswagen Beetle group than in the Mini/1100 group (55.0%) and the Ford Falcon/Fairmont group (43.1%), (the differences however were just not significant at the 5% level).

ACCIDENT STUDIES

The data available from the detailed study of real accidents ranges from the presentation of a single case in great detail to the analysis of large numbers of accidents each of which has been subject to an in-depth investigation.

Schmidt and Nagel (1971) gave details of an accident in which prompt medical attention resulted in the survival of a female pedestrian struck by a car at approximately 50 m.p.h. (80 km/h).

In Australia at-the-scene studies have been carried out in Brisbane by Jamieson et al (1971) and in Adelaide by Robertson, McLean and Ryan (1966).

In the Brisbane study Jamieson et al, investigated 49 accidents involving 51 pedestrians; 34 of these pedestrians were struck by the front of a car. It was found that, considering all the pedestrians and all severities of injury, head and leg injuries were the injuries most frequently sustained; 64.7% sustained head injuries, 70.6% injuries to the right leg and 72.5% injuries to the left leg. The 34 cases where a pedestrian was struck by the front of a car were considered in some detail, but the small number of cases made comparison of the factors influencing injury impossible. However it was suggested that when the vehicle is braking it is preferable for the motion of the pedestrian after impact to consist of translation, rather than rotation, as rotation of the head towards the car can result in head impacts on the stiff vehicle structures and rotation away from the car exposes the pedestrian to being run over by the vehicle.

Robertson, McLean and Ryan reported on 79 accidents involving 82 pedestrians; 63 of the pedestrians were involved with cars and 45 were struck by the front of a car. For pedestrians struck by cars, and for all severities of injury, injuries to the head and the legs were the injuries most frequently sustained 87.3% receiving lower limb injuries and 76.2% head injuries. It was noted that 83.6% of the leg injuries and 35.4% of the head injuries resulted from vehicle contact. Half the fatal head injuries came from vehicle contact and half from ground contact. In an attempt to consider the effect of vehicle shape on injury severity a comparison was made of the severity of injuries sustained by pedestrians struck by the front of Volkswagen 1200's and Ford Falcons. It was concluded that:

'(a) below 20 m.p.h. (<30km/h) a Falcon is more likely to injure a pedestrian seriously than is a Volkswagen 1200.
(b) in the speed range 20-25 m.p.h. (30-40 km/h) the injury producing potential is the same for each of these two cars.
(c) above 25 m.p.h. (40+km/h) the Volkswagen 1200 will probably cause more severe injuries than the Falcon'

However the small number of cases available for analysis, 6 Volkswagens and 6 Falcons, makes these conclusions extremely tenuous. Variations in the age of the pedestrians in each group could have a greater effect on injury severity than the vehicle shape.

Wooler (1968) reanalysed the results of these two studies with particular emphasis on the speeds of the vehicles. He considered the relationships between impact speed and travelling speed and concluded that at travelling speeds greater than 25 m.p.h. (40 km/h) the impact speed is normally close to the travelling speed.

The Transport and Road Research Laboratory in the United Kingdom (T.R.R.L. 1974) have studied pedestrian accidents using a follow-up technique, the vehicle being examined a few days after the accident. The study reported on mechanisms of injury to 104 pedestrians requiring hospital inpatient treatment and 45 fatally injured pedestrians. It was reported that

'the region of the body most commonly injured by contact with the vehicle is the lower leg'

and that

'for the upper part of the body ... contact with the ground is of almost equal importance as a cause of injury'

The bumper bar was identified as being responsible for 84.1% of lower leg injuries and the windscreen frame as responsible for 33.9% of the head injuries. These figures only refer to situations where the cause of injury could be established. In 22.0% of the injuries the cause could not be determined.

In Germany at-the-scene accident investigations have been carried out in Hannover and Berlin under the direction of the Institute of Automotive Engineering at the Technical University Berlin. Wanderer and Weber (1974) reported on 50 pedestrian accidents. They suggested that approximately two-thirds of minor injuries (65.6%) were caused by ground contact but that for the more severe injuries the vehicle was most frequently responsible; for AIS 04 83.3% of the injuries were vehicle induced. Figures were presented showing the average AIS rating by impact speed for vehicle contacts and ground contacts for two vehicle shapes, the Volkswagen Beetle and the more common rectangular front structure or 'pontoon form'. It was suggested that there was little difference in the severity of ground induced injury sustained between the two shapes but that at higher speeds less severe injuries followed contact by the Volkswagen. Once again only a small number of cases were available for analysis and the results must be treated with caution.

Sturtz et al (1974; 1975) have described the study in greater detail and in a review paper by Appel, Sturtz and Gotzen (1975) the various results of the study were presented.

Appel et al reported on 150 pedestrian accidents; 80 of which involved children - defined as a person under 15 yrs old. It was noted that contact with the vehicle generally produces more severe injuries than contact with the road. Vehicles were divided into three main shapes.

- the box form:- these are vehicles with a flat front structure such as the Volkswagen Minibus
- the pontoon form:- the normal rectangular front structure
- the 'v' form:- these are vehicles with a low front structure and smoothly curved bonnet structure such as the Volkswagen Beetle

It was found that injuries from contact with the box form were generally more severe than injuries following contact with the pontoon form or 'v' form. At low speeds, less than 43 km/h (≈ 27 m.p.h.) the pontoon form is more dangerous than the 'v' form but that at higher speeds the converse is true. Differences in injury patterns between the various shapes were noted. For children the head was the body area most frequently involved for all three shapes. With the pontoon form 54% were reported to have upper leg injuries and 28% lower leg injuries whilst with the 'v' form 11% had upper leg injuries and 67% lower leg injuries. No injuries to the legs were recorded for the box form. The number of pedestrians contacted by each shape and their age distribution was not given, consequently the confidence of the results is open to question.

