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Effectiveness of ADR 69: A Case-Control Study of Crashed Vehicles Equipped with Airbags

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Abstract

Australian Design Rule (ADR) 69 called for all new passenger cars to comply with a dynamic full frontal barrier crash test requirement, similar to US safety standard FMVSS 208 but with restrained test dummies. This study set out to evaluate how effective ADR 69 has been at preventing injuries and Harm to passenger car occupants in Australia since its introduction.

A case-control study of real-world crashed vehicles equipped with and without Supplementary Restraint Systems was conducted. Data included 253 drivers in airbag-equipped vehicles and 130 drivers in non-airbag vehicles, involved in a frontal collision. The analysis revealed reductions in the numbers of injuries to the head, face, chest and neck in the airbag-equipped vehicles although the numbers of upper extremity injuries increased. At higher injury severities (AIS2+) reductions were also observed in injuries to the head, face, neck and chest. Further analysis using Harm as an outcome measure found that the mean Harm per driver (in terms of $AUD) was 60% greater in the non-airbag vehicles compared with the airbag-equipped vehicles. The main conclusion from the study was that the results offer a strong indication that the Australian Design Rule (ADR) 69 requirement has been successful in addressing some of the outstanding issues that remain for injury prevention for drivers involved in frontal impacts.

Keywords

AIRBAG, SEAT BELT, ADR, CRASH TEST, CRASH, OCCUPANT PROTECTION, SAFETY, INJURY, COUNTER-MEASURE, ECONOMIC, COST-BENEFIT, HARM, EVALUATION, CASE-CONTROL

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EXECUTIVE SUMMARY

In 1989, the Australian Federal Office of Road Safety (FORS) embarked upon a comprehensive 3-year crash investigation, testing and standards development programme. The aim of this programme was to examine passenger car occupant injuries in frontal crashes and to develop appropriate countermeasures to minimise the level and type of injuries occurring.

The end result of the programme was the introduction of a dynamic full frontal crash protection requirement on passenger cars sold in Australia: Australian Design Rule (ADR) 69. This performance-based standard requires vehicle manufacturers to design their Australian passenger models to meet specific injury level criteria for a particular crash configuration. The type of vehicle design changes incorporated to meet the new ADR requirements were left to individual manufacturers.

The regulation was based on the US Federal Motor Vehicle Safety Standard FMVSS208 but importantly specified that the Hybrid III test dummies be restrained with a seat belt. This led to the adoption of Supplementary Restraint Systems in Australian vehicles, which are less aggressive and fire at higher thresholds than their American counterparts.

The ADR 69 took effect on 1 July 1995 with design changes in response to the ADR being quickly implemented in the Australian market place. This was clearly demonstrated by the increased availability of airbags across new model ranges. Although airbags were not the only option open to vehicle manufacturers to meet ADR 69 requirements, the majority of vehicle manufacturers demonstrated a strong preference for them.

In order to evaluate the impact of ADR 69 on passenger car occupant injuries, the Federal Office of Road Safety commissioned the Monash University Accident Research Centre to undertake an analysis of real-world crashes to evaluate its effectiveness. A programme was subsequently developed that allowed occupant injuries to be compared in a representative sample of pre- and post-ADR 69 passenger vehicles.

Study Objectives

The objectives of the study were:

- to assess the effectiveness of new occupant protection measures, particularly the airbag, in reducing trauma on the road;
- to identify any problems associated with new occupant protection measures (e.g. failure of airbag to deploy, injuries caused by the new safety devices);
- to ensure that information about the impact of ADR 69 and airbags is available for public policy purposes; and
- to highlight areas where further improvement in occupant protection systems are still required.

The methodology adopted for the study involved a case-control analysis of crashed vehicles equipped with and without SRS airbag technology. Vehicles were inspected and occupants interviewed according to the National Accident Sampling System (NASS). Overall data were available for 476 individual vehicles involved in frontal impacts. This sample was further refined so that comparative groups could be defined particularly in terms of crash severity.

Study Results

There was a total of 383 belted drivers involved in frontal crashes in the comparative sample groups, including 253 drivers in airbag-equipped vehicles and 130 drivers in non-airbag vehicles. The analysis revealed statistically significant reductions in the numbers of injuries (at all levels) to the neck ($p<0.007$) in the airbag-equipped vehicles although the numbers of upper extremity injuries increased significantly ($p<0.001$).

Other reductions in injury frequency were observed which were non-significant. At higher injury severities (AIS2+), significant reductions were observed in injuries to the head ($p<0.02$), neck ($p<0.05$) and chest ($p<0.01$).

Further analysis found that the average societal Harm per driver (in $AUD) was 60% greater in the non-airbag vehicles compared with the airbag-equipped vehicles. Thus airbags in Australia offer a significant saving in terms of costs to society when used in conjunction with the seat belt.

Conclusions

This study is the most comprehensive study of the ADR 69 requirement that has been performed to date in Australia. The results offer a strong indication that it has been successful at addressing injuries sustained by front seat occupants in frontal crashes. These benefits accrue from an improved occupant protection system including a driver’s side airbag and an improved seat belt system.

Manufacturers are now in the process of developing second generation airbags and it is important that evaluations of these systems are also undertaken through real-world studies such as this. This is particularly as laboratory crash tests of improved vehicle technology and enhanced legislation can never provide a thorough analysis of the effectiveness of such advancements.

CHAPTER 1 INTRODUCTION

In 1989, the Federal Office of Road Safety (now the Australian Transport Safety Bureau) embarked upon a comprehensive research program to examine the need for further regulation aimed at improved protection for passenger car occupants in frontal crashes. This research involved injury analysis, crash testing and benefit-cost analysis. The aim of this programme was to examine passenger car occupant injuries in frontal crashes and to develop appropriate countermeasures to minimise the level and type of injuries occurring.

1.1 RESEARCH PROGRAM

The first task undertaken was to commission the Monash University Accident Research Centre to undertake an analysis of occupant injuries to passenger car occupants in frontal crashes (Fildes, Lane, Lenard and Vulcan, 1991). This report identified a number of frequent injuries and sources of injury to car occupants. Most notable was frequent head and chest injuries from contacts with the steering wheel, instrument panel and the seat belt. A range of potential countermeasures was identified including padded wheels, belt tighteners, airbags, improved seat belt systems, and structural improvements. The introduction of a dynamic frontal crash requirement, based on FMVSS 208 was also raised.

The next task was for the Monash University Accident Research Centre to undertake a benefit-cost analysis of 16 potential frontal crash countermeasures as well as 3 packages or combinations of measures to provide direction for mandating improvements (MUARC, 1992). This analysis revealed that supplementary airbags, webbing clamps, pretensioners and other measures would be cost-beneficial and that a package comprising a full-size airbag, an energy absorbing steering wheel, seat belt pretensioners or webbing clamps, better seat belt geometry and knee bolsters was expected to reduce frontal Harm by up to 25% if adopted in all passenger cars in Australia.

The last research task was to crash test 7 of the most popular passenger cars sold in Australia to demonstrate how much effort would be involved in their compliance with FMVSS 208 (Seyer, 1993). Initial studies found that the majority of the cars performed well, with injury assessment reference values not exceeded apart from the HIC (Head Injury Criterion) in one car, although threshold limits were being approached in a few of the tests. Further crash studies and computer simulation studies with optimisation of restraint mechanisms in one of the original seven cars were then undertaken. It was identified that the airbag and the energy absorbing steering wheel effectively reduced the HIC levels for both the driver and passenger. The webbing clamping and seat belt pretensioners were effective against reducing forward excursion of the occupants with a corresponding reduction in HIC, chest deflection and deceleration. The seat belt pretensioner was also found to be effective in reducing femur loads where toepan intrusion was the main force responsible for the loading.

The end result of the research programme was the development of a dynamic frontal crash protection standard, Australian Design Rule (ADR) 69. This performance-based ADR requires vehicle manufacturers to design their Australian passenger models to meet specific injury level criteria for a dynamic full frontal crash into a rigid barrier with two restrained Hybrid III test dummies seated in the frontal outboard seating positions. As is standard procedure, the type of vehicle design changes incorporated to meet the new ADR requirements were left to individual manufacturers.

The ADR 69 took effect on 1 July 1995 with design changes in response to the ADR being quickly implemented in the Australian market place. This was clearly demonstrated by the increased availability of airbags across new model ranges. Although airbags were not the only option open to vehicle manufacturers to meet ADR 69 requirements, the majority of vehicle manufacturers demonstrated a preference for them.

After introduction of the ADR 69, manufacturers chose to measure the performance criteria of vehicles in terms of injury parameters by using anthropomorphic dummies. The initial testing allowed for either the Hybrid II or Hybrid III dummies to be used, however only Hybrid III has been allowed for such testing since January 1998. The testing criteria for the crash and dummies are set out in Table 1.1.

Table 1.1 Full frontal test criteria

	Performance Criteria
Head	HIC shall not exceed 1000 over 36ms
Sternum	Compression not to exceed 76.2mm
Thorax	Chest deceleration not to exceed 60g
Femur	Axial force not to exceed 10kN
Crash barrier	To conform to SAE document J850 (1963)
Speed of test	48.3 km/h (30mph)

The car manufacturers in Australia have supported the ADR 69 and now all new passenger cars have at least the driver's airbag fitted as a standard restraint system to supplement the high seat belt wearing rate in Australia. Optimisation of the restraint system with airbags go together in maximising occupant safety to reduce injury outcomes during a frontal crash. One Australian study using computer simulation methods found that optimising the restraint systems and having an airbag fitted would reduce injury outcomes by 9%. Optimising the airbag resulted in 17% injury outcome reduction but in harness, the optimised restraint systems plus an optimised airbag increased this to a 33% reduction. These outcomes were based on the ADR 69 specifications for the Hybrid III anthropomorphic dummy in Table 1.1 (Hou, Thomas, Sparke 1995).

1.2 BACKGROUND TO CURRENT STUDY

In order to evaluate the impact of ADR 69 on passenger car occupant injuries, the FORS (now the Australian Transport Safety Bureau) perceived the need for a programme to evaluate the impact of ADR 69 using real-world crash data. A programme was developed involving a case-control methodology that would allow occupant injuries to be compared in a representative sample of pre- and post-ADR 69 passenger vehicles. To obtain a suitable data set, data collection was carried out for 5 years beginning in 1995/6. The Monash University Accident Research Centre (MUARC) was commissioned to undertake such a study.

1.3 PROJECT OBJECTIVES

The four objectives agreed to for the study were as follows:

1. To assess the effectiveness of new occupant protection measures, particularly the airbag, in reducing trauma on the road;

2. To identify any problems associated with new occupant protection measures (e.g. failure of airbag to deploy, injuries caused by the new safety devices);

3. To ensure that information about the impact of ADR 69 and airbags is available for public policy purposes; and

4. To highlight areas where further improvement in occupant protection systems was still required.

This report outlines the findings of the evaluation study of Australian Design Rule (ADR) 69 as specified by the project objectives and concludes with recommendations for future research in this area.

CHAPTER 2 LITERATURE REVIEW ON THE LIKELY EFFECTIVENESS OF ADR 69

It was generally acknowledged that mandating a full frontal crash test requirement in Australia would lead to improvements in vehicle restraint systems. Most notably, airbags and improved seat belt restraint systems were anticipated. Indeed, the experience since ADR 69 was introduced in 1995 has been the greater use of driver and front seat passenger airbags, along with the introduction of webbing clamps and pyrotechnic pretensioners as manufacturers developed integrated restraint systems.

While it is recognised the benefits of ADR 69 are likely to comprise injury reductions from both the introduction of airbags and seat belt improvements, early research by MUARC (1992) clearly demonstrated that the airbag would provide the majority of any benefit to Australian passenger car occupants. Thus, most of the focus of this international review was on airbag effectiveness.

2.1 THEORY BEHIND RESTRAINT SYSTEMS

In order to determine the benefits of airbags, it is first necessary to understand the motion of a restrained occupant in the event of a frontal collision. Mackay (1997) provides such an insight. According to him, in a typical 50km/h collision, soon after the car starts to decelerate, the occupant moves forward enough to load the seat belt. The lap-section of the belt applies forces across the iliac crests of the pelvis and the diagonal section acts upon the shoulder and rib cage. As the crash develops, the webbing stretches and allows some forward motion. The knees of the restrained occupant make contact with the instrument panel but clearly the head is free to flex forward and does so until the chin strikes the sternum. Consequently, the forward motion of the head, even when the driver is wearing the seat belt, can be in the order of 40-60cm. For such a condition, a head contact with the steering wheel is inevitable.

Additionally, Eppinger (1993) lists the maxims for good occupant restraint performance and design. In general, a good restraint system should:

- Maximise the time over which restraint forces are applied;
- Maximise the distance that the point of force application on the body moves over the ground;
- Apply as great a restraint force as possible as soon as possible during the crash event;
- Minimise the body articulations, local deformations and rate of deformations, and local inertial accelerations during the restraint event;
- Distribute forces over the greatest possible area; and
- Apply restraint forces to the bony anatomy of the femur, pelvis, upper thorax, shoulder and head while minimising loads to compliant anatomical areas.

Essentially Eppinger’s maxims involve dissipation of the occupant’s kinetic energy, and maximising the area where energy can be translated to during the crash sequence to minimise the potential injury risk from the ride down and any subsequent contact with internal structures. However, even when such maxims are taken into account when designing a restraint system, it is clear that head contacts with steering wheels can still occur to restrained drivers and it is for this reason that systems designed to supplement the actions of the seat belt are necessary in societies with high restraint usage such as Australia.

Indeed in both Europe and Australia airbags are predominantly seen as Supplementary Restraint Systems (SRS) to be used in conjunction with the wearing of the seat belt. In general, the seat belt is designed to prevent the occupant from having harsh contacts with interior surfaces of the vehicles whilst the airbag has positive internal pressures which can exert distributed restraining forces over the head and face. Furthermore, the airbag can act on a wider body area including the chest and head, thus minimising the body articulations which cause injury.

2.2 AIRBAG DEVELOPMENT

The development of airbags in their crudest form began in the 1920s but this original idea of an ‘inflatable container’ to avoid injuries to car occupants was not actually patented until the 1950s (Mackay, 1993). Further prototype experimental work in the 1960s led to small-scale trials of airbags in the early 1970s. In 1971-2 in the US, General Motors sold a trial fleet of about 11,000 cars and Volvo had a trial fleet of 1,000.

Many uncertainties surrounded the airbags of that time; questions of ear damage from noise and overpressure, the reliability of sensor technology, the use of highly toxic sodium azide, cost, reliability and the fact that they only provided partial protection in a limited range of frontal collisions. Further refinements were to follow but it was not until the 1980s that the airbag emerged as a viable restraint system with Mercedes offering a driver’s airbag in 1983 in the US. The original concept of the airbag in the United States was as a passive restraint safety feature and even today, US legislation determines that the airbag should decelerate the otherwise unrestrained driver and is of higher volume and deployed in a shorter time-frame in comparison to systems used in Europe and Australasia.

In the United States, legislation on safety issues is released by the National Highway Traffic Safety Administration (NHTSA), with the Federal Motor Vehicle Safety Standard (FMVSS) 208 for frontal impacts calling for testing of airbags as a passive restraint system without the use of a seat belt. This is because in some US states, the seat belt wearing rate is less than 50% and therefore the system has to be optimised for unrestrained occupants which implies a generally more aggressive system.

In Europe, the legislation ECE R94 for offset frontal impact protection developed by the European Enhanced-safety of Vehicles Committee (EEVC) focuses on the airbag as a supplementary restraint system with a seat belted occupant and the use of a less aggressive airbag. Therefore, the emphasis on airbags for Europe and Australasia is as a ‘Supplementary Restraint System’ to the lap shoulder seat belts. Thus in general, deployment thresholds are higher and airbag volumes lower in these ‘Supplementary Restraint Systems’ compared to the ‘Passive Restraint Systems’ found in the Unites States. Australian legislation formulated by the Federal Office of Road Safety for frontal impacts (Australian Design Rule (ADR) 69 (1995) and Australian Design Rule (ADR) 73) again focuses on belted occupants and the use of less aggressive airbags. All new cars had to comply with strict frontal crash testing procedures.

2.3 MODERN AIRBAG DESIGN

Driver airbags are housed in the steering wheel hub. In the event of a frontal crash, in the interval between the vehicle making a predetermined change in forward velocity and the first movement of the driver, the bag is rapidly inflated with gas and as such, interposes itself between the driver and the steering wheel. Following full inflation, it immediately begins to deflate via vent holes usually positioned on the underside of the airbag. The timing of inflation is critical and requires some form of electronic sensing and circuitry to fire the inflator, which produces nitrogen gas.

Airbag components have essentially remained the same with continued design improvements being made to make the gas generators less toxic and cheaper; improvements have also been made to the cover material, which now tends to be woven nylon and may be coated with silicon in parts as a timing tool in addition to the vent holes. The major components of the frontal airbag are the gas generator, a bag, cover and the fitments along with the sensor system to instigate firing of the airbag.

In general, deployment of the airbag is completed within 20ms from the initiation by the sensor and has begun deflating at that stage. The airbag generates a positive force, which acts to absorb the forward momentum of the occupant during the impact phase of the crash; this is obviously more effective if the occupant is restrained. Unrestrained occupants on impact continue travelling within the passenger compartment at the same speed of the vehicle prior to impact thus the airbag has a heavier and faster moving load to protect from injury. The airbag itself deploys at speeds between 225 and 320kp/h, which renders the airbag potentially hazardous in the deployment phase.

2.4 FIELD STUDIES OF AIRBAG DEPLOYMENTS

2.4.1 US and Canadian Field Research

US studies of field performance of airbags have been available for some time as airbags were introduced earlier in US vehicles than in other motorised societies. It must be stressed that US airbags are mandated as "*primary restraint systems*" where they must provide protection to unrestrained occupants. In all other countries, airbags tend to be "*supplementary restraint systems*" to be used in conjunction with a seat belt. The consequence of this is that US airbags (especially early models) tended to be more aggressive in their deployment rate and had a much lower firing threshold than did SRS designed airbags.

Backaitas and Roberts (1987) conducted one early study investigating 112 crashes involving government-sponsored fleet vehicles in which the airbag had deployed. It was found that the airbags deployed without failure in all 112 vehicles and of the drivers in the study, 103 (92%) sustained either no, or minor injury (at the MAIS 1 level), while of the remaining drivers, 6 received MAIS 2 injuries and 3 received MAIS 3 injuries. No injuries were found to be attributable to contact with the airbag and all moderate and serious injuries were generally attributable to contact with the intruding vehicle structure.

Huelke & Moore (1994) conducted an anecdotal study of airbag deployments in frontal collisions and found that airbags were performing well even in very severe frontal crashes. Most drivers in the study sustained minor injuries and unsurprisingly, unbelted drivers sustained more minor injuries than belted drivers and also sustained more AIS 2 injuries. In a follow-up study, Huelke et al (1994) examined upper extremity injuries in 50 cases of airbag-deployed vehicles. They found that contusions, abrasions and sprains were commonly reported whilst instances of hand and digit fractures occurred somewhat less frequently. Isolated fractures to the forearm were also reported, all injuries being attributable in some way to deployment of the airbag.

Crandall et al (1994) studied National Accident Sampling System (NASS) data to examine head and facial injuries to drivers in one of three conditions being: (i) an airbag only; (ii) a seat belt only; and (iii) a seat belt with an airbag. They found by associating this data from laboratory studies that drivers involved in the airbag-only condition incurred the risk of a head contact on the windshield and with it, increased risk of brain and facial injury when compared to seat belt only restraint emphasising the necessity for seat belts to be used in conjunction with airbags.

Augenstein et al (1994) give case reports of frontal crashes where airbags have deployed and the potential for missing occult trauma on the scene prior to transportation of occupants to a trauma centre. They found that where steering wheel deformation occurred, the driver was likely to have sustained an occult chest or abdominal injury. This was either from the airbag exerting its full force on the occupant's chest due to proximity to the steering wheel or the actual crash exceeding the airbag's protective capabilities.

The Insurance Institute for Highway Safety Status Report (1995) detailed 829 US vehicle crashes in which the airbag had deployed and found that about 43% of deployments resulted in at least one airbag-related injury. Ninety six percent of such injuries were minor (AIS=1), while 3% were moderate (AIS=2) and less than 1% were serious (AIS=3 or greater). Serious airbag-induced injuries included heart lacerations, lung contusions and fractures to the ribs. The study also included an analysis of fatal injuries attributable directly to the airbag and there were four such cases. In each case, the drivers were unbelted and sustained injuries to the head, the chest or both.

Libertiny (1995) using data from the National Accident Sampling System (NASS) observed that whilst airbags were doing what they were designed to do (i.e. decreasing the severity of injuries in major accidents), there remained the possibility of minor airbag-induced injuries increasing in frequency. However, he concluded that a decrease in overall severity was an acceptable design trade-off.

Dalmotas et al (1995) outline a Canadian study of airbag deployments. In all, 242 occupants were involved in accidents in which the airbag deployed 90% of whom wore safety belts. Most of the injuries sustained by the occupants (94%) were minor (AIS=1) while 5% were rated as AIS=2. These injuries typically included brief losses of consciousness and fractures to the upper or lower extremity, which were injuries not necessarily attributable to the airbag. The authors concluded that intervention of an airbag in moderate and severe crashes greatly reduced the likelihood of severe to fatal head injury in an unbelted occupant whilst there was a perceived risk of sustaining upper extremity and facial injuries in collisions whose severities were marginally above the deployment threshold.

In a further study, Dalmotas et al (1996) examined US and Canadian crash data. They too found that that airbag injuries comprised mainly AIS=1 facial injuries, and AIS=1-3 upper extremity injuries but they also found that AIS 3+ injuries occurred to other body regions, with airbag induced injury rates greatest among female drivers. The majority of the crashes occurred at EBS or delta-V of 25kph or less (74%). Only 5% were above 40km/h in 380 belted cases. Fifty eight percent of males sustained some degree of injury, with females having a significantly higher rate of injury (78%).

Huelke and Reed (1996) described case studies where severe neck injuries occurred to occupants from steering wheel airbag deployments. They suggested that the airbag could exert a vertical force on the occupant during deployment, which during contact with the chin can cause basal skull fractures. However this was found to be a rare phenomenon and of the 10 case studies all were women of short stature with 7 out of the 10 being unrestrained.

German et al (1998) studied the effectiveness of airbags as Supplemental Restraint Systems in Canada. They noted that first generation airbags were aggressive and gave rise to airbag-induced injuries to belted occupants. However second generation air bags were seen to be less aggressive and were generally depowered compared to 1998. Their study was divided into three phases: the first phase examined all crashes where an airbag had deployed regardless of injury (1993-1995); the second phase examined those persons taken to hospital following a crash with airbag deployment (1995-1997) and the third phase (which was in progress at the time of the study) examined modern cars 3 years or less with airbag deployments. The main findings in the first two phases were that SRS in combination with seat belts reduced head and facial injuries in high severity cases. However, in lower severity cases involving airbags there was an increased risk of injury to upper extremities and the face compared to those with just seat belts in equivalent crashes. In low severity crashes, females had a higher rate of airbag induced injury to upper extremities when compared to men. They suggested that deployment thresholds and characteristics were inappropriate for optimum protection of belted occupants. For this reason, the third phase was seen as important as it predominantly involved depowered airbags and therefore less aggressive airbags which were introduced following guidelines issued by the Canadian Government. It was predicted that some injury patterns might consequently change in comparison to earlier studies. Publication of this study is anticipated in the near future.

Huelke (1998) examined a subset of frontal crashes with a Principle Direction of Force (PDOF) of 12-o clock, where the airbag deployed and driver stature was known. Drivers were categorised as short or tall (either 165cms or less, or 168cms or over). The main injuries in each group occurred to the lower extremity, brain and upper extremity. The lower extremity injuries however were not attributable to airbag deployment. He found that 34% of tall drivers had injuries related to airbag deployments whilst short drivers appeared not to be at higher risk of injury in frontal crashes compared to the taller group. He also noted that a high proportion of MAIS 2 level injuries were unrelated to airbags in both groups.

2.4.2 Australian Field Research

In Australia, a case-control study of Holden Commodore vehicles with and without SRS airbags was undertaken during the early to mid-1990s (Fildes, Deery, Lenard, Kenny, Edwards-Coghill & Jacobsen, 1996). They found significant reductions in head and chest injuries (especially AIS2+ injuries) to occupants in comparable SRS airbag vehicles that crashed with fewer contacts with the steering assembly, seat belt and front windscreen and header rail. They also undertook an analysis to gauge the extent of savings in societal Harm for these occupants and the probability of severe injury as shown in Table 2.1. From this analysis, they concluded that while limited in the amount of data available, the analysis showed marked benefit to Commodore occupants from the fitment of SRS airbags.

Table 2.1 Mean Injury Severity Score (ISS), probability of injury and Harm sustained by drivers of airbag and non-airbag control Commodores involved in tow-away frontal crashes

Body Region Injured	Number of cases	Mean ISS	Mean Harm ($ 000s)	Probability of injury AIS 2+	AIS 3+	ISS 15+
Airbag cases	63	2.6	9.2	0.19	0.03	0.02
Non-airbag controls	85	5.4	29.2	0.31	0.07	0.05

ISS is the sum of the 3 MAIS body region scores squared.

In a subsequent Australian analysis, Deery et al (1999) reported on a comparative analysis of the early findings with those from other countries, notably the findings of Dalmotas (1995). The Australian data compared favourably in that there were no cases of AIS3+ upper extremity injuries in the Australian airbag sample. In part, the authors concluded that such results could be explained by differences in the airbag systems but they did not provide conclusive evidence to support this.

Morris et al (1998) examined data from four countries and studied injury outcomes in crashes in which airbags deployed. The data showed that in the US, Canada and Australia airbags led to a general overall reduction in AIS2+ injuries. In the study, German data was only available on head; chest, abdomen and lower limb and benefits were found for head and abdomen but dis-benefits in chest and lower limbs. US benefits in head and chest were relatively small which were suggested to be due to a low threshold for deployment unlike in Europe and Australia where deployments occurred at higher threshold. One unexpected finding was that lower limb injuries increased to the seat belt and airbag-protected drivers compared to the seat belt only protected drivers. However, it was noted that different study criteria were apparent in the samples from each of the countries in that some of the data were crash-based and others were injury-based. The authors concluded that to utilise and compare data from different countries in an effective manner, there should be some harmonisation of the methodology of data collection as well as study criteria.

2.4.3 European Studies

In Germany, Otte (1995) reviewed a series of crashes in which the airbag had deployed. He found that injuries that occurred in airbag crashes were mostly minor although there were some occupants who sustained more serious injuries (as measured by the AIS scale). The main injuries sustained were haematomas to thorax, nosebleed and burns to forearm. However, he expressed concern about the number of cervical distortions occurring in the sample of frontal impacts and concluded that the airbag may induce a powerful ‘hyper-extension’ movement of the head and cervical spine. Otte also noted that the airbag plus seatbelt lead to lower levels of injury with increasing delta-V; he further suggested that seat belts are effective up to 50km/h and for this reason, he concluded that airbags should be designed to