PASSENGER CARS AND OCCUPANT INJURY

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Abstract:
This project was undertaken to evaluate the level of protection afforded occupants of current generation passenger cars available on the Australian market and to provide directions for future improvements in occupant protection. A literature review was initially undertaken to highlight reported vehicle occupant injuries and sources of injury as well as countermeasures which are presently under consideration overseas. A mass database was constructed of injury compensation data at the Transport Accident Commission in Victoria, supplemented with police and some make/model information, for detailed analysis. In addition, a program was undertaken of detailed inspections of 227 crashed vehicles where at least one occupant was hospitalised to provide details on sources of injury from current generation vehicles involved in road crashes. This first report describes the findings to date and makes recommendations on a range of suitable countermeasures to reduce the incidence and severity of injuries for front seat occupants involved in frontal crashes. A supplementary volume provides a case by case summary of each of the crashed vehicles inspected. Further reports are planned to provide recommendations for other seating positions and crash configurations when additional data becomes available.

Key Words:
SAFETY, ACCIDENT, VEHICLE OCCUPANT, INJURY, TEST METHOD, HEAD ON, EVALUATION

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INTRODUCTION

New passenger cars sold in Australia have been required to meet vehicle safety standards specified in Australian Design Rules for Motor Vehicles and Trailers (ADRs) since 1970. For the most part, these ADRs aim to "harmonize" with similar vehicle safety standards in Europe and the USA.

Recent changes in vehicle construction, a trend towards smaller vehicles on our roads, and the effects of high levels of seat belt wearing need to be evaluated in terms of occupant protection for passenger car occupants involved in vehicle crashes. This report examines the current level of occupant protection of current generation passenger cars in Australia.

THE AIMS OF THE STUDY

The study was undertaken for the Federal Office of Road Safety by the Monash University Accident Research Centre to provide a focus for the future development of occupant protection improvements in Australian passenger cars and their derivatives. The research was in **three** parts:

1. First, a review of the international safety literature was undertaken to provide a background of the types of injuries being sustained by vehicle occupants, the sources of these injuries within the vehicle, and international developments in occupant protection.

2. Second, a detailed analysis was carried out of seven and one-half years of Transport Accident Commission (TAC) injury compensation data involving recent vehicle occupants, supplemented with police accident report details, to obtain an overview of the pattern of injuries to occupants of modern passenger cars in this country.

3. Finally, a "follow-up" study was performed of 227 passenger car crashes in and around Melbourne where at least one occupant of a modern passenger car was hospitalised from the crash (total of 269 patients). This investigation involved an examination of patients and their vehicles to link occupant injuries with sources of injury inside the vehicle for various types and severities of crashes.

All this information was then drawn together to provide a picture of the types of injuries sustained by occupants of modern passenger cars, particular design and component problems, and potential solutions for Australian vehicles.

This first stage report focuses principally on **front seat occupants involved in frontal crashes**. Recommendations are made about a range of potential countermeasures for these occupants, along with further research and development work required. Future reports are planned to provide recommendations for other crash configurations and seating positions when additional data from a larger number of crashes has been collected.

A supplementary volume is also available which provides a case by case summary of each crashed vehicle inspected.

THE EXTENT OF THE PROBLEM

From the mass data analysed and the crashed vehicles inspected, this study was able to provide an overview of the types of vehicle crashes that occur and the nature of injuries sustained by occupants of current generation vehicles.

TYPES OF CRASHES - Amongst TAC claimants, frontal impacts were most prevalent (47%), followed by side collisions (25%), rear enders (23%) and rollovers (5%). Rear end crashes were considerably under-represented in terms of severe injuries compared to all other crash configurations. These figures are roughly equivalent to those reported in other countries and illustrate the higher and lower likelihood of severe injury requiring hospitalisation for these particular crash configurations.

One-third of frontal impacts in the crashed vehicle sample were pure frontals (central and longitudinal), another third were pure offsets (longitudinal offset), while the remaining third of frontal crashes were oblique offset collisions. These figures are also similar to other reports in the literature.

Roughly half the number of front seat occupants in the crashed vehicle study were hospitalised from frontal crashes where the estimated impact velocity change (delta-V) was less than 48km/h. (This value represents the impact speed for barrier crash testing for pure frontals where belted occupants would expect to be protected from these crashes).

SEATING POSITIONS - Injured occupants were most frequently drivers (63%) or front seat passengers (24%), rather than rear seat occupants (13%) in these state-wide data. This probably reflects the frequency with which these seating positions are occupied in vehicles on the road, but may also indicate slight differences in injury susceptibility across these different seating positions.

Drivers sustained slightly more injuries than other occupants among the total crashed vehicle sample. However, there were roughly equal numbers of **severe** injuries to hospitalised occupants in all seating positions.

VEHICLE MASS - Mini cars (under 750kg) were over-involved in low speed zone crashes amongst TAC claimants, while intermediate (1250-1500kg) and large cars (more than 1500kg) were over-involved in high speed zone crashes. Mini and small cars were also associated with more severe injuries, often involving very young and very old (predominantly female) occupants from urban crashes.

It was not possible to compare vehicle involvement or injury severity rates by the different vehicle makes and models in this study.

VEHICLE INTEGRITY - Structural deformations and intrusions were quite frequent amongst the frontal crashed vehicles examined in the follow-up study. The toe pan, instrument panel, steering assembly, side panel, A-pillar and console were common sources of intrusions in the front seating areas.

Rear-wheel drive compact cars (1000-1250 kg) appeared to sustain more intrusions (including longitudinal movements of the steering column) than did front-wheel drive compact vehicles.

Steering assembly intrusions were also quite common in frontal crashes, especially those involving lateral and vertical movement. However, there were very few instances of longitudinal intrusions beyond 127mm for impact speeds of 48km/h or less, as specified by Australian Design Rule ADR 10/01.

TYPE OF OCCUPANTS - Older occupants (those aged 55 years or more) were more likely to be severely injured than younger occupants in all seating positions. Males, too, were over-represented in severe injury claims at the TAC, which is likely to be related to their over-involvement as drivers, non-wearers of seat belts, and being involved in high speed zone crashes.

SEAT BELT WEARING - Seventeen percent of hospitalised front seat occupants in the crashed vehicle study were not wearing seat belts compared with a 6 percent non-wearing rate in the population at large. This illustrates the protective nature of these restraints, although it may also indicate that unrestrained occupants are over-involved in crashes.

Seat belts did not appear to influence the number of entrapments for front seat occupants in frontal crashes. However, they were of substantial benefit in preventing ejections from the vehicle during frontal crashes.

Data on seat belt wearing behaviour in the mass data was not reliable because of artificially high rates of wearing reported by the police. However, unrestrained occupants may have experienced more severe injuries than restrained occupants for a given collision speed.

STATE-WIDE INJURY PATTERNS

The analysis of seven and one-half years of TAC vehicle occupant claims provided clear evidence of the types of injuries sustained by occupants of modern cars involved in crashes for different outcome severities.

There was a high rate of head, chest, abdomen and lower limb injuries amongst those who were killed or hospitalised for more than 6 days. Lower leg, minor head and face, and whiplash injuries were more prominent amongst occupants who were hospitalised for short periods as well as those requiring only outpatient treatment resulting from a vehicle crash.

Head injuries were more common (and chest and abdomen injuries less frequent) amongst occupants severely injured from rear end and rollover collisions than from front or side collisions. For less severe outcomes, chest and lower limb injuries were more common among occupants from front and side impacts than rear enders or rollovers.

Severe spinal fractures were more frequent amongst those injured in rollover, rear end and side than frontal crashes. Front and rear centre seat occupants were especially vulnerable to severe head and spine injuries compared to those in outboard seating positions.

There was also a suggestion in these data that drivers and front left passengers suffered more head and chest injuries than rear seat passengers in severe collisions. In addition, lower limb injuries were more prevalent in the front than the rear seats.

Occupants in mini and small cars tended to have slightly more severe head and chest injuries than occupants of larger cars, even though these small vehicles were predominantly involved in lower speed urban crashes.

CRASHED VEHICLE STUDY INJURIES

The crashed vehicle study results were in general agreement with these state-wide injury patterns and were able to provide a more comprehensive account of front seat occupant injuries (including injury severity) from frontal crashes for a limited number of crashes. It was not possible, though, to highlight differences in injury types and severities between pure and offset frontal crash injuries at this stage.

Drivers sustained more body region injuries (including more severe injuries) than front-left passengers in frontal crashes and their average injury severity score (ISS) was higher.

Drivers in frontal crashes experienced a sizable number of severe injuries to the abdomen, chest, and the upper and lower extremities. Front seat passengers also had similar injuries except for fewer severe chest injuries. There were a number of severe head injuries to injured occupants in both front seat positions.

Because of the requirement for hospital entry into the study, it was not possible to evaluate the effectiveness of seat belts in preventing injury. Nevertheless, there were subtle differences in the pattern of injury between belted and unbelted front seat occupants, where unbelted front seat passengers in particular sustained fewer severe chest, but more upper limb, pelvic, and lower limb injuries than their belted counterparts.

SOURCES OF INJURY INSIDE THE VEHICLE

The crashed vehicle study was the only source of information regarding which vehicle parts were associated with injuries in local vehicles. (While overseas information from the literature was also of interest here, it was not directly comparable because of differences in the types of vehicles and seat belt wearing rates).

The three most frequent sources of injury for drivers in frontal crashes were the steering wheel, instrument panel, and seat belts. The most common severe injury/source contacts for drivers in frontal crashes were the chest with the steering wheel, lower legs with the floor, head with the steering wheel, thigh or knee with the instrument panel, and chest with the belt.

For front left passengers, the instrument panel, seat belts, and the windscreen or header were primarily involved in their injuries. For these passengers, the most frequent severe injury and source contacts included the upper limbs with the instrument panel, the chest with the seat belt, the thigh or knee with the instrument panel, and lower leg with the floor.

Apart from the steering assembly for drivers, there were very few differences in the patterns of injuries and contact points for these front seat occupants in frontal crashes.

Again, it should be stressed that these results cannot be used to assess the overall effectiveness of the seat belt for reasons previously stated. However, there were observable differences in the pattern of contacts between belted and unbelted front seat occupants.

Unbelted front seat occupants experienced more head, face, and upper limb injuries from contact with the windscreen and header and exterior objects. Belted occupants experienced more chest and abdominal injuries, essentially from contact with the seat belt. Driver contacts with the steering wheel and instrument panel were quite common irrespective of whether they were belted or not.

Similarly, unbelted front seat passengers had more windscreen and exterior contacts, as well as more severe injuries from the instrument panel and windscreen, than their belted counterparts.

FRONTAL IMPACT COUNTERMEASURES

The three-point restraint system continues to be the main countermeasure against occupant injury for front seat occupants in frontal crashes. Current concern needs to be with increasing the protective effect of the system and reducing injuries shown to be associated with belt use.

The following list of potential countermeasures is suggested from this research program. It should be noted that further research may be required to demonstrate the cost effectiveness of some of these measures.

STEERING WHEELS - Steering wheels and hub contacts are still a major source of injury to drivers involved in frontal crashes. A padded and more forgiving steering wheel has been developed overseas to alleviate these injuries and one or two European vehicles now offer such a device as standard equipment. This study demonstrates the need for similar improvements in Australian vehicles.

IMPROVED RESTRAINT SYSTEMS - Restraint systems have been remarkably successful in reducing injuries to front seat occupants in frontal crashes. This study shows that there is still scope for further improvements to restraint systems. In particular, total seat belt extension should be reduced to minimize contact injuries while belt geometry needs improving to reduce submarining and other injuries. Attaching the belt anchorage points to the seat, D-ring adjustment, pre-tensioners or webbing clamps, and perhaps stiffer webbing or wider seat belts are all possible improvements to reduce the severity of these injuries.

SUPPLEMENTARY AIRBAGS - A further benefit for front seat occupants involved in frontal crashes could be derived from fitting airbags to supplement existing 3-point belt restraint systems. They would help reduce contacts with the steering wheel for drivers (and dashboard area for front seat passengers), cushion these impacts, and help reduce seat belt loadings. In addition, full size airbags would improved protection in frontal crashes for unrestrained front seat occupants.

Further evaluation is necessary at this time to establish the cost effectiveness of airbags as a secondary unit, bearing in mind the possible improvements in outcome from other additions such as padded steering wheels and belt tensioners and clamps. In the meantime, however, manufacturers should be encouraged to make these units available as an option for Australian models which have an equivalent model overseas with airbags fitted as standard equipment.

STEERING COLUMN MOVEMENT - ADR10/01 specifies acceptable longitudinal steering column movement requirements for vehicles involved in a frontal barrier crash. However, there is no specification of acceptable lateral and vertical column movements. As there were many instances of severe injury from contact with the wheel and column which could be directly attributed to movement in these two additional planes, it would be desirable to include acceptable levels of lateral and vertical, as well as longitudinal movements, in this standard.

INSTRUMENT PANEL - There were numerous instances of severe contacts between front seat occupants and the instrument panel in frontal crashes, involving both the upper and lower surfaces. Intrusions into occupant spaces that resulted in occupant injury need to be reduced as a matter of priority.

Furthermore, plastic materials used in these structures were aiding injury by shattering into sharp jagged segments, and lower attachments (radio components, switches, fuses, etc.) were targets for forward moving body components such as knees and lower limbs.

There is considerable scope for better padding, sheet metal rather than rigid plastic structures, and no protrusions to minimize these injuries. The safety consequences of flimsy lower parcel shelves also need to be addressed.

KNEE BOLSTERS - Reduced contacts with the lower instrument panel and minimizing the effects of submarining have been achieved overseas by fitting knee bolsters to cars at knee height and in front of the lower instrument panel across the full width of the vehicle. On the evidence collected here, these devices would seem to be applicable for Australian vehicles as well.

WINDSCREENS & HEADER SURFACES - Even with the high rates of seat belt wearing in Australian vehicles, front seat occupants (notably passengers) had frequent contacts with the windscreen and header surfaces. In addition, A-pillars were also involved in many contacts, albeit at a lesser rate.

This suggests the need for additional interior padding on these support surfaces to cushion these impacts, for plastic laminates on the interior of windscreens to reduce the instances of lacerations, and for structural improvements to minimise pillar and header rail intrusions. The safety consequences of low rake angles in some vehicles also needs to be assessed further.

FLOOR & TOE PAN - The floor and toe pan of the vehicle was associated with injury to front seat occupants in frontal crashes in 25 percent of cases, with intrusions in only 7 percent of cases. These injuries could be alleviated to some degree by better restraint systems, improved seat design, and possibly knee bolsters to prevent downward jarring injuries and submarining.

However, improved vehicle design of the floor and toe pan area and their associated structures to minimize the number and severity of intrusions would also be advantageous here. The possibility of structural changes to reduce the frequency or extent of front wheel intrusions should also be investigated.

BARRIER CRASH TEST - Some of the suggested improvements detailed above could be achieved if cars were required to meet the performance requirements of the frontal barrier crash test in FMVSS 208 (without the passive restraint requirement, ie., allowing the seat belt to be fastened manually). This standard assesses the vehicle performance based on injury criteria measured on an instrumented dummy during a crash test.

While there is some criticism of the fact that FMVSS 208 does not include an offset configuration, nevertheless, it could be argued that this existing full frontal crash requirement is better than no standard at all. Naturally, any consideration of an Australian equivalent should also address the matter of full versus offset frontal configurations and whether 48km/h is a suitable impact speed for crash protection in the longer term.

1. INTRODUCTION

Motor vehicle occupant protection has received considerable attention in this country over the last two decades. Seat belts, improved vehicle padding, head restraints and door beams have all contributed to some degree in reducing the number and severity of vehicle occupant casualties. Yet, vehicle occupant casualties are still the single largest road safety problem in this country. Roughly **two** out of every **three** persons killed or injured on the road each year are occupants of motor vehicles (Transport and Communications, 1988).

Passenger cars world-wide are currently undergoing substantial changes in design. Uni-body structure and front-wheel drive is becoming more common amongst new vehicles (American estimates for this design concept are as high as 90 percent for their current vehicles, Fildes, 1988). In addition, small cars with a body weight of less than 1100kg are also becoming more prevalent (1985 census data shows that 45 percent of new car sales were less than 1100kg compared to 42 percent in the previous 1980 census).

Seat belt wearing is also well stablised at high levels in the front seat of Australian passenger cars (94 percent) although less for rear seat passengers (80 percent, Ove Arup 1990).

Given the relative dearth of recent local research in this area, it is timely then to review the level of safety of modern passenger cars to see if the current level of occupant protection is optimal for all vehicle occupants. In particular, it would be useful to examine whether occupants of front-wheel drive vehicles are as well protected as those in conventional rear-wheel drives, given that most vehicle design standards were introduced during the reign of these more conventional transmission designs, and what improvements are necessary in seat belt design.

1.1 PROJECT OBJECTIVES

In April 1989, the Federal Office of Road Safety commissioned the Monash University Accident Research Centre (MUARC) to undertake a study into occupant protection of modern passenger cars in Australia.

The objective of this study, specified by the Federal Office of Road Safety, was to examine the nature of occupant injuries, as well as vehicle and crash relationships, to the occupants of post-1982 passenger cars involved in road crashes. An attempt was to be made to identify specific vehicle characteristics and design features that might be addressed to offer improved occupant protection for occupants of future vehicles.

It was understood that the results of this study were to assist the Federal Office of Road Safety in the future development of initiatives to improve vehicle occupant protection in Australia.

1.2 STUDY METHODOLOGY

The project design included a number of different research tasks, including a review of Australian and overseas occupant safety literature, a mass data analysis of the Transport Accident Commission's compensation data base (enhanced with additional information from the Victorian police accident data and the Victorian vehicle registry), and a detailed examination of a number of crashed vehicles and their occupants to assess the safety performance of these vehicles and which vehicle components are commonly involved in injuries to occupants for a range of different vehicle and crash configurations.

The various tasks and the methods used for each of these components of the research program is described further on in relevant sections of the report.

This report describes the findings of the study, including an overview of vehicle types and components likely to be over-involved in occupant injuries and recommendations for further research and development in improving the level of safety for Australian vehicle occupants.

2. LITERATURE REVIEW

The review of the literature was intended to include research publications on current occupant safety issues involving present day vehicles and relevant crash configurations. The overriding considerations in this review were what injuries are today's vehicle occupants incurring from front, side, rear and rollover collisions and what vehicle structures or components are currently involved in these injuries.

2.1 LITERATURE REVIEW OBJECTIVES & CONSTRAINTS

A number of constraints were necessary in selecting what literature was relevant for this project to keep the task manageable and meaningful.

First, recent literature was consulted (generally, 1982 and later) involving main-stream occupant safety literature sources. Typical literature sources included the International Council on Biokinetics of Impacts (IRCOBI) conference proceedings, the Association for the Advancement of Automotive Medicine (AAAM) conference proceedings, the STAPP Car Crash conference proceedings, the Experimental Safety Vehicle technical conference proceedings, Society of Automotive Engineers (SAE) technical papers, International Road Research Documentation (IRRD), LASOR, and MEDLINE databases, periodicals such as Injury, Journal of Trauma, and Accident Analysis and Prevention, and miscellaneous specific relevant sources (eg, Transport and Road Research Laboratory (TRRL) reports).

Second, the review was restricted to relevant occupant safety issues for this project. Consequently, mathematical modeling and crash simulation materials were mostly excluded from the review because they do not predominantly deal with injury/component interactions in real world crashes. Similarly, publications concerned with research on human tolerance to impact (eg, head biomechanics), while important in setting maximum forces or decelerations for vehicle design, were not directly useful here and, hence, not considered.

Finally, as child restraints and baby bassinets are not supplied as original equipment in Australian cars, literature describing their crashworthiness was also excluded from this study.

2.2 DETAILED BIBLIOGRAPHY

A detailed bibliography was subsequently compiled using INMAGIC software, a computerised library database structure with search and display features to store and access the references to be gathered for the project. A set of relevant keywords, based on the IRRD International Thesaurus (1985), was also developed for inputting and accessing these publications. To date, there are 814 references listed in the INMAGIC database and there are plans to continue to maintain this bibliography as a relevant up-to-date literature source.

2.3 CURRENT ISSUES IN OCCUPANT PROTECTION

A number of current issues in occupant protection have been identified from this bibliography and are described and discussed in some detail below.

2.3.1 The Need For Restraint System Improvement

The safety belt (in the form of the three-point lap-sash arrangement) is generally accepted as the most effective single countermeasure for occupant crash protection. It is highly effective, as a device, in preventing death or serious injury in frontal collisions for both drivers and front seat passengers.

It is also highly effective against ejection. In rollover its effectiveness against ejection has been estimated as 82% (Evans, 1988). According to Otte, Suren, Appel and Nehmzow (1984) the belt has significant benefits in side impacts. An estimate of the overall effectiveness in crashes of all types is that of Malliaris, Hitchcock and Hedlund (1982) based on a large collection of accidents. They estimated 53% effectiveness against serious or fatal injury. Malliaris and Digges (1987) later estimated the fatality reduction for drivers as 50%, for front seat passengers as 40% (20% less for each by lap belt only) and for rear passengers as 15-25%. Ejection, they estimated, is reduced by 70% to 80%.

The chief limitation of the belt is that it is a so-called "active" device, that is, it depends on the active cooperation of the occupant to put it on and put it on correctly. Legislation making belt use compulsory has been successful in raising wearing-rates of front seat occupants to the vicinity of 90% in a number of countries. In others, the rate has not risen as high due, in part, to lack of enforcement and to many exemptions. Comfort is thought to be a factor in the wearing rate (Zeigler, 1982). Another approach to achieving more frequent wearing is through "automatic belts", to be mentioned later.

Many of the fatal or serious injuries to front seat belt-wearers are incurred through crushing of, or intrusion into the occupied compartment (Henderson, Vazey, Herbert and Stott, 1977; Mackay 1977). Other injuries occur because body movement takes place even in belted occupants. In particular, it is apparently not possible to prevent the driver's head and face contacting the steering wheel or even the A-pillar in off-centre impacts. Face-to-wheel impacts are discussed later under "steering assembly". Knee contact with the instrument panel is not uncommon.

One form of body motion, "submarining", consists of the body slipping under the lap belt, so that the load is applied to the abdomen. In its most extreme, and rare form, termed "classical submarining" by Gallup, St-Laurent and Newman (1982), the sash may come to engage the wearer's chin.

INJURIES ASSOCIATED WITH BELTS It is convenient to consider first the substantial, mostly medical, literature in which injuries of many kinds are associated with belt wearing. The injuries include those listed in Table 2.1. Means of making the restraint system more effective will be discussed later. It is first necessary to examine situations in which the belt is said to have "caused" injuries. The concept of causation implies that the subject injury would not have occurred or would have been much less severe had no belt been worn.

TABLE 2.1
INJURIES ASSOCIATED WITH BELT WEARING

INJURY
. cervical & other spinal injuries
. rib fractures
. sternal fractures
. pulmonary injury
. cardiac injury
. diaphragmatic hernia
. abdominal wall hernia
. abdominal wall haematoma
. intra-abdominal injuries - gastro-intestinal contusion or perforation, mesenteric tear or haematoma
. liver injury
. spleen injury
. pancreas injury
. aortic or major arterial injury
. retroperitoneal haematoma
. urinary bladder injury
. breast or prosthetic injury

Source: *Simson (1989).*

The great majority of these reports are clinical or pathological descriptions in which little or no information is given of the nature of the collision, the seated position of the occupant, the condition of the car, seats or belts. The connection between injury and belt is inferential. The rate of occurrence per 1000 injured occupants is generally not stated nor calculable. It should be noted, too, that in the medical literature cases are sometimes reported, not because they are common or instructive, but because they are rare.

Nyquist and Kennedy (1987) have cautioned against inferring injury mechanisms from clinical observations only. "Descriptions of what happened at the accident scene and/or within the vehicle by such third parties as emergency room physicians ... must be factored into the analysis with extreme caution. Hospital personnel have recorded that an ejected occupant was a pedestrian struck by the vehicle."

SPINAL INJURY Cameron and Nelson (1977) compared the injuries of belted and unbelted occupants in Victorian accidents which took place in 1971 and 1972, at a time when only 13.5% of static, three-point belts were being correctly worn (Andreassend 1972). Injuries were generally less frequent in belted occupants with these exceptions: "whiplash", transient spinal cord damage, thigh fracture and, for those aged over-50, liver and spleen damage. Burke (1973) found spinal injury to be less frequent and less severe in belted occupants admitted to a spinal unit after the belt wearing law was enacted in Victoria. Maag, Desjardins, Bourbeau and Laberge-Nadeau (1990), in a study based on enhanced insurance company records, found more "neck-sprains" among belted front-seat occupants but fewer severe neck injuries (specifically fewer fractures). McPherson and Oversley (1977) and Mackay (1977) report no spine or head injury in belted occupants in the absence of head contact.

Yoganandan, Pintar, Haffner, Jentzen, Maimar, Weinshel, Larson, Nichols and Sances (1989), in their review of National Accident Sample Survey (NASS) data, showed a large reduction in serious spinal injury in restrained occupants and emphasised rollover as a cause of spinal injury. The more severe injuries (AIS 3+) had a high association with head and face injury. The level of cervical spinal injury had a close association with fatality. A summary of various data sources yielded the following - upper cord (0-A joint to C2) 79%, lower cord (C3 to C7) 25%.

Recently Cain, Ryan, Fraser, Potter, McLean, McCaul and Simpson (1989) have made a complete examination of cervical spine injuries in road accidents in South Australia. Three hundred and twenty five (86 of them fatal) vehicle occupants were recorded for a six year period. These were derived from 4.7 million vehicle-years and 49,424 vehicle-occupant casualties (Road Accidents in South Australia, 1986). Cain, Simpson, Ryan, Manock and James (1989) subsequently checked fatally injured road casualties, from a twelve month period, for neck injuries, using lateral x-rays, and showed that many fractures were not revealed by regular post-mortem examination, especially in the upper cervical spine.

By appropriate factoring of the six-year data, fatality percentages can be derived as follows: atlanto-occipital articulation to C2, 47.9%; C3 to C7, 20.6%. These are in general agreement with the rates of Yoganandan et al., though the two sets are not directly comparable as the latter refer to cases all with neurological injury. The results of Cain et al., being derived from compatible sets of high quality data, must be considered the better estimates.

Many clinical and pathological reports (eg Tolonen, Kiviluoto, Santavirta and Slatis, 1984) concern fracture of the high cervical spine, vertebrae Cl, C2, C3. One paper (Lesoin, Thomas, Lozes, Villette and Jomin, 1985), listing 33 cases, has the arresting title, "Has the seat belt replaced the hangman's noose". The remarks of Lesoin et al. appear in a brief letter to a periodical and it is not possible to decide whether the observed frequencies can reasonably be attributed to increased belt-wearing.

On the other hand, Daffner, Deeb, Lupetin and Rothfus (1988), reporting on high speed impact injuries, record nine "hangman's" type fractures, all of which were in unrestrained occupants. Hadley, Sonntag, Grahm, Masferrer and Browner (1986), reviewing cases of cervical spinal fractures at a spinal unit, found 73 cases of C2 fractures, one quarter of them "hangman's fracture". Of 30 cases for whom there were complete medical records, only one was wearing a seat belt.

One case of cervical spine fracture in a belted driver was reported in detail by Sumchai, Eliastam and Werner (1988). The driver of a "pickup truck" was an obese woman using a static three-point belt. A severe sideways collision took place with a truck. The pickup driver was found partly ejected through the open driver's side door, with the sash under her chin. This was evidently a case of classical submarining and it is likely (because of the driver's habits and the static belt) that the belt was not properly adjusted or located.

Another case is reported by Gogler, Athanasiadis and Adomeit (1979) in which the fatal injury of a 19 year old female front seat passenger in a car (which made a frontal impact with a tree) was dislocation of the atlanto-occipital joint. The male driver (with a dislocated hip, rib fractures and a haemopneumothorax) survived. Both occupants wore emergency-locking retractor (ELR)

3-point belts. In this case the impact was off-centre causing deformation of the compartment. Both occupants slid forward beneath their belts so that their knees struck the lower dashboard. The reconstruction of the passenger's head movement is complex, but there was a lateral impact of the right side of the forehead against the dashboard or window frame. Thus it is doubtful if the belt can be said to have "caused" the dislocation.

Skold and Voigt (1977) examined 34 belted occupants with fatal cervical spinal injuries from frontal collisions. The spinal injuries were considered to be due to sliding under the belt in those wearing "shoulder belts" only. In those wearing lap/shoulder belts, the cervical injury resulted from impact of the head against the internal parts of the car.

On the other hand, Huelke and Nusholz (1986) summarise several sled studies in which unembalmed cadavers in three-point belts were subjected to high but not intolerable accelerations (13 to 21g). A number of cervical fractures were recorded. One of the cited studies (Jones, Bean and Sweeney, 1978), on rear impacts, was conducted at relatively low speed, but five cadavers had injuries to the cervical spine. As spine fractures are rare in rear end collisions, there may be some degree of lack of biofidelity in these cadaver tests. Alternatively, cervical spine fractures, without head contact, may occur in properly restrained occupants only at the upper end of the range of impact severity.

At a lower level of severity, Larder, Twiss and Mackay (1985) report on a subset of occupants (93% belt wearers) from an in-depth investigation, who were recorded as having a "neck injury". Most of the impacts were frontal and the crashes ranged from fatal to property damage. In two-thirds of cases there was no head contact. Almost 40% had neck pain for at least a month. As noted above, Maag et al (1990) as well as Bunketorp, Romanus and Kroon (1985) all found that belt wearing increased the risk of "neck-sprains".

In short, for many of the injuries reported as associated with belt wearing, the injuries should perhaps be regarded not as injuries caused by the belt, but as injuries against which the belt has failed to protect - for example, by permitting body movement leading to contact with the car's interior and face impact with the steering wheel.

In two classes of injury, however, the effect of the belt may be more direct - thoracic and abdominal injuries.

THORACIC INJURY The bony skeleton of the front of the chest, and the clavicle, are loaded directly by the sash and there is a progressive severity of damage (Mackay, 1977): bruising, fracture of a single rib, clavicle, sternum and finally, multiple ribs with increasing displacement. In severe and fatal belted cases, 40% of this kind of injury is due to crushing of the compartment (Henderson & Wylie, 1973). Sternal fracture occurs also in unbelted occupants (Wocjik, 1988).

From an examination of 2097 vehicle occupant casualties, Otremski, Wilde, Marsh, McLardy Smith and Newman (1990) conclude that the incidence of sternal fractures (in observed casualties) had increased since belt wearing became common (3.7% in their series, compared with 0.44% in 1962). Sternal fracture had positive association with visceral chest injury and abdominal injury but a negative association with head injury, so that there is a tradeoff between avoiding head injury and sustaining (generally uncomplicated) sternal fracture. These data confirm the strong association between age and sternal fracture.

Bone strength in adults is inversely related to age, so a safe sash load on a driver aged 20 may cause fractures in one aged 60. It will appear later that load on the ribs and sternum can be reduced by any one or a combination of these measures: a load limiter in the sash, a belt pretensioner, an air bag or a knee bolster.

Mackay also states that "the internal contents of the thorax are not seriously damaged due to deceleration on the belt per se". In comparing 200 matched accident pairs (with belted and unbelted occupants) Hartemann, Thomas, Henry, Foret-Bruno, Faverjon, Tarriere, Got and Patel (1977) comment that the thorax is "often less severely damaged in those wearing seat belts than in those who do not".

Mackay's view has some support from Arajarvi's (1988) analysis of 280 cases of chest injury (207 fatal and 73 non-fatal) from 3468 fatal traffic accidents in Finland where there is a high belt-wearing rate. Aortic rupture occurred in 37% and heart contusion or rupture in 34%. Most had lung contusions. Impact with the steering wheel was the most important cause of these injuries. The belt was adjudged the cause in 50 cases, mostly in the non-fatal group. Since the late fifties, chest injuries as a cause of death in car crashes in Finland have declined from 40% to 25%.

Again, aortic rupture occurs in unbelted occupants. Arajarvi, Santavirta and Tolonen (1989) reported 72 aortic ruptures in non-belt-wearers. For relevant information on fatally-injured unrestrained occupants in Australia, it is necessary to go back to the sixties: Tonge, O'Reilly, Davison and Johnston (1972) found 7.4% of drivers and 8.1% of passengers to have injuries of the aorta.

An injury not due to direct loading can arise if the upper body of the occupant rolls out of the sash. This mechanism, reproduced in cadavers, is stated by Miniaci and McLaren (1989) to cause wedge compression of thoraco-lumbar vertebrae on the side opposite the restrained shoulder. It is not clear whether this occurs in oblique impacts or is associated with a misplaced buckle.

ABDOMINAL INJURY There remains the substantial class of abdominal injury. An early report was that of Kulowski and Rost (1956). In these cases the injury was usually associated with bruising and abrasion of the abdominal wall, indicating that the lap belt had failed to engage the pelvis in the crash sequence.

The injuries are contusion, laceration or rupture of liver, spleen, jejunum, ileum, colon and associated mesenteries. Sometimes the damage to the intestinal tract is associated with fracture of the lumbar spine (Appleby and Nagy, 1989; Winton, Girotti, Manley and Sterns, 1985). Similar injuries occur in the absence of belt use, due to impacts with the steering wheel or instrument panel (Tscherne and Otte, 1985) or other parts of the car (Arajarvi, Santavirta and Tolonen, 1987). Tscherne and Otte consider that "submarine movements", due to incorrect belt fitting, are necessary for intra-abdominal injury. This operated in 4.6% of belted, injured front seat occupants; 1.2% had small bowel injury. In the abdominal injury series of Arajarvi et al, the belt caused the injury in 140 cases, but no belt was worn in 110 cases.

In 1972, Ryan and Baldwin had shown, by inspecting the vehicle and measuring the length of the (static) belt, that injury to the colon was associated with loose belts and malposition of the buckle. Wearing the sash under the arm is a special case of belt misuse. States, Huelke, Dance and Green (1987) describe six fatal cases of underarm belts with injuries to the viscera, diaphragm, aorta and spine.

The clinical origin of most papers on abdominal injury, in which the cases cannot be related to a defined population, does not permit an estimate of the size of the problem. Garrett and Braunstein (1962), who coined the expression "seat belt syndrome", analysed accidents from the Cornell Crash Injury Research files in which at least one occupant was wearing a belt - in this series, lap belts. 944 of 3325 belt wearers were injured and of these: 7 had reported or possible intra-abdominal injuries, 7 had pelvic injuries, and 12 had lumbar spine injuries. In only 7 were there contusions on the hips or abdomen (4 internal, 3 pelvic). In many of these cases the crash had unusual features such as impact on the seat back by an unrestrained occupant. It should be mentioned here that, of the eleven cases of serious seat belt injury reported by Henderson et al (1977), in five the occupant's seat was struck from behind by an unrestrained rear seat occupant. Other authors report similar circumstances, for example Dalmotas (1980) and Lowenhielm and Krantz (1984).

Leung, Tarriere, Lestrelin, Hureau, Got, Guillop and Patel (1982) found that 3.8% of belted occupants in frontal collisions with injuries of MAIS 3 or more had injuries to the abdomen or torso-lumbar spine. This rate was halved in those with ELR belts (which have been standard equipment in Australia for many years). The proportion with submarine injuries was strongly related to delta-V.

The small percentages of abdominal trauma referred to by Tscherne and Otte noted above, Arajarvi's 1.2% of occupants in 3564 fatal accidents and DeRosa and Larsonneur's (1984) 3% with an Abbreviated Injury Score (AIS) of 3 are in contrast to the variable percentages in the clinical series. For example, Appleby and Nagy, from a three year collection of 562 hospital road trauma cases, identified 126 as having worn belts. Twenty-four of them (19%) had gastro-intestinal injuries and seven had major lumbar spine injuries, whereas Christophi, McDermott, McVey and Hughes (1985) found only 32 (0.8%) with injuries to the jejunum and ileum among 3870 hospital admissions in Melbourne.

The matter of the incidence of intra-abdominal injuries can perhaps be epitomised by the analysis,by Ryan and Raggazon (1979) of records of car occupants admitted to a single hospital in Melbourne over periods seven years before and after the enactment of the belt-wearing law.

Abdominal case frequencies were slightly more in the first period than the second (2.7% and 2.1% of occupant admissions), but in the after-law period, gastro-intestinal and diaphragm injuries were significantly more frequent and liver injuries less frequent. Table 2.2 is taken from their paper.

TABLE 2.2
PERCENTAGE OF INJURIES REPORTED IN A MELBOURNE HOSPITAL BEFORE AND AFTER COMPULSORY SEAT BELT LEGISLATION

PERIOD	N	LIVER	SPLEEN	KIDNEY	GIT	DIAGPHRAM
1964-70	81	26%	27%	35%	10%	1%
1971-77	70	11%	30%	33%	19%	13%

Source: *Ryan and Raggazon (1979).*

It appears, therefore, that the incidence of abdominal injuries is rather low in all occupant casualties, but this incidence factored into many crashes provides the case frequencies observed in clinical studies. Thus belt injury to the abdomen undoubtedly takes place and is serious in nature. The mechanism involves the lap belt being located over the abdomen before the crash or riding over the iliac crest on to the abdomen as the belt is loaded.

Gallup, Newman, Van Humbeck and Woods (1982) cite a Canadian study where an association was shown between abdominal injury and season: in the summer the injuries were mostly minor (skin abrasions) and in the winter, when thick clothes were worn, mostly major, perhaps because the thick clothing tended to prevent proper lap belt positioning. Gallup et al and Walz, Niederer, Zollinger and Renfer (1977) considered that the injury mechanism is attributable to a shallow belt angle and too compliant a seat. In an in-depth study, Dalmotas (1980) reported on a subset of 314 fully restrained occupants who sustained at least one injury of AIS 2 or more. He found that driver injuries to the shoulder/chest and pelvic/abdomen regions were associated with direct contact with the steering wheel or interior side surfaces; passenger injuries were unlikely to be associated with the belt itself. Abdominal injuries accounted for 11.2% of injuries in the sample.

While "classical" submarining may be rare, as Gallup et al suggested, a mechanism by which the pelvis slips under the belt has been proposed by Adomeit and Heger (1975). This mechanism will be reviewed later but, in brief, insufficient friction from the seat cushion permits the pelvis to rotate forwards and upwards (seen from the right side, anticlockwise). This disengages the belt and the bending moment at the lumbar spine provides the mechanism for lumbar spine fractures.

From this evidence, it might be cautiously generalised that:

- though there are many reports of various injuries associated with belt wearing, the same types of injury occur also in non-wearers, sometimes with greater incidence (belts reduce the risk of cervical spine fractures and spinal injuries generally but increase the risk of a minor neck injury);
- cervical spine injuries are mostly associated with head contacts and only rarely with the belt, in which cases classical submarining is the likely mechanism;
- thoracic injuries at the severity level of rib and sternal fractures can be caused by the belt loading of the skeleton, but intrathoracic injuries are usually due to impacts with the vehicle interior, crushing or penetration of the occupied space; and
- injury to the abdominal viscera and to the lumbar spine is due to displaced, loose or poorly positioned lap belts, or to pelvic rotation associated with unsatisfactory belt geometry or seat design, or to impact loading of the front seat by unrestrained rear passengers.

It seems that the safety belt (incorporating upper body restraint) is a remarkably effective device when the frequency of inadvertent or deliberate misuse is considered, but it is also evident that it is capable of more development:

. to improve the overall effectiveness of the belt;

. to reduce body and head movement and consequent secondary impacts;

. to reduce or prevent abdominal and lumbar spine injuries;

. to limit contact pressure to reduce or prevent chest injuries.

The direction of impact is directly or obliquely ahead in more than half of crashes, so frontal impact deserves primary examination.

2.3.2 Frontal Impacts

Frontal impacts (i.e. those in which the resultant force acts more or less frontally) constitute a majority of all injury-producing impacts. Contact with steering wheel, instrument panel (dashboard, fascia) and other structures in front of the front seat occupants is the common mechanism of injury. The relative frequency of these impacts is given by Jones (1982) from a series of 1100 in depth investigations and is summarised in Table 2.3.

Countermeasures mostly applied against injury from these causes include the regular or "manual" seat belt, automatic belts, knee bolsters, the air bag, modified steering assembly, treatment of instrument panels and other surfaces, and windscreen glass with non-lacerative properties.

TABLE 2.3
INJURY VEHICLE CONTACTS FROM FRONTAL COLLISIONS

VEHICLE COMPONENT	DRIVERS UNBELTED	DRIVERS BELTED	FRONT PASSENGERS UNBELTED	FRONT PASSENGERS BELTED
1. windscreen	21.8%	9.0%	33.1%	4.6%
2. steering assy	26.3%	20.5%		
3. instrument panel & general front	20.7%	16.4%	32.8%	28.0%
4. W'screen header	3.1%	2.1%	4.2%	0%
5. A-pillar	2.0%	1.9%	1.4%	1.3%

Source: *abridged from Jones (1982).*

Shortcomings of belts - the standard three-point belt with an emergency locking retractor - are:

. Inability to restrain the head, which flexes sharply, and to a lesser extent, the torso itself. For the driver this leads to abdomen, chest and head contact with the steering assembly.

. Poor belt fit exaggerates the above problem and leads to damage to ribs, sternum and abdominal viscera. In the extreme case, the body may slide under the belt - "submarining" - with injuries as far up the body as the cervical spine.

. Even in the absence of poor fit, local pressure from the sash may cause clavicular, rib and sternal fractures, particularly in older occupants.

. Inappropriate location of the sash guide or anchor point causes discomfort (so discouraging belt wearing) and may cause injury to neck structures (for example, Weimann, Rumpl and Flora, 1988; Pedersen and Jansen, 1979).

SEAT, BELT & BODY GEOMETRY Holt and Stott (1976) pointed out with regard to the pelvis that "the region which [it is intended] transmits belt loads is obscured by musculature and fat in the lower abdomen and thighs leaving a small area on each side of the body [to] sustain the lapstrap forces" (see Figure 2.1).

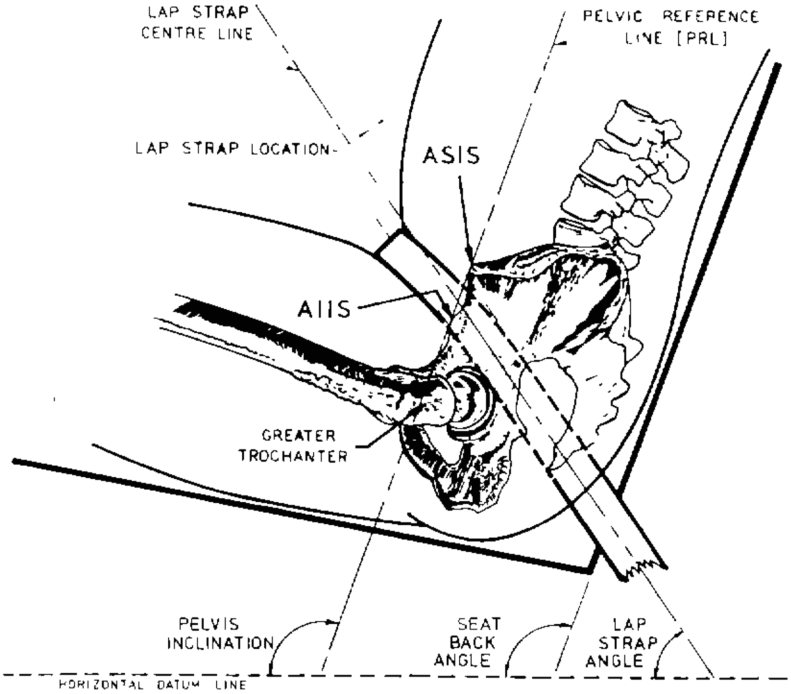

Figure 2.1 *Lap strap loading areas (from Holt and Stott, 1976)*

By taking lateral x-rays of volunteers, they showed that their "pelvic reference line", from the anterior superior iliac spine (ASIS) to the anterior inferior, is approximately parallel to the backrest. The relation of the pelvis and the pelvic reference line to the belt and body surface, shown in Figure 2.2, illustrates the problem of achieving good lap belt fit.

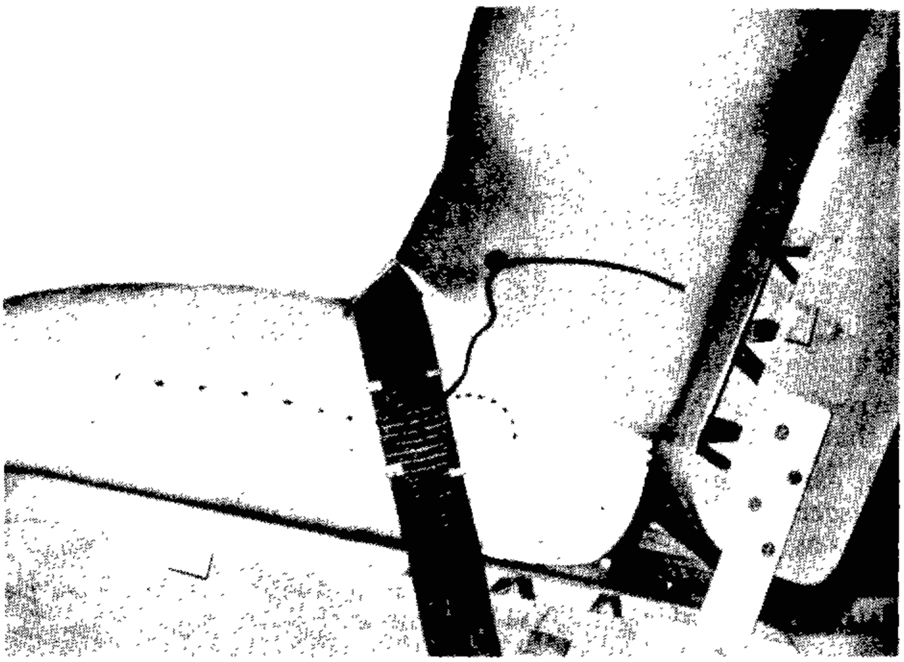

Figure 2.2 ***Relation between a properly adjusted belt and the bony outline of the pelvis, derived from a lateral X-ray superimposed on the corresponding photograph (from Holt and Stott, 1976)***

Evidently, to prevent the belt riding up over the pelvis, the line of the lap belt, viewed from the side, should intersect the pelvic reference line at an angle substantially less than 90 degrees. This is difficult to achieve on the forward part of the seat adjustment range if the lap belt is anchored to the floor. (Holt and Stott's paper should be consulted in the original by those concerned with belt geometry or the relevant ADRs.)

Satisfactory seat belt geometry requires the lapstrap to be steeply inclined (60deg or more to the horizontal) when viewed from the side (Holt and Stott, 1976). According to DeRosa and Larsonneur (1984), a steeper belt angle is required as the horizontal splay of the lap belt increases, a relationship described mathematically by Leung at al (1982).

A suitable belt angle can be achieved for all adjustment positions by anchoring the strap to the seat structure (Rattenbury, Gloyns, Hayes and Griffiths, 1979). This mounting requires extra strength in the seat structure and seat to floor attachment, but Gallup, Newman, Van Humbeck and Woods (1984) were able to make a satisfactory kit modification for two then current U.S. models. Newman, Woods, Garland and Van Humbeck (1984) devised a submarining test method for belt-plus-seat installations.

Wells, Norman, Bishop and Ranney (1986) found, from a questionnaire survey, that half of lap belts were malpositioned in a normal sitting posture. On an experimental rig simulating seven car models, more than half the belts were maladjusted even when the experimenter adjusted the belts. "The subjects did not, in general, know how to adjust a seat belt to obtain maximal protection." There was a substantial improvement in fit with increasing lap belt angle. A belt angle of 73deg was needed for acceptable fit for 95% of subjects. Slouching frequently displaced the belt upwards. (This paper contains a summary of other studies on lap belt fit). Slouched posture has become perpetuated by its incorporation into seat design via the SAE seating template, according to Reynolds and Hubbard (1986).

Lumbar support in the backrest not only improves comfort but rotates the pelvis forwards (clockwise, viewed from the right), moving the hip-joint rearward and downwards from the current H-point location. As will be seen, this is a desirable effect.

Sled tests by Rouhana, Horsch and Kroell (1989), using dummies, showed that belt slipping from the pelvis was associated with rotation of the pelvis (anticlockwise, viewed from the right). Shortening of the buckle strap length increased the submarine threshold (the delta-V at which slippage occurred). When the lap belt slipped off the pelvis on one side only it was always on the buckle side. A fifth percentile female dummy submarined at a lower threshold than a Hybrid III dummy.

Horsch and Hering (1989) showed that, with their rig, there was a critical angle between pelvis and belt for submarining, which was related to velocity. Evidently the steeper the belt, the more pelvis rotation that can be tolerated without submarining, for a given speed. (Their belt to pelvis angle is specific to a marker on the dummy pelvis used.)

In dynamic tests the belt will slip at a smaller angle than in static tests. During acceleration, the dummy (and presumably the occupant's body) moves downwards and forwards and so makes the belt angle more shallow. The pelvis rotates anticlockwise, so reducing the pelvis to belt angle. Thus the static geometry of the belt must provide margin for both motions. This study provides some validation for Adomeit's mechanism, noted later.

It should be noted that in the running loop lap-sash combination typical of Australian practice, from the viewpoint of lap belt angle, the geometrical inboard anchor point is not the buckle, but the point on the buckle tongue at which the sash is reflected to become the lap belt.

If checking the belt fit in a new model is delayed until a body shell or seating buck is available, it may be too late for critical dimensions to be changed. A computer program (BELTFIT) has been developed for predicting whether a proposed belt layout will suit wearers, specifically 95% male, 50% male and 5% female (Sheppard, 1982). It applies dynamic programming to predicting the shortest path across the irregular geometric surface comprising the shoulder and chest.

A number of car models have one or both lap straps mounted on the seats. An "integrated" seat has been announced that has all three anchor points on the seat, the sash mounting being adjustable and linked to the head restraint (Harbel, Ritzl, and Eichinger, 1989).

RESTRAINT IMPROVEMENT Even with good geometry and the belt well positioned, forward movement of the body and forward and downward movement of the head takes place. This effect is due to:

1. compression of clothing and soft tissues,

2. webbing stretch (there is a substantial length of webbing from buckle to reel),
3. momentary delay in activation of the inertia lock on the reel, and
4. spool out of webbing coiled on the reel.

Not only do these processes permit body movement but they cause a relatively slower increase in tension in the belt and consequently a larger than necessary peak tension in the final part of the loading sequence (Adomeit & Balser, 1987). The driver is most affected since body contact with the steering assembly and head and face contact with the wheel cannot usually be avoided in more severe impacts.

Two remedies are proposed (Mitzkus & Eyrainer, 1984). The first is a belt tensioning device, which operates before the belt-loading sequence would otherwise begin. One type of pretensioner uses as a power source a pyrotechnic with electronic sensing, another uses a pretensioned spring with a mechanical trigger. The pretensioner largely neutralises three of the four factors above and decreases the fourth (belt stretch). Pretensioners are being fitted to several car makes at present. It should be noted that the time of activation is critical to the effectiveness of the device - it should not be more than 10ms.

An alternative device, entirely mechanical in operation, which is reported to approach closely the pretensioner in activation time and early belt loading, is the webbing clamp (Mitzkus and Eyrainer, 1984; Adomeit and Balser). It can be located on the D-ring or next to the inertia reel, where it could be made vehicle sensitive. It would be less effective than the pretensioner in dealing with clothing and soft tissue compression.

In sled tests, both devices permitted less forward head movement (by 60 to 65mm) than a static three-point belt (Mitzkus and Eyrainer). Both devices cause earlier loading and lower (but more prolonged) belt forces and consequently lower forces on the chest.

This is an advantage since, with current standards as has been noted, sternal and other thoracic fractures are apt to occur. Ideally, the belt should have a stiff webbing (low elongation) and a load-limiter. Sarrailhe (1983) demonstrated the effectiveness of a load-limiter in the sash, but its benefit would have to trade off some of the reduced head motion achieved by the pretensioner or belt clamp.

AUTOMATIC BELTS A number of variants of so called passive belt systems (systems not requiring action by the user) have been designed, and in recent years several have been widely installed, for drivers and front seat passengers, in cars for the U.S. market, beginning with 10% of 1987 models. All these devices, with the exception of airbags, are intended to raise the actual wearing rate of restraints. Several arrangements have been subjected to cost- benefit analysis by Graham and Henrion (1988).

One system which was installed in production cars in the seventies was the two-point sash and knee-bolster of the Volkswagen Rabbit, as an alternative to the manual three-point belt. In a series of injury producing crashes reported by Reinfurt and Chi (1981), the automatic system was equally effective as the manual belt as a device, but was used twice as frequently. So that, overall, occupants of automatic Rabbits were 20% to 30% less likely to suffer severe injuries than occupants of Rabbits with three-point belts. In effect, the automatic system had persuaded 25% more Rabbit occupants to accept belts.

Williams, Wells, Lund and Teed (1989) have surveyed wearing rates in large volume production 1987 U.S. cars. The systems comprised combinations of motorized/non-motorized, detachable/non-detachable belts, some with knee bolsters. In all makes except one, automatic belt-wearing rates were higher than manual belt rates. Some automatic rates reached 90%. The objective of the automatic belt was evidently achieved on most models (but with unknown quality of fit), but the wearing rates are not higher than those observed with manual belts in Australia.

Reinfurt, St Cyr and Hunter (1990) surveyed seat belt use by drivers in late model cars and found 79.6% use for automatic belts, 76.3% for regular manual belts and 73.9% for belts in airbag equipped cars. Motorized shoulder belts were used by 94.2% of drivers, but only 28.6% fastened the lap belt.

SEAT FACTORS Besides the design of the restraint system itself, there are other factors that influence the outcome of frontal impacts. These include the seat and belt stiffness which affect the dynamic behaviour of the belt-plus-occupant combination (Igarashi and Atsumi, 1985). It is possible that the seat has been somewhat neglected because of the common use of rigid seats in experimental rigs. A number of authors have drawn attention to the desirability of stiffer seat cushions, in the interests of preventing submarining (for example, Gallup et al, 1982; Holt and Stott, 1976; and Green, German, Gorski and Nowak, 1987).

Adomeit and Heger (1975) and Adomeit (1979) have described the motion of the body, particularly the pelvis, during a frontal acceleration pulse. The lap belt force always acts above the common centre of gravity of the pelvis and femur. This can only be opposed by the reaction of the seat framework through the seat cushion. With a compliant cushion (eg a spring cushion seat) the pelvis rotates anticlockwise (viewed from the right) and the thorax descends. These authors give numerical criteria for maximum changes in torso angle and H-point vertical movement during acceleration. Tests with experimental seats showed that these criteria could be met with a seat consisting of a sheet metal pan and a foam cushion with a large front wedge of stiff energy-absorbing foam.

Note has already been made of the benefit of lumbar support in the seat back for comfort, to prevent slouch and to promote pelvic rotation in the desirable direction (Reynolds and Hubbard, 1986). Culver and Viano (1981) showed, in sled tests, that an experimental seat wing reduced dummy displacements in both lateral and frontal directions for far-side oblique impact angles of 20 to 75deg from frontal. Head excursion was reduced by over 50% for oblique decelerations greater than 45deg. The wing tended to deflect the occupant's motion more frontally.

KNEE BOLSTERS The knee bolster (pad, bar, buffer) which formed part of the Rabbit automatic belt assembly, consists of a suitably deformable part of the lower instrument panel, designed to engage the occupant's knees or upper end of the tibia. The device needs careful design to avoid overloading the femur, but has considerable virtue in controlling lower body motion where the primary restraint is by diagonal belt or air bag. With a three-point belt, it offers the possibility of sharing the restraint forces with the safety belt and the seat, and thereby reducing the load applied by the belt.

REAR SEAT OCCUPANTS The foregoing discussion applies mainly to front seats. Rear seat occupants have less to gain from webbing clamps or pretensioners since the effectiveness (in injury reduction) of belts in the rear seat is about half that in the front (Norin, Carlsson and Korner, 1984, Malliaris and Digges, 1987), presumably because there is less damaging surface for the rear occupant to contact. Unrestrained rear passengers are, however, a substantial threat to front seat occupants (Dejeammes, Nygren and Tingvall, 1986; see also sources already cited: Garrett and Braunstein, 1962; Henderson et al, 1977; Dalmotas, 1980; Lowenhielm and Krantz, 1984).

A recent OECD conference reported that unrestrained rear seat passengers caused about 6% of front seat fatalities (Milne, 1986), however the nature and source of this statement was not cited. The need to improve the geometry is still valid for rear seat occupants to prevent belt-induced injury.

According to Haberl, Eichinger and Wintershoff (1987) the poor acceptance of rear belts can be attributed to comfort and convenience factors ("It is not always clear to which seat each buckle belongs") as well as low perceived safety value. They describe a new design - a reversed shoulder belt geometry. The upper mounting points are inboard, so that the buckle can be placed on the outboard side, well forward and integrated with the seat. Buckling is a one hand operation.

The practice of routing the lap belt between the conventional cushion and backrest militates against proper belt positioning and inserts slack into the system. Laps belts should desirably be routed through slots in the cushion, as described by Haberl et al. The need for stiffer cushions (referred to above) is also applicable.

In a 1980 report, Garth & Herbert concluded that the following improvements were required **in the short term** [emphasis added]:

- increase the minimum lapstrap angle of 25deg in ADR 5B,
- integrated lower anchorages,
- investigate introduction of belt force limiters especially in the shoulder strap,
- investigate introduction of belt pre-tensioners,
- adjustable sash guides and belt tension reducers to increase wearing rate,
- automatic locking retracting lap-sash belts in all rear seating positions,

- strengthened longitudinal seat runners, adjusters and seat backrests, and
- energy absorbing padding in seats and stiffer seat suspension.

Item 6 has already been introduced for Australian cars, except for centre rear seats. The remaining items are all supported in the literature reviewed. Items 2 and 4 have variously been incorporated in a number of cars manufactured overseas.

In summary, needed improvements to belt systems are:

- lap belt anchorages on the seat (with associated strengthening of seat and tracks) so as to permit steeper lap belt angles,
- backrest designed to withstand rear impact loads,
- backrest profile to provide lumbar support,
- stiffer seat cushions, with a ramp or wedge of stiffer material at the front, to act in concert with 1 and 3,
- some adjustability in the upper sash anchor or D-ring, and
- belt pretensioner or webbing clamp.

It will be seen later that the seat may need to meet additional design objectives.

AIR BAGS The prime object in crash protection is to prevent the occupant developing a velocity relative to the interior of the vehicle. If this can be done only partly or not at all - if the restraint system slips, stretches or is not used - the next measure, in sequence, is the interposition of a non-injurious barrier between the occupant and vehicle interior.

The only such device to reach production is the air bag. The bag, made of porous plastic, is stowed on or under the instrument panel or in the steering wheel hub. In the interval between the vehicle making a predetermined change in forward velocity and the first movement of the occupant, the bag is rapidly inflated with gas, interposing itself between the driver and steering wheel or front seat passenger and structures in front. It immediately begins to deflate.

The air bag was devised originally (Clark, 1985) for use in manned spacecraft and passenger aircraft. By 1966, the device had been experimentally tested in cars and school buses.

The timing of inflation is critical and requires some form of electronic sensing and circuitry to fire the inflator, a sodium azide cartridge which produces nitrogen gas. Alternatively, the device may use a mechanical trigger mounted with the inflator in the bag assembly itself (Breed, 1985b). Ludstrom (1974) describes sled tests with air bags on 32 healthy male volunteers, subjected to impacts at speeds up to 48km/h. There were knee buffers and a slack back-up harness was worn, but this never became loaded. "Injuries" were AIS 0 or 1. The first occupant contact was knee to buffer. In earlier sled tests with bags, primates had survived decelerations of 57g compared with fatal injuries with all other restraint systems tested (Kemmerer, Slack, Chute and Hass 1968).

According to Grosch (1985), adding an air bag to a three-point belt does not reduce the chest acceleration, but reduces pressure, by providing extra area, and hence reduces chest deflection. The same is true for face-to-wheel impacts, though the Head Injury Criterion (HIC) may actually be somewhat higher.

There is general agreement that the air bag provides effective protection against injury in frontal and near frontal impacts. In its current form it is much less effective in side impacts, rollovers, and multi-collisions as are seat belts, and not at all effective against ejection.

Though the bag provides protection by itself, for maximum effectiveness it should be supplemented by use of (at least) a lap belt. In a series of accidents (described as more severe frontal crashes) in which the front seat occupants were unrestrained, used three-point (lapsash) belts or were protected by airbags (17% of these also used lap belts), Mohan, Zador, O'Neill and Ginsburg (1976) found the airbag to perform marginally better than the lap sash belt alone, as demonstrated in Table 2.4 from their work. From a series of high speed, fatal accidents, Huelke (1981) made similar estimates of effectiveness which are shown in Table 2.5.

There are individual case reports of successful bag operation. From follow-up of a fleet of 1000 bag-equipped cars, Smith (1977) describes seven of 126 bag deployments all in the same car model but in different crash circumstances. The injuries sustained were less than in matched or estimated comparison accidents. Backaitis and Roberts (1987) followed up almost 6000 airbag-equipped cars in governmental fleets. This yielded 796 crashes and 112 deployments. In non-deployment crashes no-one suffered an injury greater than AIS 1. (Unfortunately for the purposes of the study, 80% of occupants were wearing lap sash belts, so that only 28 occupants were unprotected by belt or bag).

TABLE 2.4
INJURY REDUCTIONS REPORTED FOR SEAT BELTS & AIRBAGS

INJURY REDUCTION	AIRBAG	LAPSASH
average injury severity	66%	55%
likelihood of death	79%	72%

Source: *Mohan, Zador, O'Neill and Ginsburg, 1976.*

TABLE 2.5
ESTIMATES OF RESTRAINT EFFECTIVENESS

RESTRAINT TYPE	FATALITY	SERIOUS INJURY
lap-sash belt (100% use)	32%	64%
airbag (100% deployment)	25%	58%
airbag + lap belt (100% use)	34%	68%
passive shoulder belt (100% use)	28%	58%

Source: *Huelke, 1981.*

There are a number of actual or potential problems with air bags. Special consideration is needed for small cars, in which the acceleration peak is higher than for large cars for the same impact speed and there is less time for deployment (Morris, 1985, Mertz and Marquardt, 1985). Takeda and Kobayashi (1982) emphasise the need to consider the bag at the body design stage. Other writers (for example, Seiffert and Borenius, 1972) agree that the air bag installation for a small car cannot be simply a scaled down version of a large car installation.

For the situation in which the wearing rate of front seat occupants is high, the concept has been developed of an air bag used primarily as a supplementary device for the driver. In this role it protects the driver from injurious wheel contact with the abdomen, chest and especially the face. It also provides useful protection for the unbelted driver. The bag, used in this way, can be of smaller capacity, slower inflation and be triggered at a somewhat higher threshold (18mph instead of 12mph). It presents a simpler installation problem than the regular, large bag in small cars (Mackay, 1990).

Another question concerns the child who may be out of position when in the front seat and may be struck by the bag deploying at high speed. There is no doubt that severe to fatal injury can be caused by this mechanism (Aldman, Anderson and Saxmark 1974; Mertz, Driscoll, Lenox, Nyquist and Weber, 1982). Unrestrained child kinematics under heavy braking have been described by Stalnaker, Klusmeyer, Peel, White, Smith and Mertz (1982).

Montalvo, Bryant and Mertz (1982), using survey data on child riding-positions, estimated that, in U.S.A., per million car-years exposure, there would be 3732 collision-induced bag deployments. In these there would be 149 unrestrained front seat children up to age 4, 51 of whom would be close enough to the instrument panel to risk injury from the bag. Recent Australian survey data (Heiman, 1988) showed that 25% of children (age unspecified) were unrestrained, not necessarily in the front seat, so that the 51 per million car-years of Montalvo et al might translate into 12 or less hazardous exposures in Australia.

According to Zinke (1980) this injury mechanism can be avoided by careful tailoring of the bag shape and its location and manner of deployment. Interestingly, in one of Smith's (1977) accident cases, a child aged three was standing upright in the front seat and was struck by the deploying bag. The child was forced against the upper right windscreen and sustained head lacerations rated AIS 2 severity.

Bag inflation produces a loud report with a peak of about 150dB.

Air bag deployment is slightly more startling than bonnet fly-up, according to Ziperman and Smith (1985) but, in track tests, drivers exposed to unexpected bag inflation, retained good control of the car and could see ahead sufficiently to guide it. It should be noted that these drivers wore ear-muffs. An early study (Nixon 1968, cited by Richter, Stalnaker and Pugh, 1974) concluded that the noise presented no significant risk of hearing damage. Richter et al investigated the effect of a blow on the ear by the wall of the inflating bag, using squirrel monkeys as surrogates. There was a temporary threshold shift but no anatomic or permanent hearing damage.

Disposal of electronically-triggered unfired bags, in cars being scrapped, is discussed by Kirchoff (1984), who suggested that firing the bag by a remote firing system is preferable to removing the bag and returning it to the manufacturer. Environmental consequences are discussed by Partridge, Stewart and Young (1979), but they provide an analytical technique rather than conclusions. Environmental consequences do not appear to be a major problem.

The prolonged history of rule-making about air bags in the United States is described by Rabe (1984). The argument has not been about effectiveness but about cost. Patrick (1975) ranked various systems in this order of effectiveness: three-point "mandatory" belts; "passive" (ie, automatic) three-point belts; airbag with 20% lap belt use; torso belt and knee bolster; and airbag alone. On benefit to cost ratio, and over a ten-year time span, the ranking was: mandatory three-point belt; torso belt plus knee bolster; passive three point belt; airbag with 20% lap belt use and airbag alone. Patrick assumed 80% use of "mandatory belts", a rate much higher than that achieved with current, non-automatic American belt use laws (Campbell, 1987; Campbell, Stewart and Campbell, 1988).

In Australia, for the large majority of drivers who are already belt-wearers, the air bag represents additional protection, mainly from the steering wheel. It is primary protection for the non-wearers who, it is well established, have an increased propensity to accidents (Hurst, 1979, Hunter, Stewart, Stutts and Rodgman, 1988). The belt-wearing rate in casualty accidents was 66% in rural South Australia (Ryan, Wright, Hinrichs and McLean, 1988). In urban areas, in 1975-79, the in-accident rate was 80% for drivers and 65% for front seat passengers (McLean, Aust, Brewer and Sandow, 1979). The difference between survey and in-accident wearing rates is also due to the protective effect of belts removing uninjured belt-wearers from the data collection process.

The conclusion of a cost-benefit analysis attempted by Lane (1984), in which the injuries were neurotrauma, was that, for break-even of a two-bag system, the installed cost per car should not exceed about $A100 (1977 dollars). The in-accident belt-wearing rate was taken to be 75%. Planath (1987), using a larger data base and a more comprehensive analysis, concluded that the installed cost of driver-only bags would need to be $A100 (1986 dollars) for better than break-even. Planath assumed 100% belt wearing in accidents.

Cameron (1987) extended Planath's analysis concluding that, if the installation cost (amortised over vehicle life) and maintenance cost of a driver-only system could be provided for less than $20.84 per annum, air bags would be cost-beneficial.

The key variable is evidently the installed cost. Estimates range from $US1100 to $47 (Breed, 1985a). Patrick (1975) used a value of $US185 (1975 dollars). Of 152 models manufactured for the American 1990 market, 73 will have driver-side airbags and 79 motorised or non-motorised automatic belts (Status Report, 1989). It is therefore to be hoped that reliable cost information will soon be available. It is to be expected that costs will fall as the benefits of large volume production are realised.

EURO vs USA AIRBAG Previous development effort has been towards the manufacture of airbags as a **passive restraint** mechanism to satisfy the American FMVSS208 requirement. Hence, these airbags have emphasised "fail-free" and rapidly expanding units which have been criticised as potentially harmful in some circumstances for particular occupants, e.g., children, as noted earlier. Moreover, electronic sensors are normally used with backup units under the bonnet which adds substantially to the cost of these units.

Recent interest in Europe has been on developing an alternative **supplementary restraint** airbag to that specified for the U.S. market, commonly referred to as the Euro-bag. This unit is for use in conjunction with seat belt restraints as an added protection mechanism against contacts with the steering wheel and instrument panel. As such, a smaller, simpler unit is proposed requiring only a mechanical trigger which is argued to be safer for the occupants and much cheaper to produce (Mackay, 1990). Indeed, it seems that there are companies in Europe and America who are presently conducting research into the development of a Euro-bag.

Kallina (1990) argued that in the long-term, it would be better if only the U.S. airbag was manufactured because of economies of scale. He noted that Daimler-Benz had conducted an internal analysis of the likely costs and benefits of producing one, versus both, airbags and found that the cost savings from the simpler Euro-bag construction were more than offset by the cost benefits of an increased production run in U.S. airbags. Furthermore, he claimed that the injurious nature of the U.S. airbag had not been fully established.

The fitting of U.S. airbags to all vehicles as both a passive and supplementary restraint system has other advantages as well. Not only would it help to make supplementary airbags more cost effective (and hence, more likely to be fitted to Australian passenger cars in future) but it will also offer passive restraint to those who still refuse to wear seat belts in this country. Current survey estimates are that 6 percent of motorists still are unrestrained in Australian vehicles and that these occupants are considerably over-represented in crashes involving serious casualties and deaths (see earlier discussion).

The possibility has been raised of the deleterious effect of airbags on the seat wearing behaviour of a population with a high wearing rate of three-point manual belts such as in Australia. Ultimately, this can only be observed after the event, but it is encouraging that Reinfurt et al (1990) found a relatively high use rate of three-point manual belts in airbag equipped cars (73.9% compared with 76.3% without airbags).

In summary, the air bag is an effective crash protection device in frontal collisions. For best effect a belt also needs to be worn. For unbelted drivers it provides primary protection: for belted drivers it provides supplementary benefit, largely against steering wheel impacts. The smaller, supplementary air bag appears appropriate for the Australian situation, although this needs further investigation in relation to the costs and benefits. The air bag does not appear to create problems from false positive deployments or to the environment, but it is likely that a very few out-of-position children in the front seat will be injured when deployment takes place. For Australia, the benefit-to-cost ratio depends critically on installed cost.

THE STEERING ASSEMBLY Whether based on frequency of contacts or on "harm", interaction with the steering assembly is ranked first in injury-producing mechanisms inside the vehicle. The reason lies in its high exposure: it is the structure closest in front of the driver, who is often the only occupant.

In order to mitigate the body contact, countermeasures were introduced (FMVSS 203 and 204, ECE Reg 12, ADR 1OA & B) which had two objectives. In a 30mph barrier crash, the rearward (but not upward) motion of the assembly was limited to 5 inches. In a 27km/h sled test the force on a body block was limited to 2500lb, taken to be a relatively non-injurious load on the thorax.

EFFECT OF THE PRESENT RULE Overall, the modified steering assembly conferred significant benefits. To evaluate FMVSS 203 and 204, Kahane (1981, 1982a) analysed five years crash experience as documented in the FARS (Fatal Accident Reporting System) and NCSS (National Crash Severity Study). It should be noted that these are American pre-1981 data and almost all the drivers would have been unrestrained.

In cars meeting the standard, the risk of driver fatality in frontal collisions was decreased by 12% and of severe injury, caused by the steering assembly, by 38%, corresponding to a reduction, in overall frontal impacts, of 17.5%. Earlier evaluations of the steering assembly are cited by Morris, Stucki, Morgan and Bondy (1982).

Although steering assemblies meeting the standard undoubtedly reduced injuries (and were not expensive - a car-lifetime cost of $10.46 in 1978 US dollars), protection was far from complete: in 1978, 41,000 drivers in the U.S.A. were killed or hospitalized as a result of contact with the steering assembly.

Using data from a matched file of injuries to car occupants and vehicle details, for accidents in Victoria in the early seventies, Cameron (1979) compared outcomes in cars meeting ADRs 10A and 10B and cars not required to meet these standards.

The injury level in drivers contacting the steering wheel in ADR 10A and 10B cars was 19.7% lower in rural accidents, but not different in urban accidents. The effect, when present, was non-significant except for abdominal and pelvic injuries. Because of the small number of 10B accidents, the analysis was effectively of 10A, which did not contain the rearward displacement requirement.

Modified steering assemblies have now penetrated virtually the entire car fleet, but the steering wheel continues to be the major source of occupant injury. Malliaris, Hitchcock and Hansen (1985) found that the steering assembly was the source of injury which contributed the greatest amount of harm, 25.3% of total. The body regions concerned were chest and back, 12.7%; abdomen 6.1%; face 2.6%; shoulder and arm 1.6%. Cohen, Jettner and Smith (1982) found the steering assembly to be responsible for 27% of serious injuries. Again, this refers to mainly unrestrained occupants.

For restrained drivers also, the steering assembly contributes heavily as an injury source (20.5%, according to Jones, 1982, who analyzed a large sample of casualty and tow-away accidents). Almost fifty years ago, de Haven, studying light plane accidents, found that the control wheel could be a factor for safety or danger depending on its construction and the circumstance. Rather similarly, the wheel provides some benefit for unbelted drivers, since their proportion of injury is nearly 10% less than that of unbelted front seat passengers (Jones), but, when the driver is belted, the presence of the steering wheel reduces the compartment space for effective restraint and this is reflected in the slightly higher risk of injury for belted drivers versus belted passengers. Leung et al (1982) noted that belted drivers had fewer submarining injuries than belted passengers.

Injury from abdomen and thorax contacts continues to take place in belted as well as unbelted drivers, but facial injuries are especially important in belted drivers. Comparison (which is not exact) of data assembled by Morris, Stucki, Morgan and Bondy (1982) for mainly unbelted drivers with those of Thomas (1987) for belted drivers, suggests an increase in median delta-V for injured belted drivers and a higher face-to-torso injury ratio. The trajectory of the head of a restrained occupant is hook-shaped. The head first moves mainly forwards and then rotates downwards (Adomeit and Balser, 1987).

According to Gloyns, Rattenbury and Hayes (1982), 52% of restrained drivers struck the wheel with their heads. Of restrained drivers with injuries rated AIS 2 or more, Dalmotas (1980) reported that 82% sustained facial injuries and 40% chest injuries. Hartemann, Foret-Bruno, Henry, Faverjon, Got, Patel and Coltat (1985) described similar rates of head contact.

Thomas (1987) analysed data from 1003 casualty and tow-away accidents and found that 44% of restrained drivers sustained head injuries, a third from the steering wheel, but three-quarters of these were AIS 1. 32% had "torso" (mostly chest) injuries of which 18% came from steering wheel contact. The lowest delta-Vs associated with these injuries were 17km/h for head and 16 km/h for torso injuries. The head injury percentage rose linearly with delta-V. Thomas commented that these injuries are all unwanted side effects of the benefits of belt use.

Steering wheel intrusion occur more frequently in head and torso injury cases than in frontal impacts in general. Upward (26%) and sideway (24%) intrusions were almost as frequent as rearwards (31%) in injury cases. Head and torso injuries from steering wheels contributed 16% and 25%, respectively, to total harm in these accidents, while hub and rims contributed about equally. Thomas suggested a more realistic impact speed, in the relevant tests, of 45km/h (head) and 64km/h (torso) with criterion loads corresponding to injuries of AIS 2 (the present "energy-absorbing component" test is at 27km/h).

In a detailed analysis of fifteen cases of severe frontal collisions (with belted occupants), Green, German, Gorski and Nowak (1987) found that driver injuries consisted of facial lacerations and fractures of the nose, maxilla and mandible, rib and sternal fractures and injuries of the legs from striking the instrument panel. Arm and hand injuries occurred from contact with console or instrument panel. In one severe crash (the barrier equivalent speed exceeded 80km/h) the driver suffered a fracture-dislocation of the skull and a fractured larynx from the steering assembly which had been driven rearwards and upwards.

The bony structure of the face is evidently more fragile than that of the cranium. The probability of facial bone fracture was investigated by Yoganandan, Pintar, Sances, Harris, Chintapalli, Myklebust, Schmaltz, Reinartz, Kalbfleisch and Larson (1988), by dropping cadavers on to "standard" and energy-absorbing steering wheels. Contact was made between the zygoma and junction of spoke-and-rim, with the wheel at 30deg to the horizontal. Fracture of the zygoma, zygomatic arch, maxilla and orbit took place at velocities for the EA wheel of 6.93m/s (24.9km/h) and 3.58m/s (12.9km/h). It follows that if face impact velocities above 11.3km/h are expected, the rim plus spoke must be made more compliant.

Injuries to the spleen and liver are important causes of death due to lacerations of blood vessels and consequent hypovolemic shock. Steering wheel impacts of the upper abdomen were investigated by Nusholz, Kaiker, Huelke and Suggitt (1985) who point out that, from a biomechanical viewpoint, the liver and spleen react as thoracic organs, as they are largely protected by the thoracic cage. Unrestrained, re-pressurised cadavers were subjected to frontal impact with a steering wheel assembly. Rim impact with the ribs was followed by hub impact with the sternum.

For low velocity impacts (2.7 to 3.6m/s, usually non-injurious) the steering wheel force was between 88 and 2500N. At high velocities, 7 to 12m/s, the force was 4500 to 10000N (average 6200N). The wheel rim penetrated below the rib margin, then the spokes loaded the lower ribs, compressing the liver, then the hub contacted the sternum, further compressing the liver against the spine and posterior abdominal wall. Finally injury occurred when the liver was displaced beyond the range permitted by its tethers and/or the compressive stresses tore the liver. An additional mechanism was noted: stellate and linear lacerations on the surface of the liver close to the rim and hub presumed to be due to local stresses. The results support the suggestion that the force limit on the assembly, 2500lb, should be reduced.

LIMITATIONS OF THE PRESENT STANDARD There are evidently shortcomings in both parts of the existing standards. The limitation of rearward movement of the assembly applies only in the horizontal direction. It does not limit motion in the upward direction so that upward impacts on the head can occur. Petty and Fenn (1985) noted that "making the wheel rotate upwards is a simple design solution to overcome the regulation's requirement of limited rearward intrusion in the barrier test."

Kahane's analysis showed that the two components of the assembly did not perform equally well. The rearward displacement mechanism operated in 81% of relevant casualty collisions, but did not alter the frequency of upward or sideways displacements, which, he found, were uncommon. The energy-absorbing feature failed to operate in about 50% of cases in which the wheel was heavily impacted by drivers - the components tended to bind rather than compress when exposed to non-axial loads.

There are several mechanical arrangements that meet the energy-absorbing (more correctly, force-limiting) requirement. It appears to have been assumed that the motion of the upper body would align itself with the axis of the column, as in a lap-belted driver, and the several devices do not respond equally well to impacts that are not aligned with the axis of the column. Gloyns et al (1982) showed that restrained drivers fared better with wheels that had self-aligning properties (the so-called "collapsing-can" devices) than those that did not. On the other hand Kahane, while noting differences in the performance of the various devices, found these not to be significant and suggested that the conclusions of Gloyns et al related to smaller European cars that had steeper column angles than American cars.

Several improvements are available. The movement of the upper body, and consequently the head and neck, can be reduced by a better restraint system. Belt-tensioners and webbing clamps (discussed earlier) will reduce head motion, but it is not certain that face to wheel impacts will always be avoided. Alternatively (or additionally) an airbag would interpose itself between head and steering wheel.

Petty and Fenn (1985) report the performance of six standard wheels and a specially developed wheel. This wheel had a deep foam pad over the end of the steering column, four padded spokes designed to buckle when struck and a thick soft rim. It was the only wheel to satisfy a proposed performance test (a hemispherical headform impacting the wheel at 26km/h).

With regard to column intrusion, Kahane's analysis of American crashes indicated that upwards and sideways intrusions were uncommon, in contrast to the observations of Thomas for British collisions. In view of the proportion of small cars in the Australian fleet, it is probable that the British experience has the greater relevance to this country. A program of evaluation of measures to improve steering assemblies is described by Digges, Cohen, Eppinger, Hackney, Morgan, Stucki and Saul (1987). For drivers in frontal collisions, "a large fraction" (60%) of facial harm occurs at speeds below 20mph. 95% occurs below 30mph (48.3km/h), more in line with Thomas's suggestion of 45km/h for a head impact test.

Much effort has been made in the recent past to develop a surrogate for the face (Petty and Fenn, 1985; Warner, Wille, Brown Nillson, Mellander and Koch, 1986; Grosch, Katz, Marneitz and Kassing, 1986). A test procedure in which the "face" is impacted at 10 to 26km/h by a device resembling an unyielding wheel rim has been described by Nyquist, Cavanaugh, Goldberg and King (1986).

In Summary, the current design rules covering the steering assembly have produced a significant benefit, but further benefits appear to be achievable. Improvements in the restraint system, already discussed, will contribute to better performance but the assembly itself requires:

- a limit on the upwards displacement of the wheel;
- a more reliable energy-absorption arrangement which is responsive to off-axis impacts;
- a hub and wheel rim less injurious in facial impact.

In view of the sophisticated steering systems appearing in some cars, it is surprising that none of the literature reviewed (except very briefly in Clark, 1985) considered the possibility of replacing the conventional wheel with a wrist-operated device (with appropriate control laws). This would remove the steering assembly as an impact source and provide a clearer view of the instrument panel and, for drivers of small stature, the road ahead.

2.3.3 Rear End Crashes

Although injuries in rear end collisions do not rank high in frequency or "harm" compared with injuries in other collision types, and do not cause many fatalities (4% in FARS data), neck injuries subsumed under the imprecise term "whiplash", cause much disability and persistence of symptoms (Thomas, Faverjon, Hartemann, Tarriere, Patel and Got, 1982). This kind of neck injury is the source of a large fraction of personal insurance claims (McLean, Simpson, Cain, McCaul, Freund and Ryan, 1987).

A review of 229 rear end accidents to Volvo cars (Norin, Tingvall, Nilsson-Ehle and Saretok, 1980) showed these incidences of neck injury: drivers 35%, front seat passengers 25%, and rear seat passengers (with no head restraint) 16%. For rear seat occupants of height 150cm and over, the incidence was 22%. Most injuries were rated AIS 1, but Nygren (1984) found 9.6% of those with neck injuries to have permanent disability. The lower incidence in rear seat passengers conforms to general experience.

While most neck injury from rear end collisions is classed as "soft-tissue" injury, a small but not negligible fraction of casualties appears to suffer organic brain damage, presumably because of high angular accelerations of the head (Hamley Wilson, personal communication).

The prevention of neck injury in rear end collisions seems, at first sight, to be simple. Thirty five years ago, Severy, Mathewson and Bechtol (1955) showed that in a 20mph (32km/h) rear end collision, the driver's head in the struck car accelerated backwards at 11.4g. A human subject in a 10mph (16km/h) collision had a head acceleration of about one quarter of that of a dummy. The subject's head was, in consequence, violently hyper-extended and the struck car body was accelerated at about 3g.

The tolerance of a well-supported adult to rearward acceleration is high, 45g for 0.1 s being taken as tolerance by the United States Air Force, though one volunteer had no lasting ill effects from 82.6g, measured on the chest (Snyder, 1982). Rear-facing seats are long established in aviation (though seldom used on non-military aircraft) for crash protective purposes (Snyder). Rear-facing infant seats for cars have also been found to be highly effective (Turbell, 1989).

HEAD RESTRAINTS AND THEIR EVALUATION The obvious countermeasure was an upward extension of the seat back to prevent hyperextension of the neck. Severy and Mathewson experimented with prototype restraints as early as 1956. Australian Design Rule 22, for cars in Australia, became effective in January 1972 and was extended by ADR 22A, effective January 1975, to overcome improper setting of adjustable head restraints.

On the road the performance of head restraints has been given variable assessments. Six studies in the United States in the seventies were summarised by Cameron and Wessels (1979). Of these, five found decreases in neck injury up to 20% and one found no reduction. A Volvo study (cited by Cameron and Wessels) found a 55% decrease. One of these evaluations (O'Neill, Haddon, Kelley and Sorenson, 1972) was based on insurance claims in the Los Angeles area for drivers only, nearly all of whom would have been unbelted. The collisions took place in 1970, involving 1966 through 1970 model-year cars. The study was based on a substantial case frequency, 6833 struck cars. There were overall 18% fewer claims in drivers of cars with head restraints, even though an estimated 65% of adjustable devices were wrongly positioned. The reduction for females was 22%, more than twice that for males, 10%.

In Australia, Cameron and Wessells made use of Motor Accidents Board (MAB) data in which the cars from which claims arose were mainly those with ADR 22 restraints. There was a significant reduction in neck injuries, for females only, in the left front seat. A disbenefit concerned drivers of ADR 22 cars who had more whiplash and intracranial injuries than drivers of cars without head restraints.

Cameron (1980b) examined MAB data for a later period (1977-78) to determine the effect of ADR 22A. There was a reduction in neck injuries for both the driver and left front seat positions, for females in the age range 17 to 49. No disbenefits were found in rear end or frontal impacts. The overall reduction in whiplash for ADR 22A was about 30%. Cameron drew the conclusion that the minimum height of adjustable head restraints was too low.

Using other data in which belt use was recorded, Cameron found that ADR 22 appeared to decrease AIS 1 neck injuries and increase AIS 2-or-more neck injuries in belt-wearers. This conclusion is qualified by the observation that at least 31% of ADR 22 head restraints were not set at the optimal position. In addition, the lap-sash belts concerned were mainly static belts. The converse process, the effect, if any, of belt wearing on occupants in rear end collisions with and without a head restraint was not investigated.

Thus the countermeasure for neck injuries in rear end collisions which should, from considerations of tolerance and the input acceleration, be highly effective is only moderately effective and seems to be of benefit only or mainly to female front seat occupants. The other pertinent observation is that rear seat passengers, even with no head restraints, have a lower neck injury incidence than front seat occupants with head restraints. This is true even when, as in the Swedish study, rear seat occupants of smaller stature are excluded from the analysis.

Head restraint devices are of two kinds. In an **integral restraint** the seat back is extended upwards to form the restraint, so that the restraint and seat back are one structure. An **adjustable restraint** is a separate structure attached to the seat back by a suitable means which may permit a degree of vertical adjustment.

Kahane (1982a), who made an exhaustive study of the effects of the U.S. Federal Motor Vehicle Safety Standard dealing with head restraint (FMVSS 203), cited Texas data from the years 1972, 1974 and 1977, to show the following reductions in overall injury in rear impacts: integral versus no restraint, 17%; adjustable versus no restraint, 10%; and integral versus adjustable, 7%. NASS data on tow-away accidents, also cited by Kahane, contained too few cases for a comparison of head restraint versus no head restraint, but showed an overall injury 20% lower from integral than adjustable restraints and neck injury 25% lower. According to Kahane, head restraints have little effect in severe crashes and negligible effect on fatalities.

According to Kahane, accident data from Indiana show a negligible effect on accident causation due to obstruction of vision. Nor do head restraints materially affect the injuries of rear seat occupants. The only disbenefit reported is that described by Cameron, that ADR 22 appeared to increase AIS 2 or more injuries in belt wearers.

Lovsund, Nygren, Salen and Tingvall (1988) examined rear end collisions in which there was at least one occupant in the back seat, from a very large series of 80,000 crashes. Children had a lower neck injury rate (5.2%) than adults (9.4%). Rear seat occupants had a lower neck injury rate than front seat occupants, but body height (in front seat occupants) had no influence. Females had a higher neck injury rate than males. The head restraint was effective in reducing neck injury (by 30% in the front seat). The authors conclude that, "the effect of moving from front to rear seat is thereby greater than that of fitting a head rest to the front seat" and "the rear seat back is more rigid and behaves differently from the front seat".

Olsson, Bunketorp, Carlsson, Gustafsson, Planath, Norin and Ysander (1990), from a detailed examination of 26 rear-impacted Volvo cars in which all occupants were belted and were in seats with fixed head restraints, found inter alia that duration of neck symptoms was shorter when the head-to-restraint offset distance was less than 10cm.

COST EFFECTIVENESS Kahane found that the car-lifetime costs to the consumer were (in 1981 US dollars): integral, $12.33; adjustable, $40.14. According to his calculation, integral head restraints eliminate 690 injuries per million dollars and adjustable 130 per million dollars. A reasonable benefit lies between 460 and 1500 injuries eliminated per million dollars of expenditure. Kahane does not compute benefit to cost ratios, but these would evidently be better than unity for integral restraints but below unity for adjustable.

Since integral restraints are five times more cost-effective than adjustable (which cost more and protect less) it is one of the curiosities of marketing that adjustable head restraints have tended to to displace integral restraints in production cars.

LIMITATIONS OF HEAD RESTRAINTS Thus the head restraint complying with the present rules is effective in making a reduction in overall and neck injury in rear end collisions. The question arising is why the effectiveness should be so limited in a crash situation which appears susceptible to highly effective intervention.

Kahane proposes calculations based on anthropometric studies to indicate that integral restraints do not protect the tallest occupants and concludes that the inferior performance of adjustable restraints is due to malpositioning. He suggests further that head restraint performance would increase with restraint height up to 32inches (813mm). He attributes low effectiveness to the presence of other injuries in those who have whiplash, to mechanisms other than hyperextension as a cause, to diminished effectiveness if the occupant happens to be leaning forward and to seat tilting causing the occupant to ramp up the seat back. The higher female incidence of whiplash is attributed to smaller muscle mass in the neck of females.

It is worth noting that some of these reasons would not hold, or only to a small degree, in Australia, where the adjustable head restraint must provide an upper level of impact surface no lower than 700mm and where ramping and rebound injuries from striking forward structures would be expected to be mitigated by a high belt wearing rate.

None of these processes explain the lower incidence of whiplash (and of chronic whiplash) in the occupants of rear seats, many of which at the relevant times had no head restraint, and in which the input acceleration pulse would be expected to be somewhat higher than in the front seat. This point is discussed below.

BIOKINETICS The dynamic response of the spine in rearward acceleration was investigated by Prasad, Mital, King and Patrick (1975). Their mathematical model included, not only head and neck motion, but also the interaction of the occupant with the seat back, seat cushion and the restraint. Factors taken into account were: the seat back (rotation, elasticity, cushion characteristics, height), friction between occupant and cushion, head-to-restraint offset and the input acceleration profile.

These authors found that the seat back cushion has a significant effect, as it stores energy during compression. If recovery takes place at the time of maximum extension of the head, the head-torso angle will be accentuated. Friction between cushion and occupant reduces ramping and the friction is increased by contouring. Peak loads on the head are reduced by decreased head to restraint offset. It is to be noted that the offset, the effect of which is substantial, is not prescribed by the design rule.

In these simulations, body restraint was not included because Prasad et al considered it would become slack and hence ineffective during the compression of the seat back cushion. Computer runs with rigid, elastic and plastic seat backs demonstrated large movements in the fore and aft plane, not only of the head but of the torso and pelvis. Head/T1 rotation was 45deg for a rigid seat back, 75deg for an elastic and 65deg for a plastic seat back, compared with 150deg for no head restraint.

An experimental study was made on a sled using a cadaver and a seat back equipped a hinge for constant torque rotation. The main conclusion was that the head's angular acceleration and spinal forces were reduced when there is plastic deformation of the seat back. Cushion stiffness plays a significant role. The head/torso angle can be controlled by proper selection of the stiffness of the head restraint and seat back cushion. Although the torque on the seat back was three or four times higher than that required by the standard, there was considerable ramping of the (unrestrained) cadaver.

These results suggest an explanation for the superiority of the integral head restraint and for the lower whiplash rates in the rear seat. The key to whiplash reduction evidently lies in the dynamic properties of the seat and particularly the seat backrest. The superiority of integral head restraints may be due to their slightly larger impact surface and, more importantly, to no incompatibility of stiffness between head restraint and seat back.

Strother and James (1987) reviewed the experimental results with particular reference to the back rest. They cited evidence that a seat back yielding in a "controlled fashion" reduced head loads and produced lower injury exposures. Use of belts was effective in rear end collisions, particularly at higher delta-Vs, by linking the occupant more closely to the seat and limiting ramping. Slipping upwards out of a belt is prevented because the thighs jackknife upwards.

Prasad et al (1975) found it necessary, in their experiments, to have a seat back substantially stronger that that prescribed by the relevant FMVSS and, according to the data summarised by Strother and James, the seat backs of most production cars are 2.5 to 3 times stronger in rearward loading than required by the Standard. Barrier tests of production cars show that the residual seat back angle changes by 0.8 to 1.6deg for every one mph of delta-V. Thus the residual capacity of the seat would be exceeded at inputs of 20-25mph (32-40km/h). Dynamic deflection is considerably more than residual deflection.

Strother and James (1987) concluded that a completely rigid seat is impracticable because of weight penalty and problems with seat anchorage loading. Despite this, recent seats intended for installation in some production cars have designs apparently incorporating considerable rigidity (Haberl, Ritzl and Eichinger, 1989).

Weissner and Ensslen (1985) describe a prototype seat which produces a maximum neck bending of 25deg in a Hybrid II dummy and 30deg in a Hybrid III for an input acceleration of 14g. The horizontal offset of the head restraint from the dummy's head appears to be small in this seat.

In summary, the evidence discussed suggests that integral (as opposed to adjustable) head restraints and the use of belts both confer benefits in protection. The offset of the head restraint from the back of the head should be smaller than current practice. The front seat backrest should have a minimal elastic response to backward loading and, at a predetermined point, yield in a plastic manner. The possibility of controlled horizontal backward yielding in the seat track mechanism does not appear to have been considered.

2.3.4 Side Impacts

Side impacts constitute a substantial fraction of all injury-producing collisions - 17% to 25%. About two-thirds of these are car to car collisions and another 15% to 20% are side collisions with poles or trees, a source of high mortality. About half of the side collisions are rectangular and half oblique, and about 80% involve the passenger compartment (Mackay, 1990).

According to Marcus, Morgan, Eppinger, Kallieris, Matter and Schmidt (1983), lateral impacts produce a large proportion of all serious and fatal injuries - as much as 27% to 30% according to Fan (1987). Side impacts account for 12% of total "harm" (Malliaris et al, 1982). This proportion would be higher in countries with high belt-wearing rates, as a substantial number of frontal impact casualties would be removed from the total harm.

Side impacts also present a difficult problem in crash protection as there is little crushable structure between the occupant and the impacting vehicle or object. The front structure of a car can absorb two to five times as much energy as the side structure (Cesari and Bloch, 1984). The side impact collision itself may be a complex event.

Head, thorax and pelvis are the main body areas injured and the interior door surface is the most frequent impacting part. Thoracic injury is the highest ranking injury in non-rollover, non-ejection side impacts (Hackney, Gabler, Kanianthra and Cohen, 1987). For head injuries, however, there are a number of contacting parts: the side door rail, window frame, A pillar, B pillar, other interior surfaces and the external impacting object itself as the head rocks through the window space (Wilkie and Monk, 1986). A diagrammatic representation of the sources of injury is given by Otte, Suren, Appel and Nehmzow (1984), based on a large sample of side collisions (see Figure 2.3).

Dalmotas (1983) found that, with regard to occupants restrained by seat belts, there was more injury to the shoulder/chest, pelvis and legs among impact-side occupants, whereas there was more injury to the neck, abdomen and arms in far- side occupants. The two groups had similar incidences of head/face injury. The distribution of injuries in this series was very similar to that in Holt and Vazey's 1977 series (pre-ADR 29), shown in Table 2.6.

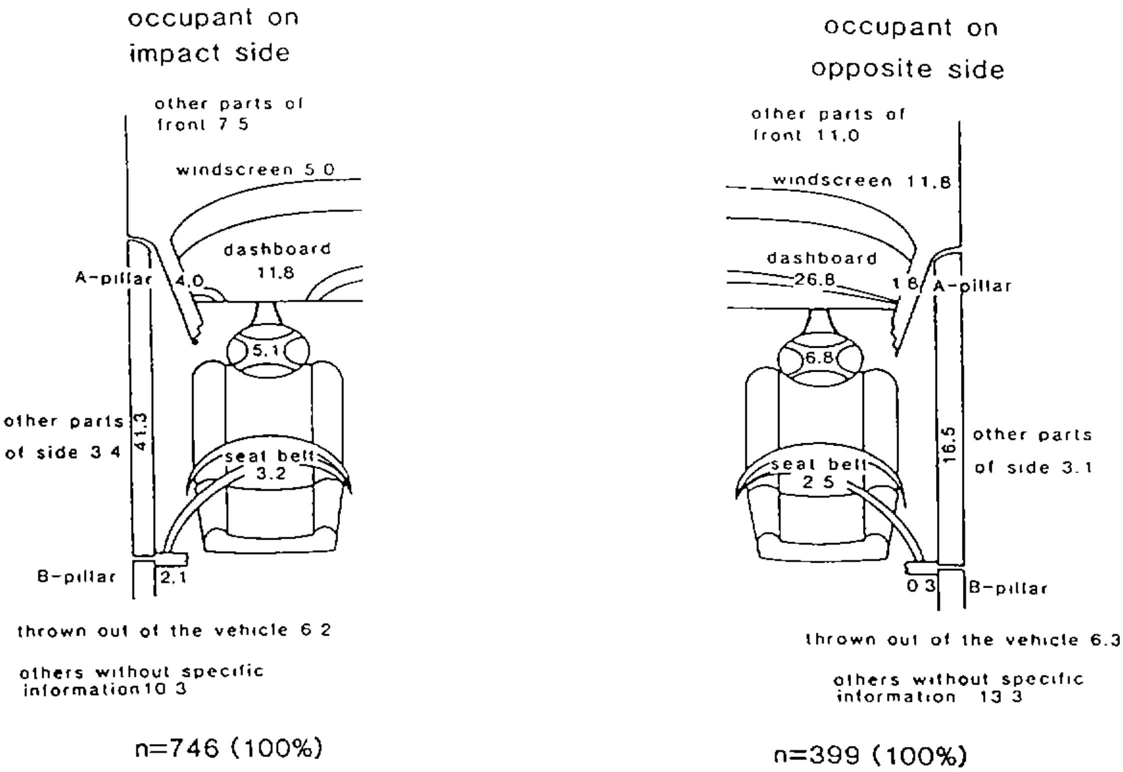

Figure 2.3 *Injury-causing parts for laterally impacted passengers, differentiated by seating position (for all injuries 100%) on the impact side and on opposite side (from Otte et al, 1984).*

TABLE 2.6
PERCENT OF 3-POINT BELTED CASUALTIES WITH AIS>= 3 IN SIDE IMPACTS

BODY REGION	HOLT and VASEY	DALMOTAS
head/face	46.6	48.0
neck	1.7	7.1
shoulder/chest	48.3	40.8
pelvis	24.1	13.3
abdomen	10.3	11.2
upper extremities	12.1	14.3
back	-	1.0

Source: *Holt and Vazey (1977), Dalmotas (1983). Note that the difference in neck injury frequencies is due to a difference in sampling criteria.*

Occupants in lateral collisions can be injured by one or more of five main mechanisms (Strother, Smith, James and Warner, 1984):

. contacting the (deformed or undeformed) side structure of the occupant's vehicle,

. direct contact with the striking object or vehicle,

. being contacted by objects (or occupants) from the opposite side of the vehicle,

. being compressed between side structures and other parts of the compartment,

. being partially or totally ejected from the subject vehicle.

Strother et al (1984) commented that mechanism (d) is rare, because collisions with this degree of vehicle crushing causes early fatal impact-type injuries. Since the side of the vehicle is usually pushed inward in side impacts, the occupants' injuries were often thought of as being due to crushing. The apparent need to avoid "reduced survival space" led to the unfruitful strong-box concept of the early experimental safety vehicle program for which reduced "intrusion" was one of the design criteria.

It is now recognised that the injuries are nearly always impact injuries (Friedel, 1988). The velocity of the side door interior surface on contact with the occupant is similar to the delta-V of the struck vehicle - about 60% of the closing speed of the striking vehicle (Viano, 1987). The overall probability of injury is however not directly related to overall structural stiffness nor to the final extent of the intrusion (Hobbs and Langdon, 1988). Dalmotas (1983), also, recognises that the mechanisms of injury in side impacts are more complex than in frontal collisions.

The events are described by Cesari (1983, p 133 et seq) as follows;

"... the occupant sitting on the side of the impact will be struck by the side structure intruding into the passenger compartment while still in his original seating position, and will be accelerated towards the opposite side of the vehicle before the speed of the vehicle itself begins to change to any appreciable extent. In terms of the loading imposed on the occupants, therefore, the motion of the vehicle itself is of merely secondary importance. The decisive factor is actually the large relative motion between the side structure and the vehicle, in other words the rate of intrusion."

"For impacted side occupants, this intrusion related phenomenon explains injuries to the thorax, to the pelvis, to the abdomen and to the limbs for impacted side occupants. Abdominal injuries can also be consequence of armrest impact: the armrest intruding inside the abdomen even in accidents with few intrusion levels can create abdominal injuries in the area below the ribs and behind the iliac wing. Mechanisms of injuries to the head are generally more complex: some of the head injuries are due to direct impact to the B pillar (or possibly against the A pillar), but injuries to the head in side impact can also be related to a partial ejection of the head through the window area. This ejection could either allow a head impact against the bonnet or the front face of the striking vehicle or give an important head rotational acceleration, which might induce severe head injuries as found in accident reconstructions."

"If we consider the case of only one occupant seated in the opposite side injuries are often related to impacts against internal parts of the car, some of them having been deformed by the collision. In the case of two occupants on the same seat row the interaction between them could produce injuries to both of them."

These interactions between passengers are likely to be important in right angle collisions (Faerber, 1983), the actual consequences depending on whether the interaction takes place after or before the primary impact pulse is finished. Forces between occupants may be one-third of those on the impact-side occupant from the primary impact. Belts may mitigate or even eliminate interactions between occupants (Jones, 1982).

Strother et al (1984) analysed the side collision in terms of velocity time diagrams. By the time the impact-side occupant has contacted the interior panel, only about one-third of the eventual intrusion has taken place. He argued that the velocity of contact is independent of side stiffness for the first 10" (25.4mm) or so of side crush. The far-side occupant (belted or not) may benefit from more intrusion, as the side interior velocity may then be lower when the far-side occupant encounters it. Because of the early (about 25ms) contact between impact-side occupant and door interior, this occupant may not benefit from breakaway utility poles - the damaging contact will have taken place before the pole separates from its base. Post-collision intrusion is a poor and unreliable measure of countermeasures for fixed object lateral collisions (Strother et al, 1984; Dalmotas, 1983).

The important factors generating injuries include direction of impacting force, collision severity, mass ratio between striking object and struck car, the response of the car to lateral loading as well as car structural details (Otte et al, 1984; Freidel, 1988). In this review only the structure of the impacted car will be considered.

EXISTING COUNTERMEASURES The three point seat belt should not be overlooked as a countermeasure. It has a substantial protective effect for opposite side occupants; even for impact-side occupants it still has a small effect - for example, reducing the chance of the head swinging through the plane of the window and contacting the striking object (Mackay, 1988). Jones found that impact-side occupants had a risk of injury of 77.9% if unbelted, but 74.5% belted; other-side occupants had 70.3% unbelted and 63.6% belted.

Door stiffness is the object of the only specific countermeasure so far implemented. The countermeasure adopted in Australia, ADR 29, effective since 1977, follows (US) FMVSS 214. It prescribes extra stiffening of the door, measured by static deflection when the door is loaded horizontally by a cylindrical impactor. The requirement is usually satisfied by the addition of a horizontal beam in the door structure, with or without extra strengthening of the door frame.

Victorian data were analysed by Cameron (1980a), who found that there was no statistically significant evidence to show that compliance with ADR 29 reduced the risk of injury to front seat occupants on the impacted side. Cameron recognised the limitation of the small sample size and that the benefits in a particular type of side impact could be diluted in the broad group of impacts considered.

Kahane (1982b) was able to use a large data base, including seven years of FARS data, NCSS data and three years of Texas accident files. Kahane found a differential effect: for fatalities, there was no significant effect in car-to-car collisions, but there was a 14% reduction in single-vehicle accidents. If this class is restricted to side impacts with fixed objects, the effectiveness was 23%. For car-to-car collisions, there was a 25% reduction in serious injuries for impact-side occupants. There was, overall, also a reduction of 9% (single vehicle accidents) and 13% (multi-vehicle accidents) in minor injuries.

Regarding vehicle deformation, in single vehicle crashes, the depth of crush decreased on average by 20%, while the width increased by 20%; in multi-vehicle crashes the depth was decreased by 20% while the width was unaffected. Ejection through door openings, incidence of door opening, of latch or hinge damage, of ejection through the door opening and of sill override were all reduced in cars complying with FMVSS 214.

The standard added an average of $30 (US, 1982) to the purchase price of the car and had an estimated car-lifetime cost of $61 per car. The standard eliminated 1.7 "equivalent fatal units" per million dollars of cost.

Kahane concluded that the standard helped cars to "glance by" fixed objects, limiting the damage in the compartment area and spreading it to less vulnerable regions of the car, but it did not produce deflection of striking vehicles. It reduced the overall severity of the collision not only for the impact-side occupants but also, to a lesser extent, for other occupants. It also helped protect the integrity of the door structure, significantly reducing the risk of ejection. Overall, the benefits were mainly in single vehicle accidents.

NEW DEVELOPMENTS During the past two decades, a large amount of research and development has been expended on the side impact problem, primarily in the area of biomechanics. According to Burgett and Brubaker (1982) the side of the vehicle should perform two functions in a crash: prevent ejection and provide a survivable impact environment. They distinguish full-scale tests from sub-system tests and analytical approaches to the development of a standard. The NHTSA side impact program concentrated on thoracic injury measures. The number of fractured ribs is related to the acceleration of the first thoracic vertebra (with age as an intervening variable) and has a curvilinear relation to thoracic AIS. Injury is also related to chest deflection. Force on the abdomen is related, fairly linearly, to its deflection.

Cesari and Ramet (1982) have investigated pelvic fractures in side impacts and found that the pubic rami were the most deformed parts. They propose a pelvic human tolerance parameter with 3ms values of 10kN for 50th percentile male and 4kN for the 5th percentile female.

There have been a number of comparisons of dummy responses with cadaver tests and reconstructions of real collisions (summarised by Burgett and Brubaker, 1982). The subsystem approach has been chiefly used for development of, for example, energy-absorbing padding material. The analytical approach requires a mathematical model which needs to reproduce both vehicle and occupant responses with great fidelity. Principal problems have been the need for detailed information on the behaviour of specific body parts.

Eppinger, Marcus and Morgan (1984) describe the derivation of an index predicting injury on the AIS scale from 49 cadaver side impacts. The best predictor, according to the authors, is the Thoracic Trauma Index (TTI), defined as:

$$\mathrm{TTI} = 1.4\ \mathrm{Age} + 0.5\ (\mathrm{T12Y} + \mathrm{LURY}) \times \mathrm{M}/165$$

where age is in years, T12Y is the peak lateral spinal (T12) acceleration, LURY is the peak upper left rib acceleration and M the mass in pounds.

Comparisons were made of the responses of cadavers with the commercially available Side Impact Dummy (SID) in lateral impacts. Small modifications were made to the dummy, but for rigid wall impacts, a mathematical transformation incorporating a damping factor was needed to match the the dummy rib acceleration to the mean cadaver response. Subsequently, as a result of extended use, small deficiencies were rectified. Eppinger et al discussed procedures for securing repeatable test results.

A parallel program for development of a dummy (EUROSID), under the auspices of the European Experimental Vehicle Committee has been described by Janssen and Vermissen (1988). The dummy was based on the best features of earlier dummies and the new parts - neck, thorax, abdomen and pelvis - were based on cadaver data. After initial trials and modifications, it was subjected to a program of tests specified by a working group of the International Standards Organisation. While the dummy performed well, it was too stiff, in some tests, which led to higher than specified accelerations. EUROSID is suitable for transducer outputs from which TTI and other indices can be derived. Current thinking in Europe is that EUROSID-1 is now fully developed and ready for production (Roberts, Cesari, Glaeser and Janssen, 1988).

Comparative evaluation of SID and EUROSID has been described by Bendjellal, Tarriere, Brun-Cassan, Foret-Bruno, Caillibot and Gillet (1988) in terms of head impacts, neck bending, shoulder, thorax and abdomen responses and pelvic performance. Neither dummy complies with all the ISO criteria, but EUROSID does so rather more closely than SID. The methodology leading to the TTI has not been without critics. Ardoino (1983) questioned the validity of cadaver responses as surrogate for live car occupants.

Viano and Lau (1985) noted that cadaver chest compression sufficient to cause injury did not have a fixed maximum, but the critical compression was inversely related to velocity of compression. They argued that chest and abdominal injury was caused by a viscous mechanism during the rapid phase of body compression. This led to the concept of a Viscous Tolerance Criterion, defined as the maximum value of the instantaneous product of compression velocity and percentage compression: $VC = v(t) \times c(t)$ max.

It has the dimensions of velocity and it is said to be a "measure of energy dissipated by viscous energy in the thorax". The VC reaches its maximum when body compression has reached only half its maximum value. The criterion was used initially for analysis of antero-posterior impacts on the thorax and has been extended to the abdomen. From cadaver tests, tolerance values (for 25% probability of serious injury) were established as VC = 1.5m/s for the chest and 2.0m/s for the abdomen. These values correspond to 38% and 44% of maximum compression, respectively.

The dummy development program has been criticised by Viano and by others for excessive dependence on skeletal injury and acceleration. Acceleration cannot distinguish between body deformation and translation of the whole body. In their view, SID is an inertia device, not one that relies on a compliant human-like response.

DESIGN FACTORS The relevant engineering factors of a vehicle that are available for manipulation are the door stiffness, energy-absorptive padding and the spacing between occupant and interior door surface. Rouhana and Kroell (1989) note that discontinuities in the door inner surface can cause significant injuries - cutouts (map pockets) are as important as protruberances (arm rests) as potential contributors to injury.

Numerous estimates have been made of the influence of spacing, padding and door stiffness, using mathematical simulations with or without experimental validation. Generally, both padding and stiffness have been considered in combination. Viano (1987) found that the crush force needed to reduce peak biomechanical response varied with impact velocity.

Deng (1988) found, with simulations, that padding would reduce occupant acceleration but would increase body deformation, indicating that padding needs to be accompanied by other design changes such as increased stiffness. Deng (1989) later showed the importance of test method: "free flight", ie, pendulum tests, were inappropriate for subsystem tests of padding materials. Brubaker and Tommassoni (1983) found that padding alone did not improve the thorax response, but was beneficial to the pelvis. Segal (1983), on the basis of trials with two computer models, found that door interior padding was beneficial across a range of body sizes.

In car-to-car oblique crashes simulated by Tommassoni (1984) most benefit came from padding, making use of the door interior, but extra stiffness was of some benefit. With regard to stiffness alone, Strother et al (1984) considered an increase of value only if it moderated the velocity history of the contact surface. An analytic study of car body lateral impact characteristics, in right angle impacts at moderately high speed (12.5 m/s, 45 km/h) suggested that stiffer door structures might actually increase dummy acceleration, but foam padding might decrease thorax and pelvic acceleration by 10%. The main conclusion of Hardy and Suthurst (1985) was the importance of compatibility between parts in modification of the vehicle structure.

The relative effects of design factors were investigated by Preuss and Wasko (1987) through side impacts tests on 16 identical cars modified to give two levels of spacing, padding and stiffness. The significant variables were found to be padding and stiffness which reduced the dummy response by 30 and 7 TTI units respectively, compared with a standard deviation of 5.6 TTI units. (Typical TTIs in sideways tests range between 100 and 150 TTI units.) According to the test analyses, the two variables can be evaluated separately. The study has been criticised by Lau and Viano (1988) chiefly on the grounds that the SID dummy exaggerates the effect of padding.

SIDE AIRBAG - A side airbag has been proposed (Anon, 1989a). If this is feasible - it would need to have a very fast inflation time - it could make valuable use of the space between occupant and interior surface to provide "ride-down", for this is space that cannot, practically, be used for energy-absorbing padding.

The property of head contact surfaces in side impacts is a special case of contact with interior surfaces generally. Willkie and Monk (1986) investigated the stiffness of narrow surfaces, pillars and roof rails, by impacts with a rigid headform at 15mph. A number of car models were used as test specimens. They were able to express the Head Injury Criterion (HIC) in terms of surface stiffness: HIC = 0.508 x k + 100, where k is the stiffness in lb/in. Attempts to develop a relation with the Mean Strain Criterion were less successful.

It appears that many factors, regardless of the mathematical or physical model used, interact to influence the effect of spacing, padding thickness and density, and door stiffness on the probability of injury to an impact-side occupant. In these circumstances, there can scarcely be an optimum mix of door design factors across all impacts.

From a consideration of the distributions of injury and speed in real world crashes, Viano (1987) suggests that reductions of up to 30% in seriously injured occupants may be possible with a low stiffness energy absorbing material that is effective in low-speed (delta-V = 4 - 8m/s) crashes. Low or high stiffness padding was ineffective in high-speed crashes (delta-V > 10m/s).

In addition to the two dummies, SID and EUROSID, there are two test procedures in which a moving barrier impacts a stationary car. The tests differ on 19 of 22 items (Fildes and Vulcan, 1989). Differing test elements, dummies and even dummy position (front or rear) had large effects on the outcome variables in replications of tests on identical 1800cc Japanese sedans (Campbell, Smith, Wasko and Hensen, 1989). This has unfavorable implications for international harmonisation of standards.

The practical thickness of energy-absorbing padding is an important variable. Since lateral clearance in traffic (eg lane width) is determined by the needs of large vehicles such as trucks and buses, it seems possible to bulge the sides of the car in the passenger area, without alteration of track or occupant position, so that a very modest increase in car width could provide a substantial proportionate increase in space available for padding. Consideration of this possibility has not been encountered in the literature reviewed and warrants further consideration.

In summary, a substantial though not spectacular reduction of injuries in side collisions would seem possible through car design, although there are still a number of unresolved issues. There is lack of agreement between experts on the critical variables or their derivatives to be used for predicting injury and there are two well-developed but different anthropomorphic test dummies and different impact test procedures. Concern has been expressed about reliance on a single test for demonstrating compliance with whatever standard is adopted.

2.4 GENERAL CONCLUSIONS

A number of general conclusions can be drawn from the preceding review of the occupant protection literature.

1. The three-point restraint continues to be the main single countermeasure proposed in the literature against occupant injury. Current issues concern the prospects for increasing the protective effect of the system and the question of injuries thought to be associated with belt use.

2. While there is a substantial medical literature on belt-associated injuries, only a few specific injuries (apart from superficial abrasions, etc.) were, in fact, caused by belts. Soft tissue neck injuries, bony injuries of the chest in mainly older belt users, and abdominal injuries related mostly to unsatisfactory belt installations and poorly positioned belts.

3. The protective effect of the belt was found, overall, to be about 50%. To improve this, several practical changes were proposed. First, better belt geometry was called for, especially a substantial increase in the minimum downward angle of the lap strap and provision for vertical adjustment for the sash D-ring.

4. Seat design was also considered important. Proposed changes included more strength to sustain both fore and aft impact loads for the seat backrest, and increased stiffness and a wedge or ramp at the front for the seat cushion.

5. Two, alternative, sophisticated improvements proposed for belt performance were belt pretensioners or webbing clamps. Both these devices aim to decrease upper torso and head excursion and reduce peak forces on the chest.

6. Improvements in rear seat belts (lap belt angle, accessibility and probably a sash for the centre seat) were called for to provide better protection and to facilitate belt wearing. An important finding was that an unrestrained back seat passenger presents a serious hazard to a belted front seat occupant.

7. The knee bolster was considered to be a useful device for preventing leg and pelvic injury, especially when the restraint is by diagonal belt or airbag only. The knee bolster was also seen as a safeguard in the case of submarining with a three-point belt.

8. The airbag was viewed as an effective injury reduction device in frontal collisions, but as a supplement to a belt for greatest benefit. It can provide substantial protection for non-belt wearers in frontal crashes. For Australia, its cost-benefit status needs further study because of uncertainties about cost. It is unlikely to present an environmental hazard, but has the potential to cause injury to out-of-position children in the front seat.

9. The steering assembly was reported to be a major source of injury. Existing design rules have provided significant benefits but needed improvements included a more reliable energy-absorbing performance particularly in off-axis impacts, a limitation on upward displacement of the wheel in frontal impacts, and a hub and rim less injurious to the face.

10. In rear impacts, head restraints have proved to be only modestly effective. Integral head restraints seem to be preferred to adjustable ones and the offset of the restraint from the back of the head should be smaller than is current practice. Further improvement requires a much stronger and stiffer front seat back, designed to yield in a plastic manner at a selected load.

11. The costs of certain design changes required for compliance with the FMVSSs have been evaluated in American cars and are modest. The car-lifetime costs for the steering column were $10.46 in 1978 US dollars, for head restraints, $12.33 (integral) and $40.14 (adjustable) in 1981 US dollars, and for increased door strength, $61 in 1982 US dollars.

12. Despite a great deal of research and development, side impacts still remain a difficult problem. Significant gains in injury reduction were considered possible, however, from carefully chosen combinations of increased door stiffness and strength and energy-absorbing material in the door. A main consideration was the need for valid test methods; there are, at present, two different test dummies and test impacts which need to be unified.

13. Damaging contacts, usually involving the head, continue to take place with the car interior, in particular with the header, roof side rails and A and B pillars. A strong case seems to exist for extending the energy-absorbing specification to these areas.

14. A major conclusion from the review is that the car seat (particularly the front seat) is by no means simply a passive device. Its design (in geometry, strength and stiffness) was reported to play a major role in occupant injury for both frontal and rear impacts.

15. Designs exist for nearly all the devices or improvements described in the literature and summarised above. Examples of many of them are to found today in certain production cars.

16. Two possible approaches were notable for the the absence of discussion in the literature reviewed. One, concerning frontal impacts, is the possibility of replacing the conventional steering wheel with a sophisticated wrist controller device. The other, for side impacts, is the possibility of bulging the side surface of small cars, without altering the track, to provide more space for energy-absorbing material.

3. MASS DATABASE ANALYSIS

The project objectives were primarily aimed at the occupant safety performance of current generation vehicles. Hence, the mass data analysis was confined to comparing the occupant protection performance of post-1981 passenger cars (and their derivatives) in crashes that occurred across the state of Victoria between 1982 and 1988. These vehicles represented 29% of all vehicle crashes that occurred during this period (i.e., the remaining 71% of crashes included pre-1981 passenger cars and non-eligible vehicles such as vans and trucks).

3.1 DATABASE CONSTRUCTION AND VARIABLES

The Transport Accident Commission (TAC) was legally constituted on the 1st January 1987 under the new Transport Accident Act 1986. Prior to this, state-wide injury compensation came under the control of the Motor Accidents Board (MAB) under the previous Motor Accident Act 1973 and section 5 of the Motor Car Act 1958. One important revision in injury compensation arrangements introduced by the new Transport Accident Act was the requirement for all crashes to be reported to the police. The legislation has greatly reduced litigation against the state and resulted in substantial reductions in the number of minor injury claims to that previously experienced.

Access to these data was provided to MUARC for mass data analysis associated with this project. A computerised database was constructed containing relevant details of vehicle crashes and occupant injuries that occurred in Victoria between the 1st July 1978 and the 30th June 1988. The database was constructed essentially from a magnetic tape of MAB and TAC claim information for the periods and variables of interest. Independent variables obtained from the TAC included vehicle make & year of manufacture, vehicle power & weight (mass), date of crash, the number of vehicles involved, crash location (municipality), age and sex of the occupant making a claim, seating position in the vehicle, level of severity of the injury (fatality, >6days in hospital, <7days in hospital, not admitted), injuries (five International Classification of Disease ICD9), and total cost of their claim (1988 A$). Injuries were subsequently recoded from the ICD9 codes into 19 body region categories for ease of interpetation.

3.1.1 Supplementary Information

A number of critical details, however, were not available from the TAC, such as whether the occupant was restrained or not, the speed zone where the crash occurred, other crash site details (eg, type of road, at or between intersections, etc.), road user movement at the time of collision, traffic control device, time of the day and week and light conditions of the crash, and uninjured occupants. These details, however, were available from police records of these crashes and Vic Roads agreed to provide MUARC with this information.

Neither of these two sources, however, currently list vehicle model as a factor in their data. As the type of injuries by model of the vehicle was of potential interest here, it was necessary to locate a means for identifying this from the information provided. RACV Limited in Victoria developed a computer program capable of identifing 37 popular vehicle models from vehicle make, year of manufacture, power units, and the vehicle's weight and this program was able to identify 47% of the TAC claimant vehicles.

Finally, the type of drive configuration was also necessary to assess the occupant safety benefits and disbenefits of one type of drive over another. As noted earlier, this was particularly relevant for this project. A software routine was further developed for identifying whether the vehicle had a front-wheel, rear-wheel, or a four-wheel drive transmission, and this was applied to these data.

3.1.2 Merged Database

To overcome these shortcomings, the data supplied by the TAC was merged with police reported data supplied by Vic Roads to construct a more comprehensive database for analysis. To the authors' knowledge, this was the first time that such a mass database has been available in this country (i.e., police reported information with comprehensive injury details) and hence, was a valuable source for mass data analysis, not only for this project, but for detailed assessments of the injury consequences of road trauma in general.

Data supplied by Vic Roads contained details of vehicle crashes for the period 1983 to 1988. The data merge was undertaken using the police accident report number which yielded a 67% match overall with TAC data. A person based data file was established such that either a person, vehicle, or crash based analyses could be undertaken. While an important aspect of this datafile was having both injured and uninjured occupants for each matched crash, time did not permit a detailed examination of this aspect here.

3.2 DEPENDENT VARIABLES & ANALYSIS PROCEDURE

The database comprised records of vehicle occupants involved in road crashes in Victoria between 1 January 1982 and 30 June 1988 involving a post-1981 vehicle where at least one of the vehicle's occupants sustained an injury resulting in costs greater than the minimum threshold for injury compensation under the Transport Accident Act ($317 in 1989 dollars). This analysis, therefore, was confined to a within-patient study of the type of crash and injury sustained and generally not amenable to incident analysis within the population at large without relevant exposure details.

A number of dependent variables, however, were still available for this analysis. As well as relative frequency comparisons, crash and injury involvement rates could be assessed relative to the population of all TAC reported crashes. Over- and under-involvement rates were established from the expected values computed from the column and row distributions of patients and crashes as in a goodness-of-fit test. A database containing suitable information was analysed using the Statistical Package for the Social Sciences SPSS-X (SPSS Inc. 1988). Because of the large number of cases involved and the tendency for significant results under these circumstances, tests of significance were not routinely performed on these data.

3.3 OVERVIEW OF THESE DATA

A series of detailed analyses were performed on the mass database to provide an overview of the types of crashes, occupants and vehicles involved in collisions during this period. In addition, this overview analysis enabled a number of checks for consistency and reliability to be made of these data, essential for understanding the value and limitations of the database. This analysis is presented below.

Table 3.1 shows the frequency distributions of several relevant crash, vehicle and patient characteristics, while Tables 3.2 and 3.3 show the breakdown of injury severity for each occupant (the occupant was killed, required long-term or short-term hospitalisation, or only required medical treatment) by impact direction (front, side, rear, or rollover), and the seating position of the occupant (driver, front-centre, front-left, rear-outboard, rear-centre).

The results of injury severity by impact direction in Table 3.2 shows that rollover, frontal, side impact collisions were all over-involved in major injury claims, while rear-end collisions were markedly over-involved in minor (non-hospitalised) injuries. The findings for seating position by injury severity are further shown in Table 3.3. These results suggest that drivers were under-involved, but that front-left and rear outboard passengers were over-involved in severe injury claims on the TAC. Tables 3.4 and 3.5 also show that rear-outboard passengers in frontal crashes and front-left passengers in side impacts were over-represented in severe injuries.

3.3.1 Yearly Analysis of Crashes

The number of crashes each year by injury severity of the crash were examined to show the pattern of crash severity in these data. While the vehicle analysis was primarily interested in post-1981 vehicles and crashes, it was possible, nevertheless, to look at patterns for the whole database which included all vehicles manufactured since 1975 and all claimant crashes since 1st July 1978. As a consequence, this provided a much expanded vehicle database which is always desirable for analysing trends over time.

TABLE 3.1
CHARACTERISTICS OF THE MASS DATA BASE FOR OCCUPANTS OF POST-1981 VEHICLES INJURED IN CRASHES BETWEEN 1982 AND JUNE 1988

CHARACTERISTIC	No. CASES	PERCENTAGE
1. SPEED ZONE OF THE CRASH*		
<76 km/h	8276	71%
>75 km/h	3319	29%
2. CRASH TYPE		
Frontal	7876	47%
Side impact	4164	25%
Rear end	3999	23%
Rollover	878	5%
3. VEHICLE TYPES		
Mini (<750kg)	250	1%
Small (751-1000kg)	7105	42%
Compact (1001-1250kg)	6588	38%
Intermediates (1251-1500kg)	2813	17%
Large (>1500kg)	394	2%
4. TYPE OF DRIVE**		
Front-Wheel-Drive	2778	35%
Rear-Wheel-Drive	5097	65%
5. SEATING POSITION		
Driver	11111	63%
Front-Centre	60	0.5%
Front-Left	4240	24%
Rear-Outboard	1892	10%
Rear-Centre	321	2.5%
6. PATIENT SEX		
Males	7005	41%
Females	9968	59%
7. PATIENT AGE		
< 17 years	1223	7%
17 - 25 yrs	4360	26%
26 - 55 yrs	8599	50%
56 - 75 yrs	2480	15%
> 75 years	298	2%

*The total number of cases shown above varied depending on which data source was used. Wherever possible, TAC data containing approximately 18,000 records (less missing values) was used. The items marked * however could only be obtained from the merged Vic Roads records (approximately 11,500 records), while those marked ** were obtained from 7,900 model identified records.*

TABLE 3.2
IMPACT DIRECTION BY INJURY SEVERITY FOR OCCUPANTS OF POST-1981 CARS INVOLVED IN CRASHES BETWEEN 1982 AND JUNE 1988

IMPACT DIRECTION	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
FRONTAL	245* (186)	938* (737)	1142* (933)	**2080* (1670)**	5551 (6020)	**7876 47%**
SIDE IMPACT	111* (99)	401 (390)	448 (493)	**849 (883)**	3204 (3183)	**4164 25%**
REAR IMPACT	7 (95)	115 (374)	216 (473)	**331 (847)**	3661* (3057)	**3999 23%**
ROLLOVER	37* (21)	129* (82)	198* (104)	**327* (186)**	514 (671)	**878 5%**
TOTAL PATIENTS	**400**	**1583**	**2004**	**3587**	**12930**	**16917**

*Cell entries show the number of injured occupants for each level of injury severity and impact direction. Figures in parenthesis are expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.3
SEATING POSITION BY INJURY SEVERITY FOR OCCUPANTS OF POST-1981 CARS INVOLVED IN CRASHES BETWEEN 1982 AND JUNE 1988

SEATING POSITION	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
DRIVERS	248 (252)	965 (1020)	1185 (1320)	**2150 (2340)**	8713 (8518)	**11111 63%**
FRONT-CENTRE	2 (1.5)	4 (5.5)	7 (7.5)	**11 (13)**	47 (46)	**60 0.5%**
FRONT-LEFT	89 (96)	433* (389)	566* (504)	**999* (893)**	3152 (3251)	**4240 24%**
REAR-OUTBOARD	54* (43)	176 (174)	281* (225)	**457* (399)**	1381 (1450)	**1892 10%**
REAR-CENTRE	7 (7)	40* (30)	56* (38)	**96* (68)**	218 (246)	**321 2.5%**
TOTAL PATIENTS	**400**	**1618**	**2095**	**3713**	**13511**	**17624**

*Cell entries show the number of injured occupants for each level of injury severity and seating position. Figures in parenthesis are expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.4
SEATING POSITION BY INJURY SEVERITY FOR OCCUPANTS OF POST-1981 CARS INVOLVED IN FRONTAL CRASHES BETWEEN 1982 AND JUNE 1988

SEATING POSITION	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
DRIVERS	150 (144)	547 (554)	630 (688)	**1177** **(1242)**	3407 (3348)	**4734** **62%**
FRONT-LEFT	45 (58)	235 (221)	295 (275)	**530** **(496)**	1315 (1337)	**1890** **25%**
REAR-OUTBOARD	32* (25)	86 (97)	145* (120)	**231** **(217)**	563 (584)	**826** **11%**
TOTAL PATIENTS	**227**	**868**	**1070**	**1938**	**5285**	**7450**

*Cell entries show the number of injured occupants for each level of injury severity and seating position. Figures in parenthesis are expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.5
SEATING POSITION BY INJURY SEVERITY FOR OCCUPANTS OF POST-1981 CARS INVOLVED IN SIDE IMPACT CRASHES BETWEEN 1982 AND JUNE 1988

SEATING POSITION	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
DRIVERS	62 (65)	216 (233)	242 (262)	**458** **(495)**	1941 (1900)	**2461** **61%**
FRONT-LEFT	31* (27)	109* (96)	116 (108)	**225*** **(204)**	755 (781)	**1011** **25%**
REAR-OUTBOARD	13 (13)	45 (47)	66* (53)	**111*** **(100)**	372 (383)	**496** **12%**
TOTAL PATIENTS	**106**	**370**	**424**	**794**	**3068**	**3968**

*Cell entries show the number of injured occupants for each level of injury severity and seating position. Figures in parenthesis are expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

Table 3.6 shows the results of this analysis. The growing number of claims on the TAC is a function of increasing exposure (the minimum 1975 vehicle entry threshold means that every year from 1978 onwards, there was a growing population of eligible vehicles). There was an increasing percentage of non-hospital claimants from 1978 up until 1988 which is probably a function of the dynamic nature of the injury compensation scheme in Victoria. There was also some variation in the hospital to fatal ratio between 1978 and 1986 throughout the reign of the Motor Accident Board. Since the introduction of the TAC (1st January 1987), there was a reduction in this ratio.

In short, while there were minor differences in the rates of hospital and non-hospital patients during the data period, there was no suggestion of any particular bias detrimental to an analysis of vehicle occupant injuries in these data.

3.3.2 Vehicle Size And Crash Involvement

Previous evidence suggested that vehicle size should have a major impact on the type of injuries sustained by vehicle occupants (cf. Evans and Wasielewski 1972; etc). Table 3.7 shows the relationship between vehicle size (based on those used by the National Accident Sampling System with minor adjustments to suit local vehicles) and injury severity resulting from the crash.

While there is some suggestion that occupants of smaller vehicles may be over-represented in severe injury crashes, the 3 larger sized vehicles were also over-represented in fatal and hospital admissions, contrary to expectations. As this finding may well be confounded with other influences (e.g., speed of the crash, age of the occupant, crash type, seating position, etc.), it is worth exploring some of these relationships further, using the Vic Roads merged information.

SPEED ZONE OF THE CRASH - Three speed zones have predominantly been used on Victorian roads (60km/h, 75km/h, and 100km/h), where the first two categories refer mainly to urban environments and the later category, rural settings. Hence, differences in vehicle mass involvement by speed environment were first examined.

Table 3.8 shows the relationship between vehicle size and speed zone where the crash occurred. This reveals that occupants of small cars (especially mini-sized vehicles) were over-represented in urban environment crashes (equal to or less than 75km/h posted speed), while intermediate and large car occupants were over-represented in higher speed (>75km/h) rural crashes.

TYPE OF CRASH - Previous evidence suggests that type of impact is likely to have a bearing on the level of injury severity sustained by the vehicle occupant and may well interact with vehicle size in determining occupant injuries (Road Traffic Authority 1988).

Table 3.9 illustrates the relationship between vehicle size and type of collision reported by TAC claimants. Occupants from mini-cars were over-represented in vehicle to vehicle crashes, those from compact and intermediate cars were over-represented in collisions with fixed objects, while occupants from large cars were over-represented in rollover crashes.

This supports the previous finding for speed zone where occupants from smaller cars were more likely to be injured from urban crashes and larger car occupants from rural crashes.

OCCUPANT SEATING POSITION - Previous studies have shown that males are more likely to be drivers, females front seat passengers, and children rear seat occupants (Rogerson and Keall 1990; Fildes et al 1990). In addition, there is a strong belief that younger adults are more likely to be drivers than older adults. It is important, therefore, to consider the effects of vehicle size by seating position for occupants injured in vehicle road crashes.

Table 3.10 shows that injured drivers were over-represented in mini-cars, while front-left and rear-outboard passengers were over-involved in intermediate and large vehicles. While the numbers were small, there was also a suggestion that rear-centre seat occupants were over-represented in the so-called family vehicles (compacts, intermediates, and large cars) and front-centre seat passengers in intermediate and large (this latter finding, however, would be strongly influenced by the general unavailability of a front-centre seat in smaller vehicles).

TABLE 3.6
YEAR OF THE CRASH BY INJURY SEVERITY FOR OCCUPANTS OF PASSENGER CARS MANUFACTURED FROM 1975 ONWARDS AND INVOLVED IN CRASHES BETWEEN 1978 AND JUNE 1988

YEAR OF CRASH	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
1978	56 (5%)	263 (23%)	205 (18%)	**468** 8.4	605 (54%)	**3848**
1979	111 (5%)	546 (22%)	446 (18%)	**992** 8.9	1375 (56%)	**2478**
1980	86 (3%)	674 (20%)	593 (18%)	**1267** 14.7	1965 (59%)	**3318**
1981	130 (3%)	749 (18%)	738 (18%)	**1487** 11.4	2554 (61%)	**4171**
1982	163 (3%)	808 (15%)	876 (17%)	**1684** 10.3	3398 (65%)	**5245**
1983	160 (3%)	750 (12%)	990 (15%)	**1740** 10.9	4549 (71%)	**6449**
1984	163 (2%)	852 (11%)	1110 (14%)	**1962** 12.0	5833 (73%)	**7958**
1985	221 (2%)	1061 (10%)	1303 (12%)	**2364** 10.7	8423 (77%)	**11008**
1986	219 (2%)	1081 (9%)	1593 (13%)	**2674** 12.2	9727 (77%)	**12620**
1987	236 (2%)	848 (7%)	1072 (9%)	**1920** 8.1	9308 (81%)	**11464**
1988	191 (3%)	390 (6%)	508 (7%)	**898** ** 4.7	5795 (84%)	**6884**
TOTAL	**1736** **(2%)**	**8022** **(11%)**	**9434** **(13%)**	**17456** 10.0	**53532** **(74%)**	**72724**

Cell entries show the number of vehicle occupant claims each year by injury severity of the crash for all the data collected by the Motor Accident Board (up until the end of 1986) and by the Transport Accident Commission since 1st January 1987. Figures in parenthesis show the annual percentage of claims for each level of crash severity while the figures underlined show the annual ratio of hospital to fatal claims.

** *is only for a partial year and therefore not totally reliable.*

TABLE 3.7
SIZE OF VEHICLE BY SEVERITY OF INJURY FOR OCCUPANTS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

VEHICLE SIZE	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
MINI-CARS (<750kg)	6 (6)	37* (24)	24 (30)	**61*** **(53)**	183 (191)	**250** **1%**
SMALL CARS (751-1000kg)	131 (167)	645 (669)	845 (851)	**1490** **(1520)**	5484 (5417)	**7,105** **42%**
COMPACTS (1001-1250kg)	186* (155)	636 (620)	780 (789)	**1416** **(1409)**	4986 (5023)	**6,588** **38%**
INTERMEDIATES (1251-1500kg)	73* (66)	247 (264)	351 (337)	**598** **(602)**	2142 (2145)	**2,813** **17%**
LARGE CARS (>1500kg)	8 (9)	49* (37)	55* (47)	**104*** **(84)**	282 (300)	**394** **2%**
TOTALS	**404**	**1614**	**2055**	**3669**	**13077**	**17,150**

*Cell entries show the number of injured occupants by vehicle size for each level of injury severity. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.8
VEHICLE SIZE BY SPEED ZONE OF THE CRASH FOR OCCUPANTS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

VEHICLE SIZE	POSTED SPEED ZONE OF THE CRASH <76km/h	POSTED SPEED ZONE OF THE CRASH >75km/h	**TOTAL VEHICLES**
MINI-CARS (<750kg)	144* (131)	40 (52)	**250** **2%**
SMALL CARS (751-1000kg)	3554 (3391)	1195 (1359)	**4,749** **41%**
COMPACTS (1001-1250kg)	3162 (3160)	1266 (1267)	**4,428** **38%**
INTERMEDIATES (1251-1500kg)	1277 (1421)	714* (570)	**1,991** **17%**
LARGE CARS (>1500kg)	139 (173)	104* (70)	**243** **2%**
TOTALS	**8276**	**3319**	**11,595**

*Cell entries show the number of injured occupants by vehicle size for the two crash zones (environments). Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.9
VEHICLE SIZE BY TYPE OF CRASH FOR OCCUPANTS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

VEHICLE SIZE	OTHER VEHICLE	FIXED OBJECT	ROLLOVER	OTHER TYPE	**TOTAL VEHICLES**
MINI-CARS (<750kg)	149* (133)	22 (30)	3 (5)	11 (17)	**250** **2%**
SMALL CARS (751-1000kg)	3505 (3432)	669 (760)	142 (133)	467 (457)	**4,783** **41%**
COMPACTS (1001-1250kg)	3131 (3195)	786* (708)	110 (124)	425 (426)	**4,428** **38%**
INTERMEDIATES (1251-1500kg)	1412 (1432)	348* (317)	45 (56)	191 (191)	**1,991** **17%**
LARGE CARS (>1500kg)	171 (175)	28 (39)	24* (7)	21 (23)	**243** **2%**
TOTALS	**8368**	**1853**	**324**	**1115**	**11,595**

*Cell entries show the number of injured occupants by vehicle size for the different crash types listed. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.10
VEHICLE SIZE BY OCCUPANTS SEATING POSITION OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

VEHICLE SIZE	DRIVER	FRONT CENTRE	FRONT LEFT	REAR OUTBOARD	REAR CENTRE	**TOTAL VEHICLES**
MINI-CARS (<750kg)	178* (151)	0 (1)	47 (58)	14 (26)	1 (5)	**240** **2%**
SMALL CARS (751-1000kg)	4566 (4268)	15 (22)	1514 (1631)	666 (735)	92 (127)	**6,853** **42%**
COMPACTS (1001-1250kg)	3865 (3956)	21 (20)	1570 (1512)	669 (682)	130* (118)	**6,255** **38%**
INTERMEDIATES (1251-1500kg)	1511 (1707)	11* (9)	727* (653)	367* (294)	71* (51)	**2,687** **16%**
LARGE CARS (>1500kg)	198 (236)	5* (1)	86 (90)	62* (41)	14* (7)	**365** **2%**
TOTALS	**10,318**	**52**	**3944**	**1778**	**308**	**16,400**

*Cell entries show the number of injured occupants by vehicle size for the different age groups listed. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

These results probably reflect the fact that larger cars are more likely to have more passengers.

AGE OF THE OCCUPANT - Age of the occupant could be expected to be a compounding factor in the analysis of the effect of vehicle size on injury severity as vehicle usage patterns are likely to be different across the various age groups and that frailty increases with increasing age. Hence, it is necessary to examine the relationship between occupant age and vehicle usage fully.

Table 3.11 shows that children aged below 17 years were over-represented as injured occupants of large cars, young adults (those 17 to 25 years) were over-represented as injured occupants from small vehicles, adults aged 26 to 55 years were over-involved in intermediate and large vehicle crashes, while the very old (those aged greater than 75 years) were more likely to have come from mini and small passenger cars.

These results would be expected to reflect differences in both usage patterns and occupant frailty amongst the motoring population.

SEX OF THE OCCUPANT - Previous studies by Fildes et al (1990) have shown a higher rate of male drivers and female front seat passengers in urban and rural areas than expected from licensing rates. Differences in the sex of occupants by vehicle size, therefore, was examined in Table 3.12.

These results show that the larger the passenger car, the more likely the injured occupant is going to be male. Females made up 59% of the total number of injured occupants recorded by the TAC. This figure is noticeably higher than that observed for licensed drivers (46%, Vic Roads 1989) or the population at large (51%, ABS 1990).

SUMMARY - The above analysis of vehicle size suggests that the speed zone of the crash, the type of crash, the seating position of the occupant, and possibly the age and sex of the occupant were, to some degree, confounding factors in the vehicle size (mass) analysis. Of these, speed zone appeared to be an important factor in these analyses. When controlling for speed zone (that is, for crashes that occurred in urban areas only, <76km/h), Table 3.13 reveals, in fact, that occupants of smaller cars were over-represented in severe injury crashes, compared to occupants from larger passenger cars.

Given the influence of these confounding variables and the relatively small amount of data available, it is doubtful whether analysis of vehicle model by injury severity is feasible without the use of sophisticated modelling techniques beyond the scope of resources available for this project.

3.3.3 Seat Belt Wearing

Seat belt wearing information was available for approximately 60% of the TAC claimants after the police data was merged with the TAC data file. Hence, it was possible to analyse injuries and injury severity by whether the occupant was reportedly restrained or not. However, it was first necessary to examine the incidence of seat belt wearing by the various crash, vehicle, and personal characteristics to understand these data fully.

Table 3.14 shows the relationship between seat belt wearing (reported by the police) and injury severity resulting from the crash, where those not reportedly wearing seat belts at the time of their collision were over-represented in severe injury categories (killed or hospitalised). This has been reported previously (McLean et al 1979; Ryan et al 1988).

It should be noted that belt wearing as reported by the police was 98% of all known cases. This is higher than that expected from exposure studies of seat belt wearing (94% in this state) and from what was expected, given the fact that seat belts are supposed to reduce occupant injuries (McLean et al 1979 reported non-wearing rates among road fatalities around 40%).

A small comparative examination was carried out of seat belt wearing as reported on police accident reports and from a detailed examination of the belts in the crashed vehicle sample reported in a later section of this report. The results are shown in Table 5.8 on page 115 and show a 12% over-reporting rate of seat belt use by police for those hospitalised from road crashes.

TABLE 3.11
VEHICLE SIZE BY AGE OF THE OCCUPANTS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

VEHICLE SIZE	AGE OF THE OCCUPANT <17yrs	17-25yrs	26-55yrs	56-75yrs	>75yrs	**TOTAL VEHICLES**
MINI-CARS (<750kg)	14 (18)	60 (64)	131 (126)	34 (36)	9* (4)	**248** **2%**
SMALL CARS (751-1000kg)	400 (506)	2143* (1803)	3218 (3556)	1098 (1025)	156* (123)	**7,015** **41%**
COMPACTS (1001-1250kg)	491 (469)	1621 (1672)	3376 (3298)	930 (951)	87 (114)	**6,505** **38%**
INTERMEDIATES (1251-1500kg)	265* (202)	491 (721)	1632* (1422)	377 (410)	40 (49)	**2,805** **17%**
LARGE CARS (>1500kg)	53• (28)	45 (99)	242* (196)	41 (57)	6 (7)	**387** **2%**
TOTALS	**1223**	**4360**	**8599**	**2480**	**298**	**16,960**

*Cell entries show the number of injured occupants by vehicle size for the different age groups listed. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.12
VEHICLE SIZE BY SEX OF THE OCCUPANT OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

VEHICLE SIZE	SEX OF THE OCCUPANT females	males	**TOTAL VEHICLES**
MINI-CARS (<750kg)	176* (146)	72 (102)	**248** **2%**
SMALL CARS (751-1000kg)	4646* (4123)	2375 (2898)	**7,021** **41%**
COMPACTS (1001-1250kg)	3563 (3822)	2945 (2685)	**6,508** **38%**
INTERMEDIATES (1251-1500kg)	1402 (1649)	1406* (1158)	**2,808** **17%**
LARGE CARS (>1500kg)	181 (228)	207* (160)	**388** **2%**
TOTALS	**9968**	**7005**	**16,973**

*Cell entries show the number of injured occupants by vehicle size for the two sexes of the occupants. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.13
SIZE OF VEHICLE BY SEVERITY OF INJURY FOR DRIVERS INVOLVED IN FRONTAL COLLISIONS IN AN URBAN SPEED ENVIRONMENT (<76km/h).

VEHICE SIZE	FATAL	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
MINI-CARS (<750kg)	4* (2)	20* (12)	14 (15)	**34*** **(27)**	106 (115)	**144** **2%**
SMALL CARS (751-1000kg)	39 (55)	315* (293)	378 (370)	**693** **(663)**	2822 (2836)	**3554** **43%**
COMPACTS (1001-1250kg)	65* (49)	257 (261)	327 (329)	**584** **(590)**	2513 (2523)	**3162** **38%**
INTERMEDIATES (1251-1500kg)	20 (20)	82 (105)	127 (133)	**209** **(238)**	1048 (1018)	**1277** **15%**
LARGE CARS (>1500kg)	1 (2)	8 (12)	16* (15)	**24** **(27)**	114 (111)	**139** **2%**
TOTALS	**129**	**682**	**862**	**1544**	**6603**	**8276**

*Cell entries show the number of injured occupants by vehicle size for each level of injury severity. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.14
SEAT BELT WEARING BY SEVERITY OF INJURY FOR OCCUPANTS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

SEAT BELT WEARING	FATAL	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
WEARERS	226 (258)	1049 (1065)	1414 (1432)	**2460** **(2497)**	8023 (7953)	**10,709** **98%**
NON-WEARERS	37* (5)	40* (21)	46* (28)	**86*** **(49)**	85 (154)	**208** **2%**
TOTALS	**263**	**1086**	**1460**	**2546**	**8108**	**10,917**

*Cell entries show the number of injured occupants by seat belt wearing for each level of injury severity. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

It is important therefore to realise that the group of vehicle occupants reported as wearing seat belts in these data contain a proportion of non-wearers of around 12 percent. This will introduce a degree of error in any subsequent analysis of injuries to belt wearers amongst this group. However, those reported to be non-wearers are most likely to be accurate assessments. These findings need to be considered carefully in any further analysis of belt wearing in these data.

SPEED ZONE OF THE CRASH - Table 3.15 shows the finding for seat belt wearing by speed zone (urban or rural environment) where the crash occurred, which shows an over-involvement of non-wearing occupants for crashes that occurred in rural settings (i.e., in speed zones greater than 75km/h).

VEHICLE SIZE - The restraint status of injured occupants by vehicle size is elaborated upon in Table 3.17 below. While the numbers in some of the categories were really quite small, nevertheless there was a tendency for unrestrained occupants of compacts and large passenger cars to be over-represented.

OCCUPANT SEATING POSITION - The relationship between seat belt wearing and occupant seating position in the crash is shown in Table 3.18. This demonstrates an over-involvement of injured occupants who were unrestrained passengers in the front-centre and rear seating positions. This result needs to be viewed in conjunction with the findings for seat belt wearing by age and sex of the occupant.

OCCUPANT AGE - The analysis of reported seat belt wearing status by age group of the occupant is shown in Table 3.19, revealing than children under 17 years, young adults (17 to 25 years) and those older than 75 years are over-represented as non-wearers of seat belts in these crashes.

SEX OF THE OCCUPANT - Table 3.20 illustrates the relationship between seat belt status and sex of the occupant, where males were over-involved as non-wearers of seat belts amongst TAC injured occupant claimants.

SUMMARY - The analysis of seat belt wearing behaviour showed that non-wearing occupants were over-represented in severe injury crashes, those occurring in high speed rural environments, and those involving frontal impact and rollovers. Non-wearing injured occupants were also over-involved as front-centre or rear seat passengers from compact and large vehicles, although this result is likely to be compounded by differences in the speed of the impact. Non-wearing behaviour was more prevalent amongst children, young and very old adults, and males. These results were generally consistent with what is known about seat belt wearing behaviour and the protective effects of seat belts in collisions. However, as previously discussed, some caution needs to be exercised in these results because of the tendency for seat belt wearing to be over-reported in these data.

3.3.4 Occupant Characteristics

CRASH INVOLVEMENT RATES - Figure 3.1 shows the crash involvement rates by age group per 100,000 population, revealing that children were generally less likely to be a claimant on the TAC than adults. Those aged 17-25 years were considerably over-involved in all injury severity categories and involvement rate decreased with age up to 75 years. While elderly occupants were less likely to be involved in injury crashes than younger adults, they were, however, more likely to be killed, given a crash. These findings do not take into account differences in vehicle exposure between the different aged occupants.

FIGURE 3.1 Crash involvement rates per 100,000 population of the various claimant age groups on the TAC.

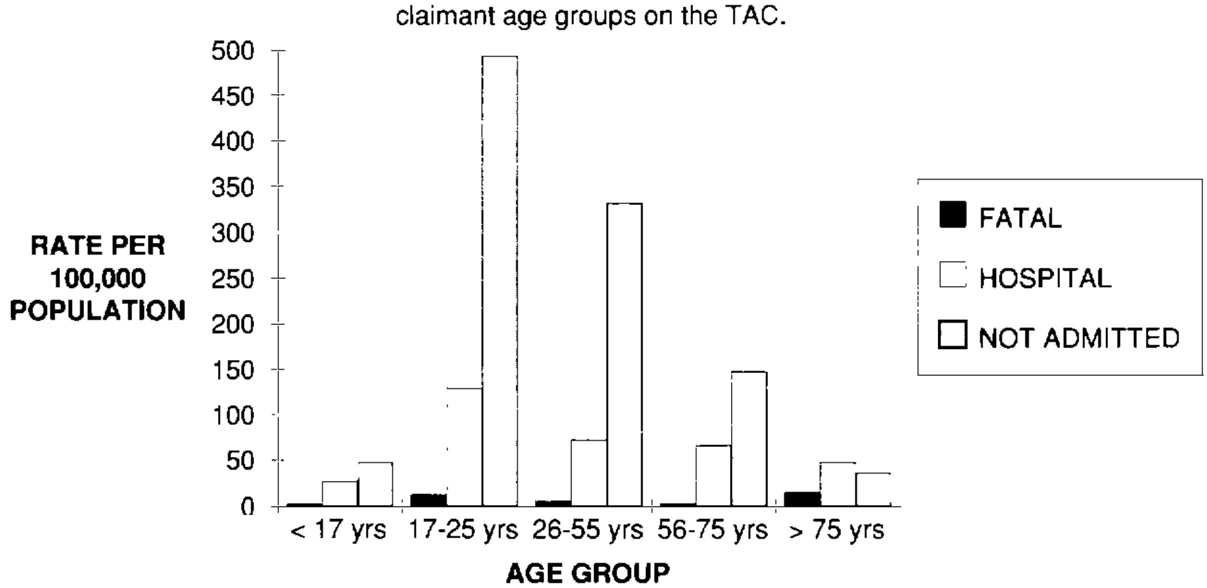

TABLE 3.15
SEAT BELT WEARING BY SPEED ZONE OF THE CRASH FOR OCCUPANTS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

BELT WEARING	POSTED SPEED ZONE OF THE CRASH SITE <76km/h	>75km/h	**TOTAL VEHICLES**
WEARERS	7684 (7653)	2971 (3002)	**10,655** **98%**
NON-WEARERS	115 (146)	88* (57)	**203** **2%**
TOTALS	**7799**	**3059**	**10,858**

*Cell entries show the number of injured occupants by seat belt wearing for the two crash zones (environments). Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.16
SEAT BELT WEARING BY IMPACT DIRECTION OCCUPANTS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

BELT WEARING	IMPACT DIRECTION FRONTAL	SIDE	REAR-END	ROLLOVER	**TOTAL VEHICLES**
WEARERS	5208 (5219)	2824 (2816)	1869 (1858)	550 (559)	**10,451** **98%**
NON-WEARERS	107* (96)	44 (52)	23 (34)	19* (10)	**193** **2%**
TOTALS	**5315**	**2868**	**1892**	**569**	**10,644**

*Cell entries show the number of injured occupants by seat belt wearing for the different impact directions listed. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.17
VEHICLE SIZE BY SEAT BELT WEARING STATUS FOR OCCUPANTS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

BELT WEARING	VEHICLE SIZE mini	small	compact	inter.	large	**TOTAL VEHICLES**
WEARERS	156 (155)	4136 (4128)	3784 (3794)	1723 (1721)	206 (207)	**10,005** **98%**
NON-WEARERS	2 (3)	72 (80)	84* (74)	32 (34)	5* (4)	**195** **2%**
TOTALS	**158**	**4208**	**3868**	**1755**	**211**	**10,200**

*Cell entries show the number of injured occupants by seat belt wearing for the different vehicle sizes listed. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.18
SEAT BELT WEARING BY SEATING POSITION FOR OCCUPANTS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

BELT WEARING	SEATING POSITION driver	F-centre	F-left	R-out.	R-centre	**TOTAL VEHICLES**
WEARERS	7063 (7032)	24 (27)	2596 (2597)	1068 (1090)	171 (176)	**10,922** **98%**
NON-WEARERS	95 (126)	3* (1)	48 (47)	42* (20)	8* (3)	**196** **2%**
TOTALS	**7158**	**27**	**2644**	**1110**	**179**	**11,118**

*Cell entries show the number of injured occupants by seat belt wearing for the different seating positions. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

OCCUPANT AGE BY SEVERITY - Table 3.21 shows the relationship between occupant age group and crash severity for TAC claimants. These results show that young (under 17 years) and older occupants (over 55 years) are more likely to be killed in vehicle crashes than other age groups. For those aged 55 years or more, they are also more likely to be hospitalised.

The occupant age by injury severity comparison is broken down further by seating position in Tables 3.22 to 3.24. These results demonstrate that elderly occupants were more likely to be severely injured in all seating positions (drivers, front seat, and rear passengers) than all other age groups. There is also a tendency for adolescents and young drivers to be slightly over-represented as drivers killed and as serious hospital cases for rear seat passengers, but under-represented as severely injured front seat passengers.

TABLE 3.19
SEAT BELT WEARING BY AGE OF THE OCCUPANTS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

VEHICLE SIZE	AGE OF THE OCCUPANT <17yrs	17-25yrs	26-55yrs	56-75yrs	>75yrs	**TOTAL VEHICLES**
WEARERS	774 (788)	2907 (2915)	5484 (5464)	1724 (1719)	216 (219)	**11,105** **98%**
NON-WEARERS	29* (15)	64* (56)	84 (104)	28 (33)	7* (4)	**212** **2%**
TOTALS	**803**	**2971**	**5568**	**1752**	**223**	**11,317**

*Cell entries show the number of injured occupants by seat belt wearing for the different age groups listed. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.20
SEAT BELT WEARING BY SEX OF THE OCCUPANT OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

VEHICLE SIZE	SEX OF THE OCCUPANT females	males	**TOTAL VEHICLES**
WEARERS	6518 (6489)	4592 (4620)	**11,110** **98%**
NON-WEARERS	95 (124)	117* (88)	**212** **2%**
TOTALS	**6613**	**4709**	**11,322**

*Cell entries show the number of injured occupants by seat belt wearing for the two sexes of the occupants. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.21
OCCUPANT AGE BY SEVERITY OF INJURY FOR OCCUPANTS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

OCCUPANT AGE	FATAL	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
< 17 yrs	38* (31)	81 (123)	221* (157)	**302 (280)**	979 (1009)	**1,319 7%**
17 - 25 yrs	105 (108)	333 (433)	533 (552)	**866 (985)**	3671 (3549)	**4,642 26%**
26 - 55 yrs	162 (213)	773 (858)	1004 (1094)	**1777 (1952)**	7257 (7031)	**9,196 51%**
56 - 75 yrs	81* (62)	410* (250)	360* (319)	**770* (569)**	1830 (2050)	**2,681 15%**
> 75 yrs	35* (8)	98* (31)	44* (40)	**142* (71)**	158 (256)	**335 2%**
TOTAL	**421**	**1695**	**2162**	**3857**	**13895**	**18,173**

*Cell entries show the number of injured occupants by severity of injury for the different age groups of the occupants. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.22
OCCUPANT AGE BY SEVERITY OF INJURY FOR DRIVERS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

OCCUPANT AGE	FATAL	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
< 17 yrs	3* (1)	3* (2.5)	1 (3)	**4 (5.5)**	21 (22)	**28 0.3%**
17 - 25 yrs	68 (64)	180 (250)	297 (307)	**477 (557)**	2333 (2257)	**2,878 26%**
26 - 55 yrs	116 (145)	515 (566)	661 (694)	**1176 (1358)**	5214 (5101)	**6,506 59%**
56 - 75 yrs	47* (35)	224• (134)	204* (165)	**428* (299)**	1074 (1214)	**1,549 14%**
> 75 yrs	13* (3)	43* (12)	22* (15)	**65* (27)**	64 (111)	**142 1%**
TOTAL	**247**	**965**	**1185**	**2150**	**8706**	**11,103**

*Cell entries show the number of injured occupants by injury severity for the different age groups of the occupants. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.23
OCCUPANT AGE BY SEVERITY OF INJURY FOR FRONT PASSENGERS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

OCCUPANT AGE	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
< 17 yrs	7 (8)	21 (36)	54* (47)	**75 (83)**	272 (263)	**354 8%**
17 - 25 yrs	17 (24)	82 (116)	146 (152)	**228 (268)**	899 (851)	**1,144 27%**
26 - 55 yrs	30 (40)	176 (192)	245 (252)	**421 (444)**	1443 (1409)	**1,894 44%**
56 - 75 yrs	25* (17)	123* (80)	112 (105)	**235* (185)**	529 (587)	**789 18%**
> 75 yrs	12* (3)	34* (12)	16 (16)	**50* (28)**	54 (86)	**116 3%**
TOTAL	**91**	**436**	**573**	**1009**	**3197**	**4,297**

*Cell entries show the number of injured occupants by severity of injury for the different age groups of the occupants. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.24
OCCUPANT AGE BY SEVERITY OF INJURY FOR REAR PASSENGERS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

OCCUPANT AGE	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
< 17 yrs	21 (23)	37 (80)	145* (125)	**182 (205)**	614 (590)	**817 37%**
17 - 25 yrs	15 (14)	56* (48)	75 (75)	**131 (121)**	349 (357)	**495 22%**
26 - 55 yrs	11 (16)	63* (57)	82 (88)	**145 (145)**	422 (418)	**578 26%**
56 - 75 yrs	8* (7)	42* (26)	31 (40)	**73* (66)**	183 (191)	**264 12%**
> 75 yrs	6* (2)	18* (6)	4 (8)	**22* (14)**	29 (41)	**57 3%**
TOTAL	**61**	**216**	**337**	**553**	**1597**	**2,211**

*Cell entries show the number of injured occupants by severity of injury for the different age groups of the occupants. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

Occupant age is finally examined by speed zone in Table 3.25 where it is apparent that young occupant casualties are over-represented in high speed zones (rural areas).

TABLE 3.25
OCCUPANT AGE BY SPEED ZONE OF THE CRASH FOR OCCUPANTS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

OCCUPANT AGE	POSTED SPEED ZONE OF THE CRASH SITE <76km/h	>75km/h	**TOTAL VEHICLES**
< 17 yrs	617 (697)	356 • (276)	**973** **8%**
17 - 25 yrs	2419 (2355)	871 (935)	**3,290** **27%**
26 - 55 yrs	4308 (4300)	1698 (1706)	**6,006** **48%**
56 - 75 yrs	1349 (1348)	534 (535)	**1,883** **15%**
> 75 yrs	182 (175)	63 (70)	**245** **2%**
TOTALS	**8875**	**3522**	**12,397**

Cell entries show the number of injured occupants by age group for the two crash zones (environments). Figures in parenthesis are the expected values based on row and column totals, while • shows those which are over-represented (10% or more above the expected value).

SEX OF THE OCCUPANT - Tables 3.26 to 3.28 show the relationship between sex of the occupant by injury severity, seating position, and impact direction. In Table 3.26, males were over-involved in severe injury compared with female claimants. This was probably a further reflection of their over-involvement as non-wearers of seat belts (Table 3.20), as occupants of intermediate and large cars (Table 3.12), and of having had their crash in high speed rural environments (not shown here).

In addition, Table 3.27 further shows that males were over-represented as drivers while females over-represented as front and rear seat passengers, while Table 3.28 illustrates that females were more likely to be injured from a rear-end collision, and males more likely to be in a rollover collision. Again, this could simply reflect the fact that males are more likely to be drivers of vehicles than females, especially in high speed zone rural areas (Fildes et al 1990).

Other studies (eg, Transport Accident Commission Road Trauma Unit 1988, Fildes & Vulcan 1990) have shown that females have an over-involvement in whiplash claims at the TAC and are more vulnerable to these soft tissue injuries than are males. The type of injuries sustained by both sex groups will be compared in a later section of this report.

SUMMARY - The occupant characteristics analysis showed that young and old vehicle occupants are particularly at risk of severe injury and death from vehicle crashes. Moreover, males are more vulnerable to severe injury than females, probably the result of their increased exposure as drivers in high speed rural environments. Females were especially prone to minor injuries from rear-end crashes. With the possible exception of improved seat design and head restraint (especially for females), it is doubtful, though, whether there is much that can be done in terms of improved vehicle design to alleviate these sex effects.

TABLE 3.26
SEX OF THE OCCUPANT BY INJURY SEVERITY FOR ALL OCCUPANTS OF POST-1981 CARS INVOLVED IN CRASHES BETWEEN 1982 AND JUNE 1988.

SEX OF THE OCCUPANT	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
FEMALES	171 (248)	943 (997)	1155 (1271)	**2098** **(2268)**	8429* (8180)	**10,698** **59%**
MALES	251* (174)	753* (698)	1007* (890)	**1760** **(1588)**	5478 (5726)	**7,489** **41%**
TOTAL	**422**	**1696**	**2162**	**3858**	**13907**	**18,187**

Cell entries show the number of injured occupants by severity of injury for the different sexes of the occupants. Figures in parenthesis are the expected values based on row and column totals, while • shows those which are over-represented (10% or more above the expected value).

TABLE 3.27
SEX OF THE OCCUPANT BY SEATING POSITION FOR ALL OCCUPANTS OF POST-1981 CARS INVOLVED IN CRASHES BETWEEN 1982 AND JUNE 1988.

SEX OF THE OCCUPANT	DRIVER	FRONT CENTRE	FRONT LEFT	REAR OUTBOARD	REAR CENTRE	TOTAL
FEMALES	5769 (6536)	37 (35)	3090* (2494)	1151 (1113)	212* (189)	**10,259** **58%**
MALES	5342* (4575)	23 (24)	1150 (1746)	675 (778)	109 (132)	**7,299** **42%**
TOTAL	**11111**	**60**	**4240**	**1826**	**321**	**17,558**

*Cell entries show the number of injured occupants by severity of injury for the different sexes of the occupants. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.28
SEX OF THE OCCUPANT BY IMPACT DIRECTION FOR ALL OCCUPANTS OF POST-1981 CARS INVOLVED IN CRASHES BETWEEN 1982 AND JUNE 1988.

OCCUPANT SEX	FRONT	SIDE	REAR	ROLLOVER	TOTAL
FEMALES	4477 (4628)	1223 (1193)	2553* (2350)	433 (516)	**8,686**
MALES	3399 (3247)	807 (837)	1446 (1649)	445* (362)	**6,097**
TOTAL	**7876**	**2030**	**3999**	**878**	**14,783**

*Cell entries show the number of injured occupants by severity of injury for the different sexes of the occupants. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

3.3.5 Vehicle Make & Model Analysis

The routine developed by RACV Limited for identifying the most recent and popular vehicle models, based on the vehicle's make, year of manufacture, engine power, weight, and engine number was applied to these data. In total, 7876 (43%) vehicle models were able to be identified using this method. Additional work is currently planned to improve the identification procedure and expand on the number of models that can be identified.

The previous section describing the yearly analysis of crashes on the database (Section 3.3.1) highlighted a number of inconsistencies in the ratios of fatal, hospitalised, and non-hospitalised injured vehicle occupants, especially between the MAB and the TAC records. As the identification procedure tended to emphasise recent vehicles, extensive additional analysis would be necessary (involving detailed and time consuming modelling procedures) before it would be possible to use these data in a meaningful manner. This was beyond the scope of this research program and will require additional research effort. No further model analysis of these data, therefore, are reported here.

3.3.6 Front- & Rear-Wheel Drive

The final overview analysis of the mass data examined the extent that the type of drive of the vehicle (and consequently engine configuration) had on the type of crashes and injuries to front seat occupants.

VEHICLE SIZE (MASS) - Table 3.29 illustrates the relationship between type of drive and vehicle mass (size). These results clearly show that front-wheel drive vehicles were more likely to be small and rear-wheel drive, large vehicles, demonstrating a confounding relationship between these two variables in these data.

SPEED ZONE OF THE CRASH - Table 3.30 shows very little difference in involvement pattern for front seat occupants of front- or rear-wheel drive cars by high and low speed zone of the crash.

INJURY SEVERITY - Table 3.31 shows the relationship between type of drive and outcome severity where there was some suggestion that front seat occupants of rear wheel drive cars were over-represented amongst fatal injury outcomes. Moreover, Tables 3.32 and 3.33 further show that the over-representation was equally apparent for both drivers and front seat passengers of rear-wheel drive vehicles.

IMPACT DIRECTION - Table 3.34 reveals that rear-wheel drive cars were over-involved in front and rollover collisions as expected from the size findings reported earlier. Importantly, though, Table 3.35 shows no particular difference in the severity injury pattern between front- and rear-wheel driver vehicles in frontal crashes to that reported in Table 3.31.

SUMMARY - The analysis of type of drive of vehicle involved in the crash showed that rear-wheel drives were more likely to be over-represented in high speed crashes and those involving more severe injury outcomes. However, there was a high correlation between type of drive and vehicle size where front-wheel drive vehicles were more likely to be small cars and rear-wheel drive, large cars.

There did not appear to be any specific injury disbenefits for either drive configuration in terms of outcome, seating position, or impact direction beyond that previously reported for the other variables.

3.3.7 Summary Of The Overview Analysis

The descriptive analysis of these data has demonstrated the characteristics of the variables of most

TABLE 3.29
DRIVE CONFIGURATION BY VEHICLE SIZE FOR FRONT SEAT OCCUPANTS OF POST-1981 CARS INVOLVED IN CRASHES BETWEEN 1982 AND JUNE 1988.

DRIVE TYPE	VEHICLE SIZE mini	small	compact	inter.	large	**TOTAL VEHICLES**
FRONT-WHEEL	16* (6)	1244* (684)	385 (611)	13 (342)	0 (14)	**1,658** **37%**
REAR-WHEEL	0 (10)	592 (1152)	1257* (1030)	908* (578)	38* (24)	**2,795** **63%**
TOTALS	**16**	**1836**	**1642**	**921**	**38**	**2,795**

*Cell entries show the number of front- and rear-wheel drives for the different vehicle sizes listed. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.30
DRIVE CONFIGURATION BY SPEED ZONE OF THE CRASH FOR FRONT SEAT OCCUPANTS OF POST-1981 CARS INVOLVED IN CRASHES BETWEEN 1982 AND JUNE 1988.

DRIVE TYPE	POSTED SPEED ZONE OF THE CRASH SITE <76km/h	>75km/h	**TOTAL VEHICLES**
FRONT-WHEEL	1485 (1446)	290 (329)	**1,775** **37%**
REAR-WHEEL	2377 (2415)	588 (549)	**2,965** **63%**
TOTALS	**3862**	**878**	**4,740**

*Cell entries show the number of front- and rear-wheel drive vehicles for the two speed zones (crash environments). Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.31
DRIVE CONFIGURATION BY SEVERITY OF INJURY FOR FRONT SEAT OCCUPANTS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

DRIVE TYPE	**FATAL**	HOSPITALISATION >6days	<7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
FRONT-WHEEL	3 (9)	77 (77)	116 (135)	**193** **(212)**	1370 (1345)	**1,566** **38%**
REAR-WHEEL	22* (16)	126 (126)	243 (224)	**369** **(350)**	2195 (2220)	**2586** **62%**
TOTALS	**25**	**203**	**359**	**562**	**3565**	**4,152**

*Cell entries show the number of injured occupants by type of drive for each level of injury severity. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.32
DRIVE CONFIGURATION BY SEVERITY OF INJURY FOR DRIVERS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

DRIVE TYPE	FATAL	HOSPITALISATION >6days	HOSPITALISATION <7days	TOTAL HOSPITAL INJURY	MEDICAL TREATMENT ONLY	TOTAL INJURY
FRONT-WHEEL	3 (7)	50 (51)	75 (93)	**125 (144)**	1048 (1026)	**1,176 39%**
REAR-WHEEL	15• (11)	81 (80)	165• (147)	**246 (227)**	1602 (1624)	**1,863 61%**
TOTALS	**18**	**131**	**240**	**371**	**2650**	**3,039**

*Cell entries show the number of injured drivers by type of drive for each level of injury severity. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

TABLE 3.33
DRIVE CONFIGURATION BY SEVERITY OF INJURY FOR FRONT-LEFT PASSENGERS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

DRIVE TYPE	FATAL	HOSPITALISATION >6days	HOSPITALISATION <7days	TOTAL HOSPITAL INJURY	MEDICAL TREATMENT ONLY	TOTAL INJURY
FRONT-WHEEL	0 (3)	27 (25)	41 (41)	**68 (66)**	321 (320)	**389 35%**
REAR-WHEEL	7* (5)	44 (46)	76 (76)	**120 (122)**	589 (590)	**716 65%**
TOTALS	**7**	**71**	**117**	**188**	**910**	**1,105**

Cell entries show the number of injured front-left passengers by type of drive for each level of injury severity. Figures in parenthesis are the expected values based on row and column totals, while • shows those which are over-represented (10% or more above the expected value).

TABLE 3.34
DRIVE CONFIGURATION BY IMPACT DIRECTION FOR FRONT SEAT OCCUPANTS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988.

DRIVE TYPE	IMPACT DIRECTION FRONTAL	SIDE	REAR-END	ROLLOVER	TOTAL VEHICLES
FRONT-WHEEL	5208 (5219)	2824 (2816)	1869 (1858)	550 (559)	**10,451 98%**
REAR-WHEEL	107* (96)	44 (52)	23 (34)	19* (10)	**193 2%**
TOTALS	**5315**	**2868**	**1892**	**569**	**10,644**

Cell entries show the number of injured occupants by type of drive for the different impact directions listed. Figures in parenthesis are the expected values based on row and column totals, while • shows those which are over-represented (10% or more above the expected value).

TABLE 3.35
DRIVE CONFIGURATION BY SEVERITY OF INJURY FOR FRONT SEAT OCCUPANTS OF POST-1981 CARS INVOLVED IN FRONTAL CRASHES BETWEEN 1982 AND JUNE 1988.

DRIVE TYPE	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
FRONT-WHEEL	2 (8)	40 (44)	74 (81)	**114 (125)**	653 (636)	**769 37%**
REAR-WHEEL	20* (14)	78 (74)	143 (136)	**221 (210)**	1055 (1072)	**1296 63%**
TOTALS	**22**	**118**	**217**	**335**	**1708**	**2065**

*Cell entries show the number of injured occupants by type of drive for each level of injury severity. Figures in parenthesis are the expected values based on row and column totals, while * shows those which are over-represented (10% or more above the expected value).*

interest in these data and highlighted some potential problems and limitations. For instance, it would be problematic to undertake extensive further analysis by seat belt wearing, given the apparent extent of over-reporting in these data, or by type of drive, given its interrelationship with vehicle size. In addition, an evaluation of occupant protection performance by vehicle make and model would be premature without further research to assess the effects of variations in data reporting on this analysis.

The overview analysis, however, does suggest that further analysis by occupant injury is justified for a number of these variables and this is attempted in the next section.

3.4 ANALYSIS OF OCCUPANT INJURIES

The most valuable and unique aspect of the database assembled for this analysis was the availability of up to five ICD9 injuries coded for each TAC vehicle occupant claimant that can be analysed by the numerous crash, vehicle and occupant characteristics. Detailed and accurate data of this kind is rarely available on mass data systems for undertaking these analyses. This section concentrates on the analysis of these injuries (grouped into 17 body regions including major and minor injury severity) by severity of the outcome of the crash (killed, hospitalised, or non-hospitalised) across the various other factors of interest.

There are many potential comparisons that could be carried out on these data if an exhaustive injury analysis was to be undertaken here. Such an approach would not be easy to interpret or a particularly meaningful exercise. A better approach would be to conduct selective analyses dependent upon questions or issues particularly relevant to occupant protection. This approach was adopted in the following section.

3.4.1 Principal Versus Multiple Injuries

In coding injuries sustained by vehicle occupants, the TAC ascribe one of the 5 injuries as the principal injury sustained by each vehicle occupant. This judgement is made on the basis of the seriousness of the threat to life which, for example, ranks spinal and head injuries as more life threatening than injuries to the extremities, and fractures ahead of sprains and strains.

This study, however, was primarily concerned with all types of injuries sustained by occupants of modern passenger cars. It was considered more important to ensure that all injuries were included in any analysis of occupant injuries, rather than only the principal injury when considering possible occupant protection improvements.

Table 3.36 shows the overall pattern of multiple injuries (up to 5 per patient) sustained by occupants of current generation passenger cars involved in Victorian road crashes that were reported to the TAC between 1982 and 1988. For fatal cases, major injuries to the head (100%), chest (89%), and

TABLE 3.36
MULTIPLE INJURIES SUSTAINED BY OCCUPANTS OF POST-1981 PASSENGER CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	FATAL	HOSPITALISATION >6days	HOSPITALISATION <7days	TOTAL HOSPITAL INJURY	MEDICAL TREATMENT ONLY	TOTAL INJURY
HEAD: Major	407 (96%)	208 (12%)	81 (4%)	**289 (8%)**	72 (0.5%)	**768 (4%)**
HEAD: Minor	15 (4%)	516 (30%)	806 (37%)	**1322 (34%)**	1234 (9%)	**2571 (14%)**
FACE: Major	25 (6%)	250 (15%)	183 (8%)	**433 (11%)**	141 (1%)	**599 (3%)**
FACE: Minor	3 (1%)	123 (7%)	428 (20%)	**551 (14%)**	3902 (28%)	**4456 (25%)**
NECK: Whiplash	2 (0.5%)	194 (11%)	429 (20%)	**623 (16%)**	4884 (35%)	**5509 (30%)**
SPINE: Fracture	36 (9%)	207 (12%)	48 (2%)	**255 (7%)**	77 (0.5%)	**368 (4%)**
SHOULDER: Major	6 (2%)	147 (9%)	72 (3%)	**219 (6%)**	112 (1%)	**337 (2%)**
SHOULDER: Minor	0 (-)	42 (2%)	81 (4%)	**123 (3%)**	440 (3%)	**563 (3%)**
CHEST: Major	375 (89%)	715 (42%)	411 (19%)	**1126 (29%)**	403 (3%)	**1904 (10%)**
CHEST: Minor	1 (0.2%)	164 (10%)	407 (19%)	**571 (15%)**	2318 (17%)	**2890 (16%)**
ABDOMEN: Major	194 (46%)	186 (11%)	45 (2%)	**231 (6%)**	43 (0.5%)	**468 (3%)**
ABDOMEN: Minor	1 (0.2%)	164 (10%)	407 (19%)	**571 (15%)**	2318 (17%)	**2890 (16%)**
UPP LIMB: Major	30 (7%)	274 (16%)	131 (6%)	**405 (10%)**	209 (2%)	**644 (4%)**
UPP LIMB: Minor	6 (2%)	204 (12%)	453 (21%)	**657 (17%)**	2930 (21%)	**3593 (20%)**
LOW LIMB: Major	53 (13%)	558 (33%)	88 (4%)	**646 (17%)**	168 (1%)	**867 (5%)**
LOW LIMB: Minor	8 (2%)	439 (26%)	738 (34%)	**1177 (31%)**	3772 (22%)	**4957 (27%)**
OTHER/UNKNOWN	130 (31%)	481 (28%)	363 (17%)	**844 (22%)**	3112 (22%)	**4136 (23%)**
TOTAL INJURIES	**1342**	**4851**	**5104**	**9955**	**26571**	**37868**
TOTAL PATIENTS	**422**	**1696**	**2162**	**3858**	**13907**	**18187**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

the abdomen (46%) were most frequent, while for hospitalised cases, there were frequent lower limb (48%), chest (44%), head (42%), upper limb (27%), face (25%), and abdominal (21%) injuries. Whiplash, minor face, upper and lower limb, and abdomen injuries were the most frequent injury categories for non-hospitalised injured vehicle occupants.

It is important to examine these finding further by the different crash types, seating positions, vehicle sizes, etc. to gain a clearer understanding of the role of these factors in the pattern of current occupant injuries.

3.4.2 Pattern of Crashes & Injuries

The injuries sustained by the vehicle occupant across the different levels of crash severity were further broken down by the type of crash, shown in Tables 3.37 to 3.40. For those killed in frontal collisions (Table 3.37), the most frequent injuries occurred to the head (97%), chest (93%), and abdomen (50%) involving mainly severe injury (AIS>2). For hospitalised occupants, injuries to the lower limb (56%), chest (47%), head (45%), face (28%), and upper limb (28%), predominated including roughly equal numbers of major and minor severity injuries. For non-hospitalised cases, relatively minor injuries to the lower limbs, face, whiplash, chest, and upper limbs were observed.

In side impacts in Table 3.38, major injuries to the chest (91%), head (84%), and the abdomen (54%) were observed amongst those killed. Of interest amongst this group was spinal fractures which occurred in 12% of all side impact fatalities. For those hospitalised from these impacts, severe injuries to the chest (39%) were especially noteworthy, as were all injuries to the lower limb (42%), head (39%), upper limb (24%), and the abdomen (20%). Minor injury to the lower limb, face, neck (whiplash), upper limb, and chest and abdomen predominated amongst non-hospitalised vehicle occupants. Injuries to occupants in side crashes is analysed further in the following section which examines the effect of "near-side" and "far-side" impacts.

As noted earlier, rear-end impacts were generally less severe crashes. Nevertheless, for those who were killed from rear impacts, Table 3.39 shows that severe head (114%), abdominal (71%), chest (29%) and spinal (14%) injuries were most common. For hospitalised occupants from rear-end crashes, severe whiplash was the predominant injury (47%), along with face (22%), abdomen (20%), and chest (20%) injuries. For non-hospitalised cases whiplash and minor face, and abdominal injury were most frequent.

Crashes involving vehicle rollover (Table 3.40) were the least common type of impact but they did tend to have a severe outcome. For those killed, severe injury to the head (146%) and chest (84%) were most common, and spinal fractures were evident in 16% of these cases. Occupants hospitalised for long periods received major chest (36%) and spinal injuries (29%), while minor hospital visits were associated with injuries to the upper limb (48%), head (47%), lower limb (40%), and the chest (36%). Non-hospitalised injuries were similar to those involving minor stays in hospital for this crash configuration.

SUMMARY - These results confirm the earlier findings that vehicle occupants in most crash configurations are sustaining frequent severe injury to the head, chest, and abdomen. The extremities are particularly vulnerable in front and side crashes and rollovers, while spinal injuries were more apparent in rear-end and rollover collisions. There was a notable number of whiplash injuries in rear-end crashes as well as front and side collisions, suggesting that present seat back and head restraint designs may not yet be optimal for occupant safety.

3.4.3 Seating Position & Injuries

The patterns of occupant injuries by seating position are shown in Tables 3.41 to 3.45. For drivers killed in these collisions (Table 3.41), the most frequent injuries occurred to the head (105%), chest (93%), and abdomen (44%), while for hospitalised drivers, the most frequent body regions injured included lower extremities (51%), chest (45%), head (42%), and the face (27%). For non-hospitalised cases, the most frequent injuries were whiplash (38%), and minor face, lower and upper limb injuries.

Front-left passenger injuries in Table 3.43 reveal that for those killed, the most frequent major injuries occurred in the chest (108%), head (73%), and the abdomen (57%), while for those

TABLE 3.37
MULTIPLE INJURIES SUSTAINED BY OCCUPANTS OF POST-1981 PASSENGER CARS INVOLVED IN <u>FRONTAL</u> CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	**FATAL**	HOSPITALISATION >6days	<7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
HEAD: Major	230 (94%)	136 (14%)	44 (4%)	**180 (9%)**	36 (0.5%)	**446 (6%)**
HEAD: Minor	7 (3%)	304 (32%)	455 (40%)	**759 (36%)**	590 (11%)	**1356 (17%)**
FACE: Major	15 (6%)	189 (20%)	123 (11%)	**312 (15%)**	96 (2%)	**423 (5%)**
FACE: Minor	2 (1%)	66 (7%)	213 (19%)	**279 (13%)**	1615 (29%)	**1896 (24%)**
NECK: Whiplash	0 (-)	78 (8%)	194 (17%)	**272 (13%)**	1641 (30%)	**1913 (24%)**
SPINE: Fracture	15 (6%)	111 (12%)	29 (3%)	**140 (7%)**	44 (1%)	**199 (3%)**
SHOULDER: Major	5 (2%)	68 (7%)	40 (4%)	**108 (5%)**	42 (1%)	**155 (2%)**
SHOULDER: Minor	0 (-)	18 (2%)	39 (3%)	**57 (3%)**	163 (3%)	**220 (3%)**
CHEST: Major	229 (93%)	398 (42%)	252 (22%)	**650 (31%)**	216 (4%)	**1095 (14%)**
CHEST: Minor	0 (-)	101 (11%)	231 (20%)	**332 (16%)**	1326 (24%)	**1658 (21%)**
ABDOMEN: Major	122 (50%)	119 (13%)	32 (3%)	**151 (7%)**	16 (0.2%)	**289 (4%)**
ABDOMEN: Minor	0 (-)	79 (8%)	163 (14%)	**242 (12%)**	1101 (20%)	**1343 (17%)**
UPP LIMB: Major	18 (7%)	164 (17%)	85 (7%)	**249 (12%)**	121 (2%)	**388 (5%)**
UPP LIMB: Minor	2 (1%)	110 (12%)	219 (19%)	**329 (16%)**	1287 (23%)	**1618 (21%)**
LOW LIMB: Major	34 (14%)	396 (42%)	61 (5%)	**457 (22%)**	109 (2%)	**600 (8%)**
LOW LIMB: Minor	3 (1%)	279 (30%)	433 (38%)	**712 (34%)**	1930 (35%)	**2645 (34%)**
OTHER/UNKNOWN	101 (41%)	198 (21%)	156 (14%)	**354 (17%)**	1072 (19%)	**1527 (19%)**
TOTAL INJURIES	**783**	**2814**	**2769**	**5583**	**11405**	**17771**
TOTAL PATIENTS	**245**	**938**	**1142**	**2080**	**5551**	**7876**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

TABLE 3.38
MULTIPLE INJURIES SUSTAINED BY OCCUPANTS OF POST-1981
PASSENGER CARS INVOLVED IN SIDE CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
HEAD: Major	93 (84%)	41 (10%)	16 (4%)	**57 (7%)**	20 (0.5%)	**170 (4%)**
HEAD: Minor	5 (5%)	106 (26%)	168 (38%)	**274 (32%)**	379 (12%)	**658 (16%)**
FACE: Major	3 (3%)	21 (5%)	37 (8%)	**58 (7%)**	17 (0.5%)	**78 (2%)**
FACE: Minor	1 (1%)	28 (7%)	90 (20%)	**118 (14%)**	927 (29%)	**1046 (25%)**
NECK: Whiplash	1 (1%)	48 (12%)	74 (17%)	**122 (14%)**	932 (29%)	**1046 (25%)**
SPINE: Fracture	13 (12%)	29 (7%)	8 (2%)	**37 (4%)**	9 (0.2%)	**59 (1%)**
SHOULDER: Major	0 (-)	53 (13%)	14 (3%)	**67 (8%)**	49 (2%)	**116 (3%)**
SHOULDER: Minor	0 (-)	13 (3%)	26 (6%)	**39 (5%)**	124 (4%)	**163 (4%)**
CHEST: Major	101 (91%)	220 (55%)	109 (24%)	**329 (39%)**	124 (4%)	**554 (13%)**
CHEST: Minor	1 (1%)	40 (10%)	83 (19%)	**123 (14%)**	643 (20%)	**767 (18%)**
ABDOMEN: Major	59 (53%)	49 (12%)	9 (2%)	**58 (7%)**	16 (0.5%)	**133 (3%)**
ABDOMEN: Minor	1 (1%)	33 (8%)	78 (17%)	**111 (13%)**	650 (20%)	**762 (18%)**
UPP LIMB: Major	7 (6%)	48 (12%)	16 (4%)	**64 (8%)**	51 (2%)	**122 (3%)**
UPP LIMB: Minor	3 (3%)	44 (11%)	94 (21%)	**138 (16%)**	828 (26%)	**969 (23%)**
LOW LIMB: Major	12 (11%)	88 (22%)	12 (3%)	**100 (12%)**	34 (1%)	**146 (4%)**
LOW LIMB: Minor	3 (3%)	92 (23%)	159 (35%)	**251 (30%)**	1016 (32%)	**1270 (30%)**
OTHER/UNKNOWN	49 (44%)	161 (40%)	84 (19%)	**245 (29%)**	601 (19%)	**895 (21%)**
TOTAL INJURIES	**352**	**1114**	**1077**	**2191**	**6420**	**8963**
TOTAL PATIENTS	**111**	**401**	**448**	**849**	**3204**	**4164**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

TABLE 3.39
MULTIPLE INJURIES SUSTAINED BY OCCUPANTS OF POST-1981 PASSENGER CARS INVOLVED IN REAR-END CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
HEAD: Major	8 (114%)	3 (3%)	4 (2%)	**7 (2%)**	7 (0.2%)	**22 (0.5%)**
HEAD: Minor	0 (-)	14 (12%)	36 (17%)	**50 (15%)**	111 (3%)	**161 (4%)**
FACE: Major	1 (14%)	5 (4%)	9 (4%)	**14 (4%)**	7 (0.2%)	**22 (0.5%)**
FACE: Minor	0 (-)	12 (10%)	47 (22%)	**59 (18%)**	1035 (28%)	**1094 (27%)**
NECK: Whiplash	0 (-)	49 (43%)	105 (49%)	**154 (47%)**	2066 (56%)	**2220 (56%)**
SPINE: Fracture	1 (14%)	8 (7%)	3 (1%)	**11 (3%)**	10 (0.2%)	**22 (0.5%)**
SHOULDER: Major	0 (-)	2 (2%)	2 (1%)	**4 (1%)**	7 (0.2%)	**11 (0.2%)**
SHOULDER: Minor	0 (-)	5 (4%)	3 (1%)	**8 (2%)**	112 (3%)	**120 (3%)**
CHEST: Major	2 (29%)	16 (14%)	17 (8%)	**33 (10%)**	30 (1%)	**65 (2%)**
CHEST: Minor	0 (-)	5 (4%)	25 (12%)	**30 (9%)**	187 (5%)	**217 (5%)**
ABDOMEN: Major	5 (71%)	4 (3%)	2 (1%)	**6 (2%)**	5 (0.1%)	**16 (0.5%)**
ABDOMEN: Minor	0 (-)	13 (11%)	45 (21%)	**58 (18%)**	800 (22%)	**858 (21%)**
UPP LIMB: Major	0 (-)	7 (6%)	6 (3%)	**13 (4%)**	14 (0.4%)	**27 (0.6%)**
UPP LIMB: Minor	0 (-)	12 (10%)	24 (11%)	**36 (11%)**	470 (13%)	**506 (13%)**
LOW LIMB: Major	0 (-)	9 (8%)	1 (0.5%)	**10 (3%)**	6 (0.1%)	**16 (0.4%)**
LOW LIMB: Minor	0 (-)	18 (16%)	36 (17%)	**54 (16%)**	411 (11%)	**465 (12%)**
OTHER/UNKNOWN	6 (86%)	44 (38%)	44 (20%)	**94 (28%)**	819 (22%)	**913 (23%)**
TOTAL INJURIES	**23**	**226**	**409**	**635**	**6097**	**6755**
TOTAL PATIENTS	**7**	**115**	**216**	**331**	**3661**	**3999**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

TABLE 3.40
MULTIPLE INJURIES SUSTAINED BY OCCUPANTS OF POST-1981 PASSENGER CARS INVOLVED IN ROLLOVER CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
HEAD: Major	54 (146%)	15 (12%)	7 (4%)	**22 (7%)**	6 (1%)	**82 (9%)**
HEAD: Minor	1 (3%)	55 (43%)	77 (39%)	**132 (40%)**	86 (17%)	**219 (25%)**
FACE: Major	3 (8%)	18 (14%)	6 (3%)	**24 (7%)**	5 (1%)	**32 (4%)**
FACE: Minor	0 (-)	12 (9%)	57 (29%)	**69 (21%)**	154 (30%)	**223 (25%)**
NECK: Whiplash	1 (3%)	13 (10%)	32 (16%)	**45 (14%)**	94 (18%)	**140 (16%)**
SPINE: Fracture	6 (16%)	38 (29%)	6 (3%)	**44 (13%)**	6 (1%)	**56 (6%)**
SHOULDER: Major	1 (3%)	19 (15%)	10 (5%)	**29 (9%)**	7 (1%)	**37 (4%)**
SHOULDER: Minor	0 (-)	4 (3%)	10 (5%)	**14 (4%)**	21 (4%)	**35 (4%)**
CHEST: Major	31 (84%)	46 (36%)	18 (9%)	**64 (20%)**	12 (2%)	**107 (12%)**
CHEST: Minor	0 (-)	10 (8%)	41 (21%)	**51 (16%)**	64 (12%)	**115 (13%)**
ABDOMEN: Major	2 (5%)	3 (2%)	0 (-)	**3 (1%)**	1 (0.2%)	**6 (0.7%)**
ABDOMEN: Minor	0 (-)	9 (7%)	31 (16%)	**40 (12%)**	91 (18%)	**131 (15%)**
UPP LIMB: Major	3 (8%)	34 (26%)	17 (9%)	**51 (16%)**	10 (2%)	**64 (7%)**
UPP LIMB: Minor	1 (3%)	26 (20%)	80 (40%)	**106 (32%)**	199 (39%)	**306 (35%)**
LOW LIMB: Major	3 (8%)	28 (22%)	4 (2%)	**32 (10%)**	4 (1%)	**39 (4%)**
LOW LIMB: Minor	2 (5%)	26 (20%)	72 (36%)	**98 (30%)**	192 (37%)	**292 (33%)**
OTHER/UNKNOWN	13 (35%)	43 (33%)	37 (19%)	**80 (24%)**	131 (25%)	**224 (26%)**
TOTAL INJURIES	**121**	**399**	**505**	**904**	**1083**	**2108**
TOTAL PATIENTS	**37**	**129**	**198**	**327**	**514**	**878**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

hospitalised, the most frequent body regions injured were the chest (50%), lower extremities (46%), head (38%), upper extremity (32%), and the abdomen (20%). Non-hospitalised injuries to front-left passengers frequently included whiplash and minor injuries to the lower extremity, face, and chest.

Injuries to rear-outboard passengers are shown in Table 3.44, where the most frequent major injuries for those killed were to the head (102%), the chest (67%), and the abdomen (50%). For hospitalised rear-outboard passengers, the most frequent body regions injured were the head (45%), chest (37%), lower extremity (37%), and the upper extremity (25%), while for non-hospitalised occupants, minor injury to the lower extremity, face, neck (whiplash), and the upper extremity predominated.

The number of injured occupants seated in the front-centre (Table 3.42) and rear-centre (Table 3.45) seats were substantially lower than for all other seating positions. Nevertheless, it was still possible to identify broad categories of body region injuries for these occupants. For both positions, major injury to the head, chest, and abdomen, was most frequent for those killed, although 1 in 2 front-centre and 1 in 7 rear-centre seat fatalities did record a spinal fracture.

The most frequent body regions injured for hospitalised front-centre occupants were the lower extremity, head, and chest, while for rear-centre seat occupants, the head, upper extremity, face, and abdomen predominated. Non-hospitalised injuries mainly included minor damage to the lower extremities and the face (whiplash injuries in both these seating positions were roughly 50% lower than in all other seating positions).

SUMMARY - For those killed in all seating positions, major injuries are occurring to the head chest and abdomen, often involving more than one severe injury to these body regions. Spinal injuries also appeared to be a problem for those killed in the front-centre and rear-centre seats. For hospitalised occupants, the head and chest was a common injury, and major injuries to the lower limbs occurred frequently for front seat occupants. Non-hospitalised occupants suffered more minor injuries where whiplash, face, and upper and lower extremity injuries predominated. Of special interest, whiplash injuries were less frequent in rear-centre and front-centre seating positions where 2-point lap belts are currently installed.

3.4.4 Vehicle Size & Injuries

The overview analysis showed that additional analyses of occupant injuries by vehicle size needed to take into account the speed zone of the crash. Tables 3.46 to 3.50, therefore, show the patterns of occupant injuries by injury severity for the 5 vehicle sizes for speed zones of <76km/h (urban environments). It is more informative to analyse vehicle size differences across the different severity outcomes.

For occupants killed in these crashes, major injuries to the head, chest and abdomen were most common in all vehicles up to intermediate size. For large cars, there were no major head injuries recorded (sample size = 1), although there were multiple facial injuries. Of particular note amongst these fatalities, the percentage of head injuries (including the likelihood of multiple head injuries) decreased from mini & small cars to compacts and intermediates, while the reverse was true for chest injuries. Major injury to the abdomen was consistently lower than major injury to the head and chest.

For hospitalised occupants, injuries to the lower extremities, chest and head were most frequent (the rate of lower extremity and face injuries tended to reduce as vehicle size increased, while chest, head and upper extremity injury rates were reasonably consistent). The incidence of severe whiplash and no major head injuries were especially noteworthy amongst those hospitalised from large vehicles (24 patients in total).

For non-hospitalised occupants, minor injuries to the face, lower extremity, upper extremity and the abdomen were most common and there were few notable changes or trends evident across the 5 vehicle sizes. Minor chest injuries, however, did seem to reduce slightly as vehicle size increased. Whiplash was again quite prevalent amongst occupants from all vehicles.

SUMMARY - These results seem to suggest that vehicle size was a benefit in terms of the frequency of injury experienced by these TAC vehicle occupant claimants. Major head injuries, in particular,

TABLE 3.41
MULTIPLE INJURIES SUSTAINED BY <u>DRIVERS</u> OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
HEAD: Major	260 (105%)	117 (12%)	39 (3%)	**156 (7%)**	37 (0.5%)	**453 (4%)**
HEAD: Minor	9 (4%)	310 (32%)	448 (38%)	**758 (35%)**	741 (9%)	**1508 (14%)**
FACE: Major	19 (8%)	182 (19%)	101 (9%)	**283 (13%)**	96 (1%)	**398 (4%)**
FACE: Minor	1 (0.5%)	67 (7%)	226 (19%)	**293 (14%)**	2516 (29%)	**2810 (25%)**
NECK: Whiplash	1 (0.5%)	107 (11%)	274 (23%)	**381 (18%)**	3301 (38%)	**3683 (33%)**
SPINE: Fracture	22 (9%)	89 (9%)	21 (2%)	**110 (5%)**	44 (0.5%)	**176 (2%)**
SHOULDER: Major	2 (1%)	87 (9%)	40 (3%)	**127 (6%)**	59 (0.5%)	**188 (2%)**
SHOULDER: Minor	0 (-)	26 (3%)	49 (4%)	**75 (3%)**	287 (3%)	**362 (3%)**
CHEST: Major	231 (93%)	415 (43%)	242 (20%)	**657 (31%)**	216 (2%)	**1104 (10%)**
CHEST: Minor	1 (0.5%)	90 (9%)	220 (19%)	**310 (14%)**	1347 (15%)	**1658 (15%)**
ABDOMEN: Major	110 (44%)	68 (7%)	21 (2%)	**89 (4%)**	24 (0.2%)	**223 (2%)**
ABDOMEN: Minor	0 (-)	71 (7%)	184 (16%)	**255 (12%)**	1717 (20%)	**1972 (18%)**
UPP LIMB: Major	17 (7%)	140 (15%)	56 (5%)	**196 (9%)**	137 (2%)	**350 (3%)**
UPP LIMB: Minor	4 (2%)	117 (12%)	251 (21%)	**368 (17%)**	1866 (21%)	**2238 (20%)**
LOW LIMB: Major	37 (15%)	372 (39%)	50 (4%)	**432 (20%)**	109 (1%)	**568 (5%)**
LOW LIMB: Minor	3 (1%)	256 (27%)	406 (34%)	**662 (31%)**	2250 (26%)	**2915 (26%)**
OTHER/UNKNOWN	103 (42%)	272 (28%)	210 (18%)	**482 (22%)**	1943 (22%)	**2528 (23%)**
TOTAL INJURIES	**820**	**2786**	**2838**	**5624**	**16690**	**23134**
TOTAL PATIENTS	**248**	**965**	**1185**	**2150**	**8713**	**11111**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

TABLE 3.42
MULTIPLE INJURIES SUSTAINED BY FRONT-CENTRE PASSENGERS OF POST-1981 CARS INVOLVED IN ALL CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
HEAD: Major	3 (150%)	0 (-)	0 (-)	**0 (-)**	0 (-)	**3 (5%)**
HEAD: Minor	0 (-)	1 (25%)	5 (71%)	**6 (55%)**	6 (13%)	**12 (20%)**
FACE: Major	0 (-)	0 (-)	0 (-)	**0 (-)**	0 (-)	**0 (-)**
FACE: Minor	0 (-)	1 (25%)	1 (14%)	**2 (18%)**	13 (28%)	**15 (25%)**
NECK: Whiplash	0 (-)	2 (50%)	1 (14%)	**3 (27%)**	8 (17%)	**11 (18%)**
SPINE: Fracture	1 (50%)	1 (25%)	0 (-)	**1 (9%)**	0 (-)	**2 (3%)**
SHOULDER: Major	0 (-)	0 (-)	0 (-)	**0 (-)**	1 (2%)	**1 (2%)**
SHOULDER: Minor	0 (-)	0 (-)	1 (14%)	**1 (9%)**	2 (4%)	**3 (5%)**
CHEST: Major	1 (50%)	1 (25%)	2 (29%)	**3 (27%)**	0 (-)	**4 (7%)**
CHEST: Minor	0 (-)	1 (25%)	0 (-)	**1 (9%)**	12 (26%)	**13 (22%)**
ABDOMEN: Major	1 (50%)	0 (-)	0 (-)	**0 (-)**	2 (4%)	**3 (5%)**
ABDOMEN: Minor	0 (-)	0 (-)	2 (29%)	**2 (18%)**	7 (15%)	**9 (15%)**
UPP LIMB: Major	1 (50%)	0 (-)	0 (-)	**0 (-)**	2 (4%)	**3 (5%)**
UPP LIMB: Minor	0 (-)	0 (-)	0 (-)	**0 (-)**	10 (21%)	**10 (17%)**
LOW LIMB: Major	1 (50%)	2 (50%)	0 (-)	**2 (18%)**	1 (2%)	**4 (7%)**
LOW LIMB: Minor	0 (-)	3 (75%)	3 (43%)	**6 (55%)**	20 (43%)	**26 (43%)**
OTHER/UNKNOWN	1 (50%)	0 (-)	0 (-)	**0 (-)**	10 (21%)	**11 (18%)**
TOTAL INJURIES	**9**	**12**	**15**	**27**	**94**	**130**
TOTAL PATIENTS	**2**	**4**	**7**	**11**	**47**	**60**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

TABLE 3.43

MULTIPLE INJURIES SUSTAINED BY FRONT-LEFT PASSENGERS OF POST-1981 CARS INVOLVED IN CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
HEAD: Major	65 (73%)	46 (11%)	20 (4%)	**66 (7%)**	13 (0.5%)	**144 (3%)**
HEAD: Minor	3 (3%)	116 (27%)	193 (34%)	**309 (31%)**	257 (8%)	**569 (13%)**
FACE: Major	6 (7%)	47 (11%)	49 (9%)	**96 (10%)**	22 (1%)	**124 (3%)**
FACE: Minor	1 (1%)	34 (8%)	105 (19%)	**139 (14%)**	790 (25%)	**930 (22%)**
NECK: Whiplash	1 (1%)	56 (13%)	112 (20%)	**168 (17%)**	1112 (35%)	**1281 (30%)**
SPINE: Fracture	8 (9%)	73 (17%)	16 (3%)	**89 (9%)**	20 (1%)	**117 (3%)**
SHOULDER: Major	1 (1%)	38 (9%)	18 (3%)	**56 (6%)**	26 (1%)	**83 (2%)**
SHOULDER: Minor	0 (-)	10 (2%)	17 (3%)	**27 (3%)**	101 (3%)	**128 (3%)**
CHEST: Major	96 (108%)	195 (45%)	111 (20%)	**306 (31%)**	134 (4%)	**536 (13%)**
CHEST: Minor	0 (-)	56 (13%)	138 (24%)	**194 (19%)**	675 (21%)	**869 (20%)**
ABDOMEN: Major	50 (57%)	48 (11%)	9 (2%)	**57 (6%)**	10 (0.3%)	**117 (3%)**
ABDOMEN: Minor	0 (-)	43 (10%)	93 (16%)	**136 (14%)**	665 (21%)	**801 (19%)**
UPP LIMB: Major	8 (9%)	84 (19%)	45 (8%)	**129 (13%)**	40 (1%)	**177 (4%)**
UPP LIMB: Minor	1 (1%)	55 (13%)	136 (24%)	**191 (19%)**	666 (21%)	**858 (20%)**
LOW LIMB: Major	7 (8%)	115 (27%)	20 (4%)	**135 (14%)**	30 (1%)	**172 (4%)**
LOW LIMB: Minor	2 (2%)	108 (25%)	213 (38%)	**321 (32%)**	844 (27%)	**1167 (28%)**
OTHER/UNKNOWN	39 (44%)	130 (30%)	89 (16%)	**219 (22%)**	705 (22%)	**963 (23%)**
TOTAL INJURIES	**288**	**1254**	**1384**	**2638**	**6110**	**9036**
TOTAL PATIENTS	**89**	**433**	**566**	**999**	**3152**	**4240**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

TABLE 3.44
MULTIPLE INJURIES SUSTAINED BY REAR-OUTBOARD PASSENGERS OF POST-1981 CARS INVOLVED IN CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
HEAD: Major	55 (102%)	23 (13%)	16 (6%)	**39 (9%)**	16 (1%)	**110 (6%)**
HEAD: Minor	2 (4%)	52 (30%)	112 (40%)	**164 (36%)**	173 (13%)	**339 (18%)**
FACE: Major	0 (-)	10 (6%)	23 (8%)	**33 (7%)**	13 (1%)	**46 (2%)**
FACE: Minor	1 (2%)	12 (7%)	65 (23%)	**77 (17%)**	410 (30%)	**488 (26%)**
NECK: Whiplash	0 (-)	18 (10%)	34 (12%)	**52 (11%)**	320 (23%)	**372 (20%)**
SPINE: Fracture	3 (6%)	31 (18%)	9 (3%)	**40 (9%)**	10 (1%)	**53 (3%)**
SHOULDER: Major	3 (6%)	14 (8%)	10 (4%)	**24 (5%)**	10 (1%)	**37 (2%)**
SHOULDER: Minor	0 (-)	4 (2%)	9 (3%)	**13 (3%)**	38 (3%)	**51 (3%)**
CHEST: Major	36 (67%)	75 (43%)	45 (16%)	**120 (26%)**	41 (3%)	**197 (10%)**
CHEST: Minor	0 (-)	14 (8%)	38 (14%)	**52 (11%)**	222 (16%)	**274 (14%)**
ABDOMEN: Major	27 (50%)	39 (22%)	12 (4%)	**51 (11%)**	5 (0.3%)	**83 (4%)**
ABDOMEN: Minor	1 (2%)	19 (11%)	45 (16%)	**64 (14%)**	245 (18%)	**310 (16%)**
UPP LIMB: Major	3 (6%)	28 (16%)	19 (7%)	**47 (10%)**	14 (1%)	**64 (3%)**
UPP LIMB: Minor	0 (-)	21 (12%)	49 (17%)	**70 (15%)**	278 (20%)	**348 (18%)**
LOW LIMB: Major	6 (11%)	33 (19%)	13 (5%)	**46 (10%)**	18 (1%)	**70 (4%)**
LOW LIMB: Minor	2 (4%)	46 (26%)	77 (27%)	**123 (27%)**	483 (35%)	**608 (32%)**
OTHER/UNKNOWN	21 (39%)	44 (25%)	43 (15%)	**87 (19%)**	284 (21%)	**392 (21%)**
TOTAL INJURIES	**160**	**483**	**619**	**1102**	**2580**	**3842**
TOTAL PATIENTS	**54**	**176**	**281**	**457**	**1381**	**1892**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

TABLE 3.45
MULTIPLE INJURIES SUSTAINED BY <u>REAR-CENTRE</u> PASSENGERS OF POST-1981 CARS INVOLVED IN CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
HEAD: Major	12 (171%)	8 (20%)	4 (7%)	**12 (13%)**	2 (1%)	**26 (8%)**
HEAD: Minor	0 (-)	15 (38%)	25 (45%)	**40 (42%)**	27 (12%)	**67 (21%)**
FACE: Major	0 (-)	4 (10%)	4 (7%)	**8 (8%)**	5 (2%)	**13 (4%)**
FACE: Minor	0 (-)	3 (8%)	20 (36%)	**23 (24%)**	76 (35%)	**99 (31%)**
NECK: Whiplash	0 (-)	4 (10%)	4 (7%)	**8 (8%)**	33 (15%)	**41 (13%)**
SPINE: Fracture	2 (29%)	7 (18%)	0 (-)	**7 (7%)**	1 (0.5%)	**10 (3%)**
SHOULDER: Major	0 (-)	4 (10%)	2 (4%)	**6 (6%)**	6 (3%)	**12 (4%)**
SHOULDER: Minor	0 (-)	1 (3%)	1 (2%)	**2 (2%)**	4 (2%)	**6 (2%)**
CHEST: Major	5 (71%)	3 (8%)	2 (4%)	**5 (5%)**	2 (1%)	**12 (4%)**
CHEST: Minor	0 (-)	0 (-)	3 (5%)	**3 (3%)**	17 (8%)	**20 (6%)**
ABDOMEN: Major	4 (57%)	10 (25%)	2 (4%)	**12 (13%)**	1 (0.5%)	**17 (5%)**
ABDOMEN: Minor	0 (-)	6 (15%)	7 (13%)	**13 (14%)**	47 (22%)	**60 (19%)**
UPP LIMB: Major	0 (-)	7 (18%)	5 (9%)	**12 (13%)**	4 (2%)	**16 (5%)**
UPP LIMB: Minor	0 (-)	2 (5%)	5 (9%)	**7 (7%)**	35 (16%)	**42 (13%)**
LOW LIMB: Major	0 (-)	10 (25%)	3 (5%)	**13 (14%)**	0 (-)	**13 (4%)**
LOW LIMB: Minor	0 (-)	11 (28%)	17 (30%)	**28 (29%)**	73 (33%)	**101 (31%)**
OTHER/UNKNOWN	2 (29%)	19 (48%)	7 (13%)	**26 (27%)**	55 (25%)	**83 (26%)**
TOTAL INJURIES	**25**	**114**	**111**	**225**	**388**	**638**
TOTAL PATIENTS	**7**	**40**	**56**	**96**	**218**	**321**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

TABLE 3.46
MULTIPLE INJURIES OF OCCUPANTS OF POST-1981 MINI-CARS INVOLVED IN URBAN CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
HEAD: Major	5 (125%)	1 (5%)	0 (-)	**1 (3%)**	0 (-)	**6 (4%)**
HEAD: Minor	0 (-)	6 (30%)	3 (21%)	**9 (26%)**	11 (10%)	**20 (14%)**
FACE: Major	0 (-)	2 (10%)	5 (36%)	**7 (21%)**	0 (-)	**7 (5%)**
FACE: Minor	0 (-)	1 (5%)	4 (29%)	**5 (15%)**	25 (24%)	**30 (21%)**
NECK: Whiplash	0 (-)	3 (15%)	1 (7%)	**4 (12%)**	38 (36%)	**42 (29%)**
SPINE: Fracture	0 (-)	0 (-)	0 (-)	**0 (-)**	0 (-)	**0 (-)**
SHOULDER: Major	0 (-)	2 (10%)	0 (-)	**2 (6%)**	0 (-)	**2 (1%)**
SHOULDER: Minor	0 (-)	0 (-)	0 (-)	**0 (-)**	7 (7%)	**7 (5%)**
CHEST: Major	2 (50%)	3 (15%)	2 (14%)	**5 (15%)**	5 (5%)	**12 (8%)**
CHEST: Minor	0 (-)	1 (5%)	8 (57%)	**9 (26%)**	29 (27%)	**38 (26%)**
ABDOMEN: Major	1 (25%)	1 (5%)	0 (-)	**1 (3%)**	0 (-)	**2 (1%)**
ABDOMEN: Minor	0 (-)	2 (10%)	0 (-)	**2 (6%)**	20 (19%)	**22 (15%)**
UPP LIMB: Major	0 (-)	3 (15%)	0 (-)	**3 (9%)**	1 (1%)	**4 (3%)**
UPP LIMB: Minor	0 (-)	1 (5%)	4 (29%)	**5 (15%)**	21 (20%)	**26 (18%)**
LOW LIMB: Major	0 (-)	6 (30%)	0 (-)	**6 (18%)**	1 (1%)	**7 (5%)**
LOW LIMB: Minor	1 (25%)	7 (35%)	9 (64%)	**16 (47%)**	40 (38%)	**57 (40%)**
OTHER/UNKNOWN	2 (50%)	6 (30%)	2 (14%)	**8 (24%)**	19 (18%)	**29 (20%)**
TOTAL INJURIES	**11**	**45**	**38**	**83**	**217**	**311**
TOTAL PATIENTS	**4**	**20**	**14**	**34**	**106**	**144**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

TABLE 3.47
MULTIPLE INJURIES OF OCCUPANTS OF POST-1981 SMALL-CARS INVOLVED IN URBAN CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	FATAL	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
HEAD: Major	50 (128%)	36 (11%)	18 (5%)	**54 (8%)**	11 (0.3%)	**115 (3%)**
HEAD: Minor	2 (5%)	84 (27%)	138 (37%)	**232 (32%)**	282 (10%)	**506 (14%)**
FACE: Major	0 (-)	50 (16%)	35 (9%)	**85 (12%)**	28 (1%)	**113 (3%)**
FACE: Minor	0 (-)	26 (8%)	51 (13%)	**77 (11%)**	866 (31%)	**943 (27%)**
NECK: Whiplash	0 (-)	34 (11%)	67 (18%)	**101 (15%)**	910 (32%)	**1011 (28%)**
SPINE: Fracture	2 (5%)	31 (10%)	5 (1%)	**36 (5%)**	13 (0.5%)	**51 (1%)**
SHOULDER: Major	2 (5%)	41 (13%)	8 (2%)	**49 (7%)**	34 (1%)	**85 (2%)**
SHOULDER: Minor	0 (-)	3 (1%)	6 (2%)	**9 (1%)**	92 (3%)	**101 (3%)**
CHEST: Major	33 (85%)	175 (56%)	93 (25%)	**268 (39%)**	85 (3%)	**386 (11%)**
CHEST: Minor	0 (-)	35 (11%)	80 (21%)	**115 (17%)**	581 (21%)	**696 (20%)**
ABDOMEN: Major	20 (51%)	35 (11%)	8 (2%)	**43 (6%)**	4 (0.1%)	**67 (2%)**
ABDOMEN: Minor	0 (-)	21 (7%)	58 (15%)	**79 (11%)**	613 (22%)	**692 (19%)**
UPP LIMB: Major	6 (15%)	36 (11%)	20 (5%)	**56 (8%)**	47 (2%)	**109 (3%)**
UPP LIMB: Minor	1 (3%)	34 (11%)	81 (21%)	**115 (17%)**	623 (22%)	**739 (21%)**
LOW LIMB: Major	5 (13%)	82 (26%)	17 (4%)	**99 (14%)**	34 (1%)	**138 (4%)**
LOW LIMB: Minor	0 (-)	83 (26%)	125 (33%)	**208 (30%)**	917 (32%)	**1125 (32%)**
OTHER/UNKNOWN	11 (28%)	105 (33%)	61 (16%)	**166 (24%)**	540 (19%)	**717 (20%)**
TOTAL INJURIES	**132**	**911**	**871**	**1782**	**5680**	**7594**
TOTAL PATIENTS	**39**	**315**	**378**	**693**	**2822**	**3554**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

TABLE 3.48
MULTIPLE INJURIES OF OCCUPANTS OF POST-1981 COMPACTS INVOLVED IN URBAN CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	**FATAL**	HOSPITALISATION >6days	<7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
HEAD: Major	53 (82%)	29 (11%)	14 (4%)	**43 (7%)**	21 (1%)	**117 (4%)**
HEAD: Minor	1 (2%)	73 (28%)	128 (39%)	**201 (34%)**	250 (10%)	**452 (14%)**
FACE: Major	5 (8%)	40 (16%)	30 (9%)	**70 (12%)**	28 (1%)	**103 (3%)**
FACE: Minor	0 (-)	21 (8%)	60 (18%)	**81 (14%)**	763 (30%)	**844 (27%)**
NECK: Whiplash	0 (-)	33 (13%)	62 (19%)	**95 (16%)**	773 (31%)	**868 (27%)**
SPINE: Fracture	7 (11%)	19 (7%)	7 (2%)	**26 (4%)**	7 (0.2%)	**40 (1%)**
SHOULDER: Major	0 (-)	24 (9%)	13 (4%)	**37 (6%)**	19 (0.7%)	**56 (2%)**
SHOULDER: Minor	0 (-)	9 (4%)	17 (5%)	**26 (4%)**	69 (3%)	**95 (3%)**
CHEST: Major	60 (92%)	112 (44%)	76 (23%)	**188 (32%)**	64 (3%)	**312 (10%)**
CHEST: Minor	0 (-)	24 (9%)	47 (14%)	**71 (12%)**	471 (19%)	**542 (17%)**
ABDOMEN: Major	32 (49%)	38 (15%)	10 (3%)	**48 (8%)**	11 (0.5%)	**91 (3%)**
ABDOMEN: Minor	0 (-)	27 (11%)	49 (16%)	**76 (13%)**	508 (20%)	**584 (18%)**
UPP LIMB: Major	2 (3%)	28 (11%)	17 (5%)	**45 (8%)**	35 (1%)	**82 (3%)**
UPP LIMB: Minor	0 (-)	22 (9%)	54 (17%)	**76 (13%)**	510 (20%)	**586 (19%)**
LOW LIMB: Major	7 (11%)	73 (28%)	10 (3%)	**83 (14%)**	24 (1%)	**114 (4%)**
LOW LIMB: Minor	0 (-)	74 (29%)	96 (34%)	**170 (29%)**	754 (30%)	**924 (26%)**
OTHER/UNKNOWN	34 (52%)	80 (31%)	54 (29%)	**134 (23%)**	520 (21%)	**690 (29%)**
TOTAL INJURIES	**201**	**728**	**744**	**1472**	**4827**	**6500**
TOTAL PATIENTS	**65**	**257**	**327**	**584**	**2513**	**3162**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

TABLE 3.49
MULTIPLE INJURIES OF OCCUPANTS OF POST-1981 INTERMEDIATE SIZED CARS INVOLVED IN URBAN CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
HEAD: Major	18 (90%)	11 (13%)	3 (2%)	**14 (7%)**	3 (0.2%)	**35 (3%)**
HEAD: Minor	0 (-)	24 (29%)	55 (43%)	**79 (38%)**	105 (10%)	**184 (14%)**
FACE: Major	3 (15%)	9 (11%)	18 (14%)	**27 (13%)**	12 (1%)	**42 (3%)**
FACE: Minor	1 (5%)	5 (6%)	24 (19%)	**29 (14%)**	320 (31%)	**350 (27%)**
NECK: Whiplash	0 (-)	9 (11%)	26 (20%)	**35 (17%)**	311 (30%)	**346 (27%)**
SPINE: Fracture	3 (15%)	4 (5%)	2 (2%)	**6 (3%)**	6 (0.5%)	**15 (1%)**
SHOULDER: Major	0 (-)	6 (7%)	5 (4%)	**11 (5%)**	7 (0.5%)	**18 (1%)**
SHOULDER: Minor	0 (-)	1 (1%)	2 (2%)	**3 (1%)**	34 (3%)	**37 (3%)**
CHEST: Major	18 (90%)	36 (44%)	22 (17%)	**58 (28%)**	38 (4%)	**114 (9%)**
CHEST: Minor	0 (-)	11 (13%)	26 (20%)	**37 (18%)**	197 (19%)	**234 (18%)**
ABDOMEN: Major	7 (35%)	10 (12%)	3 (2%)	**13 (6%)**	2 (0.2%)	**22 (2%)**
ABDOMEN: Minor	0 (-)	9 (11%)	20 (16%)	**29 (14%)**	231 (22%)	**260 (20%)**
UPP LIMB: Major	1 (5%)	17 (21%)	5 (4%)	**22 (11%)**	11 (1%)	**34 (3%)**
UPP LIMB: Minor	0 (-)	11 (13%)	14 (11%)	**25 (12%)**	267 (25%)	**292 (23%)**
LOW LIMB: Major	3 (15%)	37 (45%)	3 (2%)	**40 (19%)**	18 (2%)	**61 (5%)**
LOW LIMB: Minor	0 (-)	21 (26%)	48 (38%)	**69 (33%)**	304 (29%)	**373 (29%)**
OTHER/UNKNOWN	8 (40%)	21 (26%)	20 (16%)	**41 (20%)**	215 (21%)	**264 (21%)**
TOTAL INJURIES	**62**	**242**	**296**	**538**	**2001**	**2681**
TOTAL PATIENTS	**20**	**82**	**127**	**209**	**1048**	**1277**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

TABLE 3.50
MULTIPLE INJURIES OF OCCUPANTS OF POST-1981 LARGE-CARS INVOLVED IN URBAN CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	**FATAL**	HOSPITALISATION >6days	<7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
HEAD: Major	0 (-)	0 (-)	0 (-)	**0 (-)**	0 (-)	**0 (-)**
HEAD: Minor	0 (-)	1 (13%)	5 (31%)	**6 (25%)**	9 (8%)	**15 (11%)**
FACE: Major	3 (300%)	1 (13%)	0 (-)	**1 (4%)**	0 (-)	**4 (3%)**
FACE: Minor	0 (-)	0 (-)	3 (19%)	**3 (13%)**	24 (21%)	**27 (19%)**
NECK: Whiplash	0 (-)	2 (25%)	3 (19%)	**5 (21%)**	42 (37%)	**47 (34%)**
SPINE: Fracture	0 (-)	2 (25%)	0 (-)	**2 (8%)**	2 (2%)	**4 (3%)**
SHOULDER: Major	0 (-)	0 (-)	1 (6%)	**1 (4%)**	2 (2%)	**3 (2%)**
SHOULDER: Minor	0 (-)	0 (-)	0 (-)	**0 (-)**	1 (1%)	**1 (1%)**
CHEST: Major	0 (-)	2 (25%)	3 (19%)	**5 (21%)**	3 (3%)	**8 (6%)**
CHEST: Minor	0 (-)	1 (13%)	4 (25%)	**5 (21%)**	8 (7%)	**13 (9%)**
ABDOMEN: Major	1 (100%)	0 (-)	0 (-)	**0 (-)**	0 (-)	**1 (1%)**
ABDOMEN: Minor	0 (-)	1 (13%)	3 (19%)	**4 (17%)**	21 (18%)	**25 (18%)**
UPP LIMB: Major	0 (-)	1 (13%)	0 (-)	**1 (4%)**	2 (2%)	**3 (2%)**
UPP LIMB: Minor	0 (-)	1 (13%)	2 (13%)	**3 (13%)**	33 (29%)	**36 (26%)**
LOW LIMB: Major	0 (-)	5 (63%)	0 (-)	**5 (21%)**	2 (2%)	**7 (5%)**
LOW LIMB: Minor	0 (-)	3 (38%)	3 (19%)	**6 (25%)**	29 (25%)	**35 (25%)**
OTHER/UNKNOWN	1 (100%)	2 (25%)	4 (25%)	**6 (25%)**	31 (27%)	**38 (27%)**
TOTAL INJURIES	**5**	**22**	**31**	**53**	**209**	**267**
TOTAL PATIENTS	**1**	**8**	**16**	**24**	**114**	**139**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

seemed to be more frequent and more severe amongst smaller vehicle occupants. Lower extremity injuries, too, appeared to be more common in small vehicle occupants, perhaps suggesting that these smaller (and lighter) vehicles are more prone to severe intrusions into the floor space in road crashes. This will be examined further in the crashed vehicle study to follow.

3.4.5 Belt Wearing & Injuries

The overview analysis revealed an over-reporting wearing rate of seat belts amongst injured vehicle occupants, estimated to be roughly 12%. While further detailed analysis of these data is potentially problematic, the fact that the trends described in the overview analysis were in the predictable direction suggests that this over-reporting is random throughout the data. Moreover, those reported not to be wearing belts were most likely to have been accurately reported. Thus, a simple injury by severity analysis for belt wearers and non-wearers would still be appropriate here.

Table 3.51 shows the injuries by injury severity results for belted vehicle occupants. For those killed, major injuries were observed in the chest (99%), head (97%), and abdomen (44%), while for those hospitalised, the most frequent injuries occurred to the lower limbs (53%), chest (48%), head (42%), upper limbs (30%), and the face (27%). For non-hospitalised cases, minor injuries were recorded to the lower limbs, face, the neck (whiplash), upper limbs, and the chest.

For unbelted killed vehicle occupants in Table 3.52, major injuries to the head (105%), chest (81%), and abdomen (32%) were most common, while for those unbelted and hospitalised, frequent injury was noted to the head (68%), lower limbs (50%), face (32%), chest (32%), and the upper limbs (27%). Minor injury to the lower limb, neck (whiplash), face, upper limb and head predominated amongst non-hospitalised occupants.

SUMMARY - Non-wearers of seat belts appeared to sustain considerably more major and minor head injuries at all levels of injury severity than belted occupants. Conversely, belt wearers who were killed or hospitalised sustained proportionally more chest and abdominal injuries than similar non-wearers.

Interestingly, there was only half the proportion of whiplash injuries amongst non-wearing hospitalised cases, yet there was practically no difference in the rates for non-hospitalised injured occupants.

Given the level of over-reporting in these data and the possibility that unbelted injured occupants may have sustained a disproportionate number of specific injuries, care should be taken not to interpret too much from these findings.

3.4.6 Front- & Rear-Wheel Drive

Given the close association between drive configuration and vehicle size described in the overview analysis, it was not appropriate to present an occupant injury analysis by front- and rear-wheel drive vehicle (i.e., it would mirror the results presented in the earlier Tables).

The earlier injury severity analysis in Table 3.35 suggested that there was little injury penalty for either drive type, but this really requires further detailed investigation, possibly by make and model and certainly controlling for vehicle size. The role of drive configuration on front seat occupant injuries will be examined further in the crashed vehicle analysis to follow in Chapters 5 and 6.

3.4.7 Summary Of The Injury Analysis

Those killed in vehicle crashes commonly sustained major injuries to the head, chest, and abdomen. Spinal injuries, too, were reasonably frequent amongst fatal cases, especially those involving side, rear, and rollover collisions. For hospitalised cases, injuries to the lower limbs, head, chest and abdomen were apparent, the severity of which was associated with how long the occupant spent in hospital.

Severe whiplash injuries were especially noted in rear-end crashes resulting in occupant hospitalisation. Non-hospitalisation injuries frequently involved minor injuries to the lower limbs, face, neck (whiplash) and chest in most crash configurations and seating positions. Vehicle size appeared to influence the pattern of injuries sustained where larger vehicles seemed to reduce the likelihood of a severe head and lower limb injury. The effects of seat belt wearing and drive configuration need further examination.

TABLE 3.51
MULTIPLE INJURIES OF BELTED OCCUPANTS OF POST-1981 CARS INVOLVED IN CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
HEAD: Major	220 (97%)	117 (11%)	49 (3%)	**166 (7%)**	46 (0.5%)	**432 (4%)**
HEAD: Minor	9 (4%)	315 (30%)	550 (39%)	**865 (35%)**	847 (11%)	**1721 (16%)**
FACE: Major	12 (5%)	176 (17%)	126 (9%)	**302 (12%)**	101 (1%)	**415 (4%)**
FACE: Minor	2 (1%)	74 (7%)	291 (21%)	**365 (15%)**	2558 (32%)	**2925 (27%)**
NECK: Whiplash	1 (0.5%)	111 (11%)	249 (18%)	**360 (15%)**	2388 (30%)	**2749 (26%)**
SPINE: Fracture	19 (8%)	132 (13%)	31 (2%)	**163 (7%)**	46 (0.5%)	**228 (2%)**
SHOULDER: Major	1 (0.5%)	106 (10%)	59 (4%)	**165 (7%)**	76 (1%)	**242 (2%)**
SHOULDER: Minor	0 (-)	24 (2%)	59 (4%)	**83 (3%)**	231 (3%)	**314 (3%)**
CHEST: Major	224 (99%)	472 (45%)	309 (22%)	**781 (32%)**	274 (3%)	**1279 (12%)**
CHEST: Minor	1 (0.5%)	108 (10%)	291 (21%)	**399 (16%)**	1677 (21%)	**2077 (19%)**
ABDOMEN: Major	99 (44%)	112 (11%)	26 (2%)	**138 (6%)**	28 (0.3%)	**265 (2%)**
ABDOMEN: Minor	0 (-)	87 (8%)	229 (16%)	**316 (13%)**	1717 (21%)	**2033 (19%)**
UPP LIMB: Major	20 (9%)	188 (18%)	96 (7%)	**284 (12%)**	150 (2%)	**454 (4%)**
UPP LIMB: Minor	3 (1%)	130 (12%)	322 (23%)	**452 (18%)**	1994 (25%)	**2449 (23%)**
LOW LIMB: Major	32 (14%)	390 (37%)	66 (5%)	**456 (19%)**	112 (1%)	**600 (6%)**
LOW LIMB: Minor	7 (3%)	295 (28%)	534 (38%)	**829 (34%)**	2723 (34%)	**3559 (33%)**
OTHER/UNKNOWN	96 (42%)	296 (28%)	230 (16%)	**526 (21%)**	1699 (21%)	**2321 (22%)**
TOTAL INJURIES	**746**	**3133**	**3517**	**6650**	**16667**	**24063**
TOTAL PATIENTS	**226**	**1049**	**1414**	**2460**	**8023**	**10709**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

TABLE 3.52
MULTIPLE INJURIES OF UNBELTED OCCUPANTS OF POST-1981 CARS INVOLVED IN CRASHES BETWEEN 1982 AND JUNE 1988

BODY REGION INJURED	**FATAL**	HOSPITALISATION >6days	HOSPITALISATION <7days	**TOTAL HOSPITAL INJURY**	MEDICAL TREATMENT ONLY	**TOTAL INJURY**
HEAD: Major	39 (105%)	8 (20%)	3 (7%)	**11 (13%)**	4 (5%)	**54 (26%)**
HEAD: Minor	3 (8%)	16 (40%)	31 (67%)	**47 (55%)**	19 (22%)	**69 (33%)**
FACE: Major	2 (5%)	5 (13%)	6 (13%)	**11 (13%)**	3 (4%)	**16 (8%)**
FACE: Minor	1 (3%)	5 (13%)	11 (24%)	**16 (19%)**	23 (27%)	**40 (19%)**
NECK: Whiplash	0 (-)	1 (3%)	3 (7%)	**4 (5%)**	24 (28%)	**28 (13%)**
SPINE: Fracture	3 (8%)	10 (25%)	1 (2%)	**11 (13%)**	1 (1%)	**15 (7%)**
SHOULDER: Major	0 (-)	3 (8%)	1 (2%)	**4 (5%)**	1 (1%)	**5 (2%)**
SHOULDER: Minor	0 (-)	1 (3%)	0 (-)	**1 (1%)**	2 (2%)	**3 (1%)**
CHEST: Major	30 (81%)	17 (43%)	6 (13%)	**23 (27%)**	3 (3%)	**56 (27%)**
CHEST: Minor	0 (-)	0 (-)	4 (9%)	**4 (5%)**	18 (21%)	**22 (11%)**
ABDOMEN: Major	12 (32%)	7 (18%)	2 (4%)	**9 (10%)**	1 (1%)	**22 (11%)**
ABDOMEN: Minor	0 (-)	1 (3%)	4 (9%)	**5 (6%)**	16 (19%)	**21 (10%)**
UPP LIMB: Major	1 (3%)	11 (28%)	4 (9%)	**15 (17%)**	4 (5%)	**20 (10%)**
UPP LIMB: Minor	1 (3%)	3 (8%)	6 (13%)	**9 (10%)**	22 (26%)	**32 (15%)**
LOW LIMB: Major	4 (11%)	21 (53%)	0 (-)	**21 (24%)**	1 (1%)	**26 (13%)**
LOW LIMB: Minor	0 (-)	14 (35%)	8 (17%)	**22 (26%)**	32 (38%)	**54 (26%)**
OTHER/UNKNOWN	13 (35%)	15 (38%)	7 (15%)	**22 (26%)**	22 (26%)	**57 (27%)**
TOTAL INJURIES	**109**	**138**	**97**	**235**	**196**	**540**
TOTAL PATIENTS	**37**	**40**	**46**	**86**	**85**	**208**

Figures show the total number of multiple body region injuries recorded by the TAC for each body region and level of severity (up to 5 injuries per claimant). Percentages of body region injuries per total patients for each level of injury severity (column percentage) are shown in parenthesis.

4. DISCUSSION OF THE MASS DATABASE ANALYSIS

The mass data analysis was undertaken to illustrate the types and extent of injuries to occupants of current generation passenger cars involved in road crashes. A descriptive analysis was carried out on data supplied by the Victorian Transport Accident Commission, supplemented with information from Police accident reports, and other sources. The following discusses the results of this analysis, including what conclusions can be drawn about the level of protection afforded occupants of modern passenger cars in this country and directions for future improvements.

4.1 RELIABILITY OF THESE DATA

The database constructed was the most comprehensive set of data available on occupant injuries involving post-1981 passenger cars and derivatives (29% of all vehicle occupant claims during that period). Moreover, it was the first instance of a successful enhancement of state-wide injury data with police information in Victoria. Consequently, it was possible to undertake an analysis of a number of important comparisons not previously possible. The overview analysis was intended as a descriptive account of these data and a demonstration of their strengths and weaknesses. In respect of the latter, some differences in the level of injury severity were apparent year by year, although not sufficient to invalidate the analysis. While differences were more apparent between MAB (the predecessor to the TAC) and TAC data sources, they, too, were not likely to have a major influence on an injury analysis of these data.

The initial comparison of injury severity by vehicle size was disappointing in that there was no systematic improvement in outcome for those travelling in larger vehicles (a result expected from previous literature). On closer examination, it was apparent that there were a number of confounding factors influencing this result. In particular, the analysis between vehicle size and speed zone of the crash showed that small cars were more likely to be involved in urban collisions while larger cars, rural crashes. Controlling for this factor illustrated that occupants of small cars had a higher risk of severe injury than those of large cars.

Over-reporting by about 12% was apparent in the level of seat belt wearing over that expected from other reports. However, the breakdown of seat belt wearing by other factors (severity, speed zone, impact direction, and so on) revealed predictable trends of over-involvement for non-wearers of seat belts (more severe injuries, high speed crashes, frontal collisions and rollovers, etc.). While there was likely to be some errors in the belt wearing analysis, non-wearing classifications were likely to be pure. Hence, it was still possible to analyse occupant injuries by belt wearing, although interpreting these results needed some caution.

As noted earlier, it was not possible to conduct a reliable analysis of injuries by vehicle make and model. This was because of the lack of data available, the need for additional research to determine suitable comparative measures of performance and the development of suitable techniques to control for confounding factors. This is the subject of an additional research program.

4.2 CHARACTERISTICS OF THE MAJOR VARIABLES

As noted earlier, the overview analysis provided a descriptive account of the variables of prime interest in this study, such as crash direction, occupant seating position, age and sex of the occupant, speed zone of the crash, size of the vehicle, type of drive (front- or rear-wheel), etc. As the analysis was injury based, the effects of these variables will be discussed in relation to the different levels of injury severity observed among this injured population of car occupants.

4.2.1 Impact Direction

Occupants killed or hospitalised from frontal impact collisions and rollover crashes were over-represented as TAC claimants. Side impact occupants, too, were over-involved in fatal crashes, although not substantially different to that expected for hospitalised and non-hospitalised cases. Severely injured occupants were markedly under-represented in rear-end crashes.

Frontal crashes accounted for almost one-half the total number of TAC claimants between 1982 and mid-1988, suggesting that future efforts to improve vehicle occupant protection need to emphasise this crash configuration. As one-quarter of all other crashes involved a side impact, this configuration, too, should receive priority attention. While rollovers accounted for only 5% of injured occupants, they did result in severe injuries to these vehicle occupants and should not be overlooked. Rear-end crash protection needs to be focussed primarily on providing solutions for a number of relatively minor injuries (i.e., whiplash injuries to the neck).

4.2.2 Occupant Seating Position

The overall analysis of seating position by injury severity showed an over-involvement in fatalities for rear-outboard occupants and an over-involvement as hospitalised patients for all rear and front-left occupants. Drivers, surprisingly, were not over-represented in any particular injury severity level, even though they faced added injury risk from the steering assembly, foot pedals and engine intrusions. This was shown to be true, not only for all crashes combined, but also for frontal and side impact crashes alone.

This result is difficult to explain. It may well be that the over-involvement of rear seat passengers injured, presumably because they are less likely to be wearing their seat belt than front seat occupants, is overwhelming this analysis, although it should be pointed out that rear seat occupants only accounted for 12.5% of the total injured population. If this was the case, then it is yet another demonstration of the efficacy of seat belts. As the number of drivers injured was 62% of the total injured population (a reflection of exposure for this seating position), it may also be a function of the statistical difficulty of observing a 10% variation from the expected value for such a major contributing factor.

4.2.3 Vehicle Size

Increased vehicle mass has been shown to be of benefit in occupant protection in terms of lower severity of injury outcome (eg, Evans and Waislenski 1972; Gustafsson et al 1989). However, as noted earlier, the overall comparison between vehicle size and injury severity failed to confirm this relationship because of confounding factors, most noticeably the speed zone of the crash (a proxy for the speed of impact).

Small cars were subsequently shown to be over-involved in low speed zone crashes, impacts involving other cars, driver casualties, and older occupants (characteristics reflecting urban crashes). When the analysis of vehicle size by injury severity was adjusted to control for the most critical of these features (i.e., crashes that occurred in urban speed zones of <76km/h), the analysis clearly illustrated that occupants of small cars were over-represented as severe injury claimants compared with occupants of larger cars.

Mini-cars (less than 750kg) appeared to be especially over-involved in urban crashes and those involving other vehicles. Moreover, while there was not a large number of cases involving these vehicles (again, a reflection of exposure), they did seem to be well represented amongst severe injury cases and noticeably more involved than small cars (751 to 1000kg). Given the increasing use of these vehicles and the fact they they are popular amongst the elderly (over-represented for those aged more than 75 years), they deserve special consideration in terms of their level of occupant protection.

4.2.4 Seat Belt Wearers

Over-reporting of seat belt wearing by the police in compiling accident reports was observed (98% usage rates were observed in these data, compared with an expected rate of 80-85% based on exposure and other Australian crash studies). This would seem to result from the fact that police accident reports are often compiled retrospectively (where seat belt status judgements need to rely on the accounts of others) and the legal ramifications of that action. However, there is reason to expect assigned unbelted occupant status to be real (albeit under-stated).

The analysis showed that occupants who were unrestrained were over-represented in severe injuries, high speed crashes, frontal and rollover collisions, young and very old occupants, males, front-centre and rear seating positions and compact to large vehicles. As many of these findings have been previously reported, it suggests that over-reporting has not unduly biased the unrestrained occupant injury data.

4.2.5 Occupant Age & Sex

The analysis of occupant age and injury severity showed that those aged over 55 years were more likely to be killed or hospitalised than younger occupants. This may be, in part, a function of their seating position in the vehicle and their tendency not to wear seat belts, although it may also reflect increased frailty (known decreased resistance to fracture and longer healing times) and differences, too, in vulnerability to complications after injury.

For children, however, the finding is less clear. While they were over-represented as fatalities and minor hospital cases, they were under-represented as major hospital cases. The abnormal number of deaths amongst these occupants may be in part a statistical fluctuation (there were only relatively small numbers of them in the more severe categories) and possibly their over-representation as unbelted occupants and passengers in the centre-front and centre-rear seat. Their under-involvement as major hospitalised cases might also reflect their superior injury recovery powers.

Males were shown to be over-involved in serious injury compared to female claimants. This result is probably a function of their over-representation as drivers, non-wearers of seat belts, occupants of large cars, crashes in high speed zones, and those involving rollover collisions. Females, on the other hand, were over-involved as front and rear seat passengers, as occupants of small vehicles, in low speed zone crashes, and those resulting in minor injury from rear-end collisions (e.g., whiplash).

These findings are only of limited value in defining vehicle design countermeasures for occupants in general, given the need to design for all ages and sexes. Nevertheless, it does suggest that current design criteria may not be optimal for the whole population and the need to consider additional occupant protection countermeasures (either as optional extras at purchase or as after-market features) for particular target groups at risk. On-board vehicle solutions for ensuring seat belts are worn (interlocks, etc) would seem to have some potential for reducing injuries to young children and elderly occupants.

4.2.6 Front- & Rear-Wheel Drive

The analysis of drive configuration of the vehicle involved in the crash showed that rear-wheel drives were more likely to be over-represented in high speed crashes and those involving more severe injury outcomes. Moreover, these vehicles were over-represented amongst large vehicle crashes, while front-wheel drives were over-represented amongst small vehicle crashes. This presents something of a difficult problem in this analysis as there seems to be a high correlation between type of drive and vehicle size.

Furthermore, there did not appear to be any specific injury disbenefits for either drive configuration in terms of outcome, seating position, or impact direction beyond that previously reported for the other variables. In short, there is little to be gained in attempting to analyse injuries by vehicle drive configuration in these data, because of the difficulty in separating drive from mass effects. It would be interesting to control for vehicle size and impact speed in attempting such an analysis, although this was not really possible here. Further effort in attempting to examine the effect of drive configuration is warranted in the crashed vehicle study.

4.3 ANALYSIS OF INJURIES

The most valuable and unique aspect of these data was the availability of ICD9 injury information for each patient. This enabled an analysis of the type of injuries sustained by these vehicle occupants to be undertaken for the factors of interest. For reasons of efficacy, a selective approach was adopted here in conducting this analysis to answer questions of particular relevance for occupant protection.

4.3.1 Primary Vs. All Injuries

It was noted earlier that the TAC injury codes ascribe one of the 5 injuries as the **principal** injury sustained by each vehicle occupant. This judgement is made on the basis of the seriousness of the threat to life of the injury where, for example, a spinal or head injury is ranked as more life threatening than say a leg injury, and fractures, ahead of sprains and strains.

This study, however, was chiefly concerned with the identification of all injuries sustained by occupants of modern passenger cars and their relative frequencies. While it would be interesting to undertake an injury analysis by principal injury as a measure of the most severe injuries sustained by vehicle occupants, it was not central to this study. Hence, it was considered more important to concentrate on examining all injuries sustained by occupants of current generation passenger cars. This will ensure that any countermeasure proposed from these analyses can be evaluated in terms of its total effects in injury reduction on vehicle occupants.

4.3.2 Pattern Of Crashes & Injuries

The results showed that the pattern of injuries sustained did vary depending on impact direction. For those severely injured from these crashes (i.e., killed or hospitalised), major and minor injuries to the head, chest and lower limbs were quite frequent amongst frontal crashes, while for side impacts, major injury to the chest and marginally fewer head injuries were observed. Abdominal injuries for both these configurations were noteworthy but of lower frequency.

These results would seem to be explainable in terms of different vehicle accelerations and the extent of intrusions, as well as the closeness of the impacting vehicle and surrounding vehicle components, although the precise nature of these effects cannot be evaluated from these data.

In severe collisions involving vehicle rollover, head, chest and upper limb injuries predominated amongst injured occupants, along with a higher incidence of spinal injuries. This would be expected from the severe deformations of the side and roof of the vehicle, typical in these crashes and the gravitational forces that would be applied to the occupants during rollover. For rear end collisions involving severe injury, head, abdominal, and spinal injuries were more common, while injuries to the chest, less common. This would seem to be a function of the superior protection afforded occupants in rear-end crashes from the seat back and direction of impact. Whiplash injuries, however, were markedly more frequent here, suggesting that head restraint design may not optimal for occupants under these conditions.

Non-hospitalised occupant injuries did not appear to differ markedly depending on the crash configuration with one or two exceptions. Whiplash injuries were most frequent for rear-end crashes and of some consequence in front and side crashes, but relatively infrequent in rollovers. This may be because there is less flexing of the head in rollover collisions as there is in the other impact directions or may simply reflect the relatively small numbers of rollover crashes that involve minor levels of injury.

Minor face and lower limb injuries were also of some consequence amongst these minor collisions, suggesting that there may be scope for relatively simple improvements in steering wheel and dashboard design (fewer obstructions, smoother surfaces, better padding, etc.) of benefit to vehicle occupants in relatively minor crashes.

4.3.3 Seating Position & Injuries

There were differences in the rates of severe injuries by body region for front seat occupants. Drivers and front-centre passengers experienced a higher proportion of major head injuries than did front-left passengers. For drivers, this could conceivably be a function of the steering wheel, while for front-centre passengers, the fact that they have only a lap belt restraint, although this needs to be firmly established.

Lower limb, chest, and abdominal injuries, however, were of roughly equal proportions across the three front seating positions. While the numbers were not large, nevertheless there was a suggestion that front-centre passengers were also particularly vulnerable to spinal injuries and severe whiplash.

For those killed or hospitalised in the rear seating positions, head and chest injuries were again most prominent, especially for those in the rear-centre seat. It would appear that these rear seat occupants may be especially vulnerable to contact with the rear of the front seat, although it is not clear how many of these occupants were properly restrained at the time of their collision.

Spinal injuries were again noticeable in the rear-centre seating position, suggesting that the lap belts normally provided here may not be optimal for occupant protection. However, it needs to be stressed that again there were relatively few cases of injured occupants in the rear seating position. Severe injuries to the lower limbs were markedly less in the rear seat than the front, indicating the added protection available to rear seat passengers from engine compartment intrusions resulting from a frontal collision, or absence of the underside of the dashboard.

Minor injuries were reasonably consistent across all seating positions, involving face, lower extremity, and abdominal body regions. Whiplash injury to the neck was most prevalent for drivers and front-left passengers and noticeably lower for those restrained with lap belts.

4.3.4 Vehicle Size & Injuries

The analysis for vehicle size showed that for crashes that occurred in urban speed zones (equal to or less than 75km/h), the size of the vehicle had a substantial influence on the rate of body regions injured for these TAC claimants.

Head injuries seemed to be more frequent and more severe, while lower limb injuries were also more prevalent for small car occupants. Chest injuries, on the other hand, were fewer amongst mini and small car than larger car occupants. Of interest, it should be noted that there was only 1 fatality involving a large car in urban crashes during the 7.5 year study period, and for the 140 hospitalised large car occupants, there was **not one** major head injury reported.

These findings suggest that the large differences in vehicle mass (weight), coupled possibly with an increased crumple zone area and more roomy cabin space available with larger vehicles may be a positive benefit for occupants involved in lower speed urban crashes. Unfortunately, though, there were no similar benefits obvious for larger car occupants from high speed rural crashes, but this may have been a function of the lack of rural road exposure of small cars or the over-involvement of single vehicle crashes in this environment.

It would be interesting to compare points of contact between occupants injured from smaller and larger vehicles, especially for similar impact velocities. One would expect there to be fewer head contacts with maybe more chest contacts with the steering wheel for drivers, although the increased prevalence of rear seat passengers in larger vehicles may have some effect here. This analysis was undertaken in the crashed vehicle study, reported in the following chapters.

4.3.5 Belt Wearing & Injuries

Not a lot of attention was paid to analysing injuries by seat belt wearing because of over-reporting of wearing and the minimal numbers of cases where non-use was recorded (2%). However, a simple overall comparison between alleged belt wearer and non-wearer injuries was performed and the results proved to be most interesting. As noted in the results section, care needs to be taken interpreting too much the wearing results.

Non-wearers of seat belts, though, sustained considerably more major and minor head injuries at all levels of severity than belted occupants, with fewer chest and abdominal injuries. In addition, there was less than 50% the rate of whiplash injuries among non-wearers than wearers.

This suggests there is potential for occupant protection solutions as mentioned earlier and will be examined in greater detail in the crashed vehicle study to follow, where seat belt wearing status can be accurately determined.

4.4 LIMITATIONS WITH THESE FINDINGS

The mass database assembled for this project was the most comprehensive possible at this time to permit a detailed analysis of the type of injuries sustained by car occupants by the type of crash, vehicle, and occupant characteristics. While further improvements are still possible (and desirable) to permit additional analyses (such as vehicle model analysis), these data nevertheless were extremely useful in identifying occupants' injuries under the various conditions of interest.

However, it should be recognised that the mass data analysis conducted here had both strengths and weaknesses in its approach. Its greatest strength was in the quantity of data available for analysis and the ability to control for extraneous factors that influenced particular results (such as in the vehicle size analysis reported here).

Its greatest weakness, however, was that it was not possible to establish causal links between vehicle components and occupant injuries from these data. Thus, there was a need to conduct a detailed prospective study of a number of real-world crashes to provide this level of information and this is reported in the following chapters.