For adults it was noted that chest injuries were more frequent with the box form than the other two forms and that abdominal injuries were more frequent with the box form and the pontoon form than with the 'v' form. These variations in injury with vehicle shape for both the children and adults are what would be expected from considering the areas of the body exposed to the initial vehicle contact.

The question of different injury potential between the various vehicle shapes was also considered by Schneider and Beier (1974). They noted the injuries sustained by pedestrians struck by the three basic shapes using data from autopsies and police reports. The effect of the location of the leading edge of the pontoon form was considered by taking cases where the leading edge was a) near the centre of gravity of the pedestrian, and b) about 20-38cms (8-15 inches) below the centre of gravity. Differences in injury between the different shapes were noted. For example when the pedestrian was struck at the centre of gravity, pelvic injuries were more frequent than femoral injuries but when the contact was below the centre of gravity the converse was true. When the striking vehicle had a 'v' form then it was found that both pelvic and femoral injuries were infrequent.

An at-the-scene study of accidents including pedestrian accidents has been carried out in the City of Houston by the University of Houston (Tharp 1974; Tharp and Tsongos 1974). One hundred and seventy five (175) accidents involving 190 pedestrians; 135 accidents involving 148 pedestrians were classified as frontal impacts. When only cases where the pedestrian sustained a direct blow from the vehicle, rather than a glancing contact i.e. corner contact are considered, the total reduces to 103 accidents. The relationship between impact speed and severity was examined by performing a regression analysis on impact speed and injury severity rated on the Abbreviated Injury Scale' (in the analysis the original version of the AIS in which the fatalities were divided into different levels was used). From this analysis it was concluded that:

'a) A fatality will result only occasionally (less than 5% probability) from a collision when the vehicle speed is 20 m.p.h. (32km/h) or less.
b) Multiple fatal injuries,... result from impact speeds above 30 m.p.h. (48 km/h).

c) The average impact speed for an injury severity of AIS 04 (serious injury) is 22 m.p.h. (35 km/h) with 90% confidence levels at 11 m.p.h. (18 km/h) and 33 m.p.h. (53 km/h).'

These results take no account of the age of the pedestrian. It was stated in the report that the correlation coefficient for age and severity varied between 0.35 and 0.24 whilst the correlation coefficient for impact speed and severity was 0.86. However a comparison between pedestrian age and impact speed suggested that these variables were related; a greater proportion of children in the sample being involved in low speed ($<$15 m.p.h. (24 km/h)) accidents.

Cornell Aeronautical Laboratory conducted a study of 265 car-pedestrian accidents in Toronto as part of a study into pedestrian, motorcycle and cycle accidents (C. A.L. 1971). The study was based on accidents investigated either by the police using specially designed forms or by an accident investigation team from Cornell. In addition the team from Cornell extended the data on those accidents investigated by the police by follow-up procedures. In describing the injuries, all injuries to the various body areas were noted, rather than the most severe injury as in most other studies. The pedestrians were divided into two groups, children and adults, by height of pedestrian rather than age, the dividing line being a height of 48 inches (122 cms). Analysis of the data was by these height groups, by two speed groupings - less than 20 m.p.h. (32 km/h) and greater than or equal to 24 m.p.h. (32 km/h) by type of vehicle - American cars, foreign sports cars and Volkswagen beetles, and by location of contact - front or side. It was reported that for frontal impacts with American cars 45.9% of all injuries to adults and 51.6% of all injuries to children were vehicle induced and that if only non-minor injuries are considered the importance of vehicle induced injuries increases; 64.9% of non-minor injuries to adults and 71.9% of non-minor injuries to children being vehicle induced. Head injuries were the most frequent injury sustained by children accounting for 33.6% of all injuries. For adults head injuries were the second most frequent injury accounting for 20.0% of the injuries, leg injuries accounting for 33.6% of the injuries. It was noted that the majority of minor head injuries were ground induced; 77.8% of the minor head injuries sustained by adults and 71.4% of those sustained by children being caused by ground contact. However for non-minor head injuries it was found that for adults 49.4% were caused by vehicle contact but that for children 80% were caused by vehicle contact.

In England on-the-spot studies of accidents in Birmingham in 1965 and 1966 and in Worcestershire in 1967 and 1968 provided data on 103 pedestrian accidents. The methodology of these studies was reported by Kolbuszewski et al (1969). McLean and Mackay (1970) suggested that child pedestrians were less severely injured than adults and that this could be due to differences in impact speeds and locations of initial contact on the vehicle rather than differences in injury tolerance. Fonseka (1969) noted that children,

> 'because of their small height and low centre of gravity they were thrown downwards. Provided they are not run over this appears better than being thrown upwards to be hit by the rest of the car'.

A further study of only pedestrian accidents was started in September 1973. Ashton, Hayes and Mackay (1974) described the results of the first 100 accidents investigated in the study together with an analysis of the cases investigated previously. Particular attention was paid to the question of bumper location and it was shown that a bumper height of 18-20 inches (45-50 cms) results in the maximum number of pedestrians sustaining a direct knee contact. In a later report on 171 pedestrians struck by cars or car derivatives (Ashton 1975) it was stated that

> '- children sustain less severe injuries than adults at high impact speeds and that this is mainly due to their sustaining less severe

head injuries.

- for both children and adults the head is the body area sustaining most life threatening or fatal injuries.
- life threatening or fatal head injuries are more often caused by vehicle contact than road contact.
- the windscreen frame is responsible for most of the life threatening or fatal head injuries caused by vehicle contact.

At the end of this review are Tables 6 through 9 which summarise the distributions of injuries to pedestrians described in these various studies. Table 6 lists the relative frequencies of injuries to the body areas of pedestrians based on studies of hospital data. Table 7 summarises the same type of data for fatally injured pedestrians.

Table 8 similarly lists the relative frequencies of injuries to various body areas for pedestrians based on field accident study data. These three tables (6 - 8) are all tabulations of the injuries per person. Table 9 lists the data in an alternative form, i.e. the relative frequency of injuries to body areas out of the total number of injuries (not persons) in the samples examined.

EXPERIMENTAL WORK

A comprehensive programme investigating problems of pedestrian protection is being carried out at the Institute of Automotive Engineering, Berlin Technical University.

A series of vehicle-pedestrian collision tests using three different vehicle shapes, the Volkswagen Beetle, the Opel R3 and the Volkswagen Minitruck, have been performed (Kuhnel 1974; Kuhnel and Rau 1974). In these tests a moving pedestrian dummy was used rather than a stationary dummy as this was felt to be more representative of real accidents. It was found that with the Opel and the Volkswagen Beetle the pedestrian generally rotated through 90^{o}, meaning that the legs did not rise above the level of the front of the bonnet, up to impact speeds of 30 km/h (19 m.p.h.). At higher speeds the angle of rotation increases; the rotation angle was generally greater for the Volkswagen Beetle than for the Opel. The height that the centre of gravity reaches was also monitored and it was found that the dummy tended to be thrown higher into the air by the Volkswagen Beetle than by the Opel. With the slab fronted minitruck the rotation angle was always zero and the dummy was not thrown into the air. It was noted that head contact with the windscreen frame produced much higher head acclerations than contact with other vehicle structures and that in general higher head accelerations resulted from impact by the Opel than by either of the Volkswagens. The ground contact tended to be more severe, at higher speeds, following impact by the Volkswagen Beetle, reflecting the greater height reached by the dummy. Kuhnel (1974(ii)) suggested that the problem with the conventional 'pontoon' form car was the stiff leading edge which resulted in considerable injury and that perhaps the best form may be a pontoon form with a much softer leading edge.

The accuracy of experimental collisions has been considered by reproducing real accidents (Kuhnel, Wanderer and Otte 1975).

A test trolley has been developed on which the shape of the vehicle front structure can be altered so that the effects of variations in design on pedestrian dynamics can be studied (Kramer 1974). The effect of varying the height and slope of the bonnet on a rounded front pontoon shape vehicle has been investigated (Kramer 1975). The overall length of the bonnet was 1.1m ($\simeq$43 inches), the slope was varied from 1^{o} to 6^{o}, and the height of the front of the bonnet from 85 cms ($\simeq 33\frac{1}{2}$ inches) through 95 cms ($\simeq 37\frac{1}{2}$ inches) to 105 cms ($\simeq 41\frac{1}{2}$ inches). The height and slope of the bonnet were both found to have an influence on the point of head contact and hence on the severity of the head injuries. The most favourable situation for head contact was found to be with the low hood (85 cms) and it was suggested that this height together with a smooth sloping profile would be preferable. It was found that the initial vehicle contact provided higher accelerations and impact forces than the secondary contact with the ground.

From injury tolerance work using cadavers (Burrow 1971; Kramer, Burrow and Heger 1973) a technique has been developed for estimating the severity of leg injuries from the measurements recorded in experimental tests using dummies (Kramer 1974). The same technique has also been applied to chest injuries (Kramer and Heger 1975).

The Laboratory of Physiology and Biomechanics of the Association Peugeot-Renault have conducted an extensive series of experimental pedestrian collisions in which eight different vehicles and two dummies, adult and child, were used (Stcherbatcheff et al 1975). The vehicles were divided into three groups for analysis —

a) low, short vehicles - height of front structure less than 70 cms
- bonnet length less than 100 cms

b) medium vehicles - height of front structure between 70 cms and 80 cms
- bonnet length between 100 cms and 130 cms

c) high, long vehicles - height of front structure greater than 80 cms
- bonnet length greater than 130 cms.

For the adult it was found that the trajectory of the head and the location of the head impact varied with the shape of the vehicle, a 'high' vehicle producing a curved head trajectory ending with a bonnet impact whilst a 'low' vehicle produced a flatter trajectory ending with an impact with the windscreen or frame; the head to vehicle impact velocity was found to be between 0.8 and 1.2 times the vehicle impact speed. The attitude of the dummy at the secondary impact with the ground was found to be influenced to a greater extent by the length of the bonnet, and to a lesser extent by the collision speed. With regard to the relative importance of vehicle and ground head contacts it was noted that the severity of the vehicle head contact increases with increasing collision speed but that there was little correlation between impact speed and ground head contact severity. In general however the severity of the head to ground contact was lowest for the long bonnet vehicles. At collision speeds less than 32 km/h (20 m.p.h.) the head to ground contact was more severe than the head to vehicle contact whilst at impact speeds between 32 and 40 km/h (20 to 25 m.p.h.) head contacts with 'medium' and 'short' vehicles were of the same severity as the ground contacts but with the long vehicle the ground contact tended to be less severe than the vehicle contact.

For the child the height of the front structure was found to have a significant effect on the motion. The low front structure resulted in the child leaving the vehicle with an angular rotation of the head towards the vehicle, this motion could be described as the legs being knocked away. The high front structure produced the opposite situation with the child being knocked over resulting in a higher head to ground impact velocity. It was found generally that the head to ground contacts tended to be more severe than the head to vehicle contacts.

The reproduction of real accidents using both anthropometric dummies and cadavers has been performed with particular emphasis on the cause of the head injuries (Stcherbatcheff et al, 1975).

One of the main differences between dummies and real people is that dummies are made much stronger and in an attempt to produce more realistic dummies frangible lower limbs have been developed (Stcherbatcheff et al 1973).

In the United States a series of 12 pedestrian impact experiments was carried out at the University of California in 1964(Severy and Brink 1966; Severy 1970). Pedestrian size was considered by using a number of dummies: a toddler dummy, a 3 year old child dummy, a 6 year old child dummy and an adult dummy. Impact speeds were varied from 10 m.p.h. (16 km/h) to 40 m.p.h. (64 km/h) in 10 m.p.h. (16 km/h) steps. It was concluded from this study that

> 'Auto-pedestrian accidents are multiple impact events for which the initial car to pedestrian contacts are not necessarily the most serious trauma likely to be inflicted. Subsequent impact with the pavement... will, for many accidents, produce injuries more serious than the original vehicle impact'.

With respect to vehicle shape it was suggested that wedge shape front ends increase upward projection of the pedestrian. A study at Battelle using a test buck consisting of a stylized car front structure on an impact sled investigated the effect of vehicle design using two basic vehicle profiles, a standard American car profile and a low sloping profile, and two pedestrian sizes, a 6 year old child and an adult. It was noted that

> 'while (on a limited sample basis) the low profile seems to cause lower injury severity than the standard profile at a 10 m.p.h. (16 km/h) impact, it also tends to cause a greater severity at higher speeds'.

An important feature of the study was the making of six identical tests to examine repeatability of dummy response. Repeatability was found to be better than expected, the attitude of the dummy at the same time after initial contact being virtually the same in each test (Herridge and Pritz 1973).

The same test buck was used in a later study using cadavers (Pritz et al, 1975). Results from this study suggested that, with regard to leg injuries, a significant increase in injuries occurs in the 15-20 m.p.h. (24-32 km/h) impact, that the injuries are localized at the point of contact and that direct impacts near the joints produce substantially more severe injuries than impacts away from the joint. The reaction between the pedestrian and the ground was measured and it was found that softening the bumper reduced the leg-bumper force but increased the foot-ground frictional force. No reduction in injury severity was found with the softened bumper and it was suggested that this was probably due to the increase in the ground frictional forces offsetting the reduced bumper force. The head velocity was calculated at the position at which the windscreen would be and it was found that lowering the front structure resulted in an increased head velocity. There was also some indication that softening the front structure increased the head velocity.

From tests in Japan using three different vehicles, a Volkswagen 1200, a Publica which has a low front and sloping bonnet and a Bluebird which has a high front and a flat bonnet it was suggested that the lower the initial contact the greater the angular rotation of the pedestrian and the higher the pedestrian is thrown (Kondo and Taneda 1971). At low impact speeds, 30 km/h (18 m.p.h.) vehicles with low front structures are preferable but that at around 40 km/h (24 m.p.h.) no differences were detected between the vehicles (Taneda et al 1973).

Fiat carried out a series of pedestrian impact tests as part of their Experimental Safety Vehicle (ESV) programme (Montanari 1974). The motion of pedestrians struck by the various E.S.V.'s was presented but as the vehicles were similar in design the effect of vehicle shape was not discussed.

In the United Kingdom experimental tests using vehicles have been carried out by British Leyland (Finch 1974) (New Scientist 1974) and at the Transport and Road Research Laboratory (T.R.R.L. 1974 i). In particular attention has been given to the design of a pedestrian catcher to keep the pedestrian on the vehicle preventing secondary ground contact. Rolls-Royce have investigated the influence of vehicle design using a simulated vehicle impact sled and child and adult dummies. Amongst the factors being considered are properties and location of the bumper, bonnet leading edge height and position and bonnet and windscreen slope.

Tests on structures have been carried out in Australia by Sarrailhe and Hearn (1971) and in America by Cornell Aeronautical Laboratory (C.A.L. 1971).

Sarrailhe and Hearn used an impactor to investigate the properties of the leading edge of a number of vehicles. It was found that the leading edge of most vehicles tested was a stiff structure, a force of 1000 lbf producing deflections of less than 1in (2.5cm). Tests on a Volkswagen produced a deflection of 6in (15cm). A further test on the boot of a Holden showed that if the leading edge of the bonnet was designed in the same way as the rear edge of the boot an improved situation would result.

The tests at Cornell used a pendulum on which a simulated headform was mounted. Areas tested were the leading edge of the bonnet and the top surface of the bonnet. It was noted that contact on the bonnet predominately resulted in elastic deformation with no permanent indentation whereas leading edge contact resulted in permanent deformation. It was suggested that modification of the leading edge to produce better load distribution should result in a reduction in pedestrian hazard.

MATHEMATICAL MODELLING

A two dimensional 5^{o} freedom pedestrian model was developed at Cornell Aeronautical Laboratory as part of their research programme into impact protection for pedestrians and and cyclists (C.A.L. 1971). Factors considered were vehicle shape, vehicle front structure stiffness, vehicle braking and pedestrian size. Two vehicle shapes were studied, a conventional square fronted vehicle and a vehicle with a smooth, rising contour leading back from the bumper. Comparison with the accident data collected in the same study showed the simulation was reasonably good in predicting the furthest point of pedestrian contact. It was suggested that the risk of receiving serious or fatal injuries increases sharply between 15 to 20 m.p.h. (24-32 km/h). Parameter studies indicated an improved pedestrian environment with a more rounded front contour and a less stiff front structure.

Katayama and Shimada (1971) described a two dimensional 7^{o} freedom model. A comparison between the model and an experimental pedestrian collision was made and reasons for the differences in results discussed.

Maclaughlin and Daniel (1974) presented a parametric study of pedestrian injury in which a two dimensional 6^{o} freedom model was used to investigate the influence of certain vehicle and pedestrian factors. The aspects of vehicle design considered were vehicle shape, stiffness of the bumper and sheet metal structures and the maximum allowable deformation of the structure contacted. Pedestrian factors considered were pedestrian size, orientation and muscle tension. The results of the study, however, were somewhat limited as the influence of impact speed was not considered, all simulations being made at an impact speed of 18 m.p.h. (29 km/h). Main conclusions were that

'- pedestrian size and orientation tended to have effects on pedestrian injury which were equally as important as the vehicle parameter effects.
- although vehicle parameter changes were generally effective in reducing injury, no single parameter was highly dominant. Rather they varied in relative degree of significance, depending on which injury criteria was considered'.

It was suggested that the reduction in stiffness of contacted areas was beneficial.

Niederer (1975) presented the first results of a study using the CALSPAN 3 dimensional simulation (Fleck et al 1974). He considered the case of a pedestrian struck by a car moving at a constant speed of 20 km/h. It was noted that although comparison of the results with experimental tests showed that the general motion of the pedestrian was predicted, there were still a number of problems to be resolved before the model was acceptable in detail.

CONCLUSIONS

The above reviews of the studies which have been conducted to date on both riders of two-wheeled machines and on pedestrians show a number of characteristics common to both groups of road users. In severe injury accidents, multiplicity of injury is the rule, with head and lower limb injuries predominating.

For motorcyclists the data show that the types and frequencies of injuries vary considerably according to the configurations of the collisions and their severities, although the question of collison speed has not been examined adequately in this context. The use of helmets by motorcyclists appears to be beneficial, but no definite study of this one crash-protective item of motorcycling has yet been conducted, because of the difficulties in the reporting procedures for single vehicle accidents.

This problem puts a reservation over much of the frequency data given in studies of two-wheeler accidents which are based on police data particularly. With regard to studies of specific origins of the various injuries sustained by riders, the most severe condition described is where the rider receives most of his injuries from striking the opposing vehicle, although the tank and handlebars of his own machine are cited as significant sources of trauma. In general much more epidemiological study of a detailed nature is needed before the various priorities for remedial measures can be established.

The biomechanics of pedestrian trauma in comparison is relatively well documented. Like riders, pedestrains receive head and leg injuries most frequently. For legs, bumper impacts are the main cause of serious leg injuries, and there is every suggestion that present bumper designs are far from optimal from this point of view. Ground contacts give rise to most of the minor leg injuries.

For adult pedestrians the vehicle accounts for at least half of the serious head injuries and and that proportion increases with children. The severity of injuries from vehicular contacts in general appears to be directly related to speed but no such dependance exists for contacts with the ground where perhaps the orientation of the pedestrian is more important than his horizontal velocity.

Studies show that a steep increase in pedestrian injury severity occurs at between 15 and 20 m.p.h. impact speed. Below 15 m.p.h. minor injuries predominate, whilst above 20 m.p.h. the chances of serious injury are high.

Vehicle design appears to have a real influence over the frequency and severity of pedestrian injury, but impact speed is a critical parameter. What may be best for one size of pedestrian at one speed may not necessarily be good for another set of conditions. Because children form a large proportion of the pedestrian casualty population, account must be taken of the circumstances of their accidents and injuries. At this stage, the optimum vehicle exterior design has not yet been defined.

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Table 1 - Relative Frequencies of Injuries to Body Areas for Motorcyclists and Pedal Cyclists Involved in Fatal Accidents

STUDY	NOTES	HEAD	NECK	SPINE	THORAX	ABDOMEN	PELVIS	ARMS	LEGS
GISSANE & BULL (1961)	non-minor injuries SAMPLE : 34 m/c	a) 64.7 # 61.8	11.8		lung 32.4 # rib 35.3		# 23.5	# 17.7	# 20.6
	SAMPLE : 22 p/c	a) 86.4 # 77.3	4.6		lung 27.3 # rib 40.9			# 4.6	# 18.2
HODGE (1962)	non-minor injuries SAMPLE : 28 m/c	a) 89.3 # 85.7	10.7	dorsal 7.1 lumbar 7.1	heart 14.3 lung 32.1 rib 28.6	liver 28.6 spleen 17.9 kidney 21.4	# 14.3	upp 10.7 low 21.4	upp 21.4 low 14.3
	SAMPLE : 17 p/c	a) 82.4 # 70.6	17.7	dorsal - lumbar -	heart 11.8 lung 11.8 rib 23.5	liver 5.9 spleen 11.8 kidney 17.6	# 5.9		upp - low 5.9
SLATIS (1962)	major injuries SAMPLE : 45 m/c	a) 64.4 # 62.2	6.7		33.3	b) 17.8 kidney 2.2	11.1	13.3	33.3
	SAMPLE : 56 p/c	a) 62.5 # 57.4	12.5		42.9	b) 10.7 kidney 3.6	8.9	3.6	17.9
TONGE et al (1964)	non-minor injuries SAMPLE : 365 m/c	d) 61.4 a) 78.2 # 68.2	1.9	3.0 e) 0.6	lung 28.2 rib 35.1	liver 21.1 spleen 17.3 kidney 8.5	# 9.9	L.upp 3.8 L.low 4.7 R.upp 4.4 R.low 6.3	L.upp 8.5 L.low 6.3 R.upp 11.0 R.low 9.6
	SAMPLE : 181 p/c	d) 54.1 e) 80.1 # 71.3	5.5	1.7 e) 0.6	lung 21.0 rib 31.0	liver 12.1 spleen 6.6 kidney 5.0	# 12.2	L.upp 2.2 L.low 2.2 R.upp 1.1 R.low 2.2	L.upp 3.9 L.low 3.9 R.upp 3.3 R.low 4.4
SEVITT (1968)	non-minor injuries SAMPLE : 41 m/c	80 c) 76	2	dorsal 7	49 c) 39	24 c) 12		17 upp 5 low 10	22 upp 21 low 9
	SAMPLE : 18 p/c	83 c) 72	2	dorsal 11	39 c) 33	5.5 c) 5.5	22	16 upp - low 11	22 upp 11 low 6

NOTES : m/c - motorcyclist (All 2-wheeled motor vehicle users)
p/c - pedal cyclist
upp - upper
low - lower
L - left
R - right

a) - Concussion and brain injury
b) - Excluding kidneys
c) - Serious injuries
d) - Surface injuries
e) - Lumbar and sacral injuries
- Fractures

Table 2 - Relative Frequencies of Injuries to Body Areas for Motorcyclists and Pedal Cyclists Involved in Fatal Accidents

STUDY	NOTES	HEAD	NECK	SPINE	THORAX	ABDOMEN	PELVIS	ARMS	LEGS
TONCE et al (1972)	non-minor injuries SAMPLE : 41 m/c	d) 85.3 a) 63.4 # 73.1	7.3	12.1	lung 31.7 rib 46.3	liver 24.4 spleen 12.1 kidney 9.8	# 4.9	L.upp 2.4 L.low 7.3 R.upp 4.8 R.low -	L.upp 4.8 L.low 7.3 R.upp 7.3 R.low 14.6
	SAMPLE : 37 p/c	d) 83.7 a) 73.0 # 70.3	10.8	5.4 e) 5.4	lung 29.7 rib 16.2	liver 10.8 spleen 8.1	# 8.1	L.upp 5.4 L.low 2.7 R.upp 5.4 R.low 5.4	L.upp 2.7 L.low 2.7 R.upp 8.1 R.low 5.4
RENTON (1973)	all injuries SAMPLE : 284 m/c	65	$\underbrace{\qquad}_{8.1}$		$\underbrace{\qquad}_{27.5}$			14.1	22.9
SEVITT (1973)	fatal injuries SAMPLE : 25 m/c	64	8		40	20	# 11		
	SAMPLE : 10 p/c	100			10	10			

NOTES :

m/c - motorcyclist
p/c - pedalcyclist
upp - upper
low - lower
L. - left
R. - right

a) Concussion and brain injury
d) Surface injury
e) Lumbar and sacral injuries
// - Fractures

Table 3 - Relative Frequencies of Injuries to Body Areas for Two-Wheeled Vehicle Users

STUDY	NOTES	HEAD	NECK	SPINE	THORAX	ABDOMEN	PELVIS	ARMS	LEGS
ASTON & PERKINS (1954)	all casualties all injuries SAMPLE : 268 m/c	51.9		11.6				L.upp 7.5 L.low 12.3 R.upp 9.0 R.low 15	L.upp 11.9 L.low 11.6 R.upp 15.7 R.low 18.3
	SAMPLE : 120 p/c	55.8		11.7				L.upp 21.7 L.low 12.5 R.upp 12.5 R.low 16.7	L.upp 3.4 L.low 1.9 R.upp 4.1 R.low 3.4
HEIDELBERG (1962)	hospital inpts all injuries SAMPLE : 2062 m/c	71.5	3.7		6.4	4.5	2.7	17.4	31.6
	SAMPLE : 747 p/c	66.6	2.18		8.1	6.0	5.6	14.7	38.3
BACKSTROM (1963)	all casualties all injuries SAMPLE : 541 m/c	55.9	0.7	3.3	6.5	3.0	4.8	26.8	47.1
	SAMPLE : 256 p/c	72.7	1.1	3.9	13.3	2.7	5.9	26.5	35.6
PELLEGRINO (1968)	all casualties all injuries SAMPLE : 569 m/c	17		(b) 52.8	13.9	33.3		R. 45.8 L. 37.4	R. 42.2 L. 32.4
	SAMPLE : 195 p/c	36.7		(b) 62.5	12.5	25.0		R. 34.5 L. 30.0	R. 46.3 L. 35.2
GISSANE, BULL, & ROBERTS (1960)	hospital inpts non-minor injuries SAMPLE : 328 m/c	8.2 (a) 45.1		2.4	#rib 4.3		3.1	#R. 7.9 #L. 6.7	#R. 20.1 #L. 11.3
	SAMPLE : 168 p/c	10.7 (a) 48.8		0.3	#rib 4.2		1.2	#R. 10.7 #L. 8.9	#R. 7.1 #L. 3.0

NOTES :
m/c - motor cyclist
p/c - pedal cyclist
upp - upper
low - lower
L. - left
R. - right

a) - Concussion and brain injury
b) - Includes pelvis
- Fractures

Table 4 - Relative Frequencies of Injuries to Body Areas for Two-Wheeled Vehicle Users

STUDY	NOTES	HEAD	NECK	SPINE	THORAX	ABDOMEN	PELVIS	ARMS	LEGS
JAMIESON & TAIT (1966)	hospital inpts non-minor injuries SAMPLE : 151 m/c	68.2 a) 29.8			14.6	10.6		46.4	
	SAMPLE : 70 p/c	75.7 a) 27.1	1.4	7.1	15.7	2.9		27.1	
JAMIESON et al (1971)	all injuries SAMPLE : 18 m/c	61.1		b) 5.6	5.6	11.1		R. 38.9 L. 61.1	R. 44.4 L. 38.9
CLARK & MORTON (1971)	SAMPLE : 226 m/c	14.3	1.6	3.4	4.4	2.8	3.1	25.2	42.7
BO (1972)	hospital inpts major injuries SAMPLE : 345 m/c	45.0		1.3	1.4	2.35		14.5	35.9
	SAMPLE : 189 p/c	64.5		3.2	2.1	2.6		13.8	13.8

NOTES :

m/c - motorcyclist
p/c - pedalcyclist
L. - left
R. - right

a) Concussion and brain injury
b) Includes pelvis

Table 5 - The Percentage of Injuries to a Given Body Area for Two Wheeled Vehicle Users

STUDY	NOTES	HEAD	NECK	SPINE	THORAX	ABDOMEN	PELVIS	ARMS	LEGS
GRAHAM (1969)	fatalities all injuries SAMPLE 324 m/c	56.0		5.3	18.0	4.0		2.3	14.4
ROBERTSON, MCLEAN, & RYAN (1966)	all injuries m/c,N=71 I=148	26.4			6.1	2.7		21.6	43.2
	p/c,N=35 I=98	29.6		a) 5.1	8.2	7.1	a)	18.4	31.6
SLATIS (1967)	all casualties all injuries m/c,N=1776 I=2896	41.1	0.7		1.6	0.6	0.7	16.8	20.0
	p/c,N=1221 I=1828	44.5	0.4		1.7	0.3	1.0	16.4	17.1
HICHT et al (1973)	m/c accidents all injuries by occupant's kinematics								
	1) Non-ejected N=36	92	19	8	53	31.	17	47	83
	2) Ejected N=46	83	15	7	35	15	20	46	72
	3) Deflected N=44	68	18	14	34	9	7	41	93
DRYSDALE et al (1975)	non-minor injuries m/c,N=370 I=505	11.3		3.5	4.1		2	25.8	42.6

NOTES :

m/c - motorcyclist
p/c - pedalcyclist
N - number of casualties

I - number of injuries
a) - includes pelvis and spine

Table 6 - Relative Frequencies of Injuries to Body Areas for Pedestrians from Hospital based Studies (i.e. Injuries per Person)

STUDY	NOTES	HEAD	NECK	SPINE	THORAX	ABDOMEN	PELVIS	ARMS	LEGS
ASTON & PERKINS (1954)	all casualties all injuries SAMPLE = 91	53.8		16.5				L.upp 12.1 L.low 9.9 R.upp 4.4 R.low 8.8	L.upp 20.9 L.low 11.0 R.upp 23.1 R.low 9.9
McNICOL SMITH & LETHEREN (1961)	hospital inpatient non-minor injuries SAMPLE = 169	# 22.5 a) 24.3	# 3.0	0.0	#rib 6.5		# 18.9	# upp 3.0 # low 7.7	# upp 17.2 # low 56.2
GOGLER (1962)	hospital inpatient SAMPLE = 1149	66.6	2.2		8.1	6.0	5.6	14.7	38.3
BACKSTROM (1963)	all casualties all injuries SAMPLE = 220	65.9	3.2	4.5	9.5	4.1	7.3	21.4	47.3
JAMIESON & TAIT (1966)	hospital inpatient non-minor injuries SAMPLE = 243	a) 66.7	0.0	14.0	26.3	31.3		17.3	50.2
GISSANE, BULL & ROBERTS (1970)	hospital inpatient non-minor injuries SAMPLE = 398	# 12.1 a) 59.0	0.5		# rib 4.3	-	# 8.0	# L 4.5 # R 5.3	# L 13.1 # R 18.8
BØ (1972)	hospital inpatient major injuries SAMPLE = 648	48.4		2.8	3.4	4.8		11.8	28.6

NOTES: L - Left side
R - Right side
upp - Upper
low - Lower
- Fracture
a) - Concussion and Brain Injury

Table 7 - Relative Frequency of Injuries to Body Areas of Fatally Injured Pedestrians (i.e. Injuries per Person)

STUDY	NOTES	HEAD	NECK	SPINE	THORAX	ABDOMEN	PELVIS	ARMS	LEGS
JAMIESON et al (1971)	all injuries all contacts SAMPLE = 51	$\underbrace{\qquad}_{64.7}$		a)	13.7	27.5	a) 25.5	L 35.3 R 43.1	L 72.5 R 70.6
	all injuries front contact cars SAMPLE = 34	$\underbrace{\qquad}_{64.7}$		a)	5.9	23.5	a) 26.5	L 35.3 R 41.2	L 79.4 R 70.6
ROBERTSON, McLEAN & RYAN (1966)	all injuries all contacts cars SAMPLE = 63	$\underbrace{\qquad}_{76.2}$		a)	22.2	15.9	a) 17.5	50.8	87.3
STURTZ et al (1975)	all injuries children (15yr) SAMPLE = 76	92	1	1	20	26	17	11	Upper 40 Lower 26
	adults (15 - 65yr) SAMPLE = 37	81	3	5	16	14	16	8	Upper 27 Lower 62
	adults (65yr) SAMPLE = 30	90	13	13	23	7	47	27	Upper 30 Lower 73
ASHTON (1975)	all injuries front contact cars children (15yr) SAMPLE = 51	76.5	0.0	b)	5.9	19.6	c)	29.4	c) 78.4
	adults (15yr) SAMPLE = 66	83.3	6.1	b)	25.8	19.7	c)	48.5	c) 87.9

NOTES: L - Left
R - Right

a) - Pelvis includes Spine
b) Spine included in Body Area applicable
c) Legs includes Pelvis

Table 8 - Relative Frequency of Injuries to Body Areas of Pedestrians from Field Accident Studies (i.e. Injuries per Person)

STUDY	NOTES	HEAD	NECK	SPINE	THORAX	ABDOMEN	PELVIS	ARMS	LEGS
ROBERTSON, McLEAN & RYAN (1966)	all injuries all contacts cars N:63 I:170 B:6	28.2		h)	8.2	5.9	h) 6.5	18.8	32.4
	non-minor injuries all contacts cars N:63 I:95 B:6	41.1		h)	10.5	5.3	h) 11.6	8.4	23.2
JAMIESON et al (1971)	all injuries all contacts N:51 I:180 B:8	18.3		h)	3.9	7.8	h) 7.2	L 10.0 R 12.2	L 20.6 R 20.0
	non-minor injuries all contacts N:51 I:90 B:8	27.8		h)	6.7	11.1	h) 14.4	L 2.2 R 4.4	L 16.7 R 16.7
T.R.R.L. (1974)	non-minor injuries N:149 I:382 B:10	27.2	2.9	a) 1.3	6.3	3.1	b) 14.1	c) 6.8	Upper 12.8 Knee 1.8 Lower 23.6
C.A.L. (1971)	all injuries front contact cars children* N:39 I:137 B:6	33.3	0.7		d) 8.0	e) 11.7		18.2	27.7
	all injuries front contact cars adults* N:110 I:444 B:6	20.0	0.2		d) 5.4	e) 17.8		18.2	38.3
ASHTON (1975)	all injuries front contact cars children (14yr) N:51 I:107 B:6	36.4	0.0	f)	2.8	9.3	g)	14.0	g) 37.4
	all injuries front contact cars adults (14yr) N:66 I:179 B:6	30.7	2.2	f)	9.5	7.3	g)	17.9	g) 32.4

NOTES:
N - Number of Pedestrians
I - Number of Injuries
B - Number of Body Areas
* - Child defined as person less than 48in (122cm) tall
L - Left
R - Right

a) - Back (Thoraco-lumbar)
b) - Includes Hip joint
c) - Includes Shoulder
d) - Upper Torso

e) - Lower Torso
f) - Spine included in Body Area applicable
g) - Includes Pelvis
h) - Pelvis includes Spine

Table 9 - Relative Frequency of Injuries to Body Areas out of Total Number of Injuries to Pedestrians (i.e. Injury Based)

STUDY	NOTES	HEAD	NECK	SPINE	THORAX	ABDOMEN	PELVIS	ARMS	LEGS
GISSANE & BULL (1961)	fatalities non-minor injuries SAMPLE = 97	a) 69.1 # 58.8	# 15.5		lung 27.8 # rib 33.9		# 32.0	# 17.5	# 42.3
McCARROLL et al (1962)	fatalities non-minor injuries SAMPLE = 200	61.0	22.0		50.0	42.0	46.0	19.0	54.0
ECKERT et al (1959)	fatalities quoted in HODGE SAMPLE = 121	61	4		# rib 67		66		upp 17 low 53
HODGE (1962)	fatalities non-minor injuries SAMPLE = 61	a) 77.0 # 54.1	# 29.5	dorsal 21.3 lumbar 1.6	heart 11.5 lung 21.3 rib 36.1	liver 18.0 spleen 13.1 kidney 23.0	49.2	upp 14.8 low 16.4	upp 26.2 upp 65.6
SLATIS (1962)	fatalities main cause of death SAMPLE = 192	a) 64.1 # 58.3	14.1		49.5	b) 22.9 kidney 8.9	24.0	21.4	44.8
SOLHEIM (1964)	fatalities non-minor injuries SAMPLE = 168	72.0	16.1		53.6	24.4	25.6	19.0	33.3
PERRY (1964)	fatalities non-minor injuries SAMPLE = 57	61.4	7.0		29.8	24.6	c)	24.6	c) 70.2
SEVITT (1968)	fatalities non-minor injuries SAMPLE = 125	63.2	10.4	dorsal 7.2	38 d) 29.6	14 d) 9.6	36.0	14 upp 10 low 4	48 upp 16 low 37
TONGE et al (1964)	fatalities non-minor injuries SAMPLE = 910	e) 62.2 a) 73.2 # 61.0	12.4	7.8 f) 2.2	lung 18.3 rib 42.4	liver 19.0 spleen 11.6 kidney 3.9	21.8	L.upp 4.4 L.low 3.8 R.upp 4.3 R.low 4.8	L.upp 6.9 L.low 6.9 R.upp 18.7 R.low 18.7
TONGE et al (1972)	fatalities non-minor injuries SAMPLE = 355	e) 81.4 a) 48.7 # 49.5	19.8	12.8 f) 2.5	lung 28.5 rib 42.2	liver 20.0 spleen 18.9 kidney 10.1	33.2	L.upp 10.1 L.low 5.6 R.upp 4.5 R.low 4.8	L.upp 17.7 L.low 14.1 R.upp 36.1 R.low 31.3
HUELKE & DAVIS (1969)	fatalities non-minor injuries SAMPLE = 232	61 g) 55.0	33 g) 42.2		44 g) 41.7	28 g) 19.8	39 g) 4.8	14	58

NOTES: L - Left side
R - Right side
upp - Upper
low - Lower

- Fracture
a) - Concussion and Brain Injury
b) - Excluding Kidneys
c) - Legs include Pelvis

d) - Serious injuries
e) - Surface injuries
f) - Lumbar and Sacral injuries
g) - Fatal injuries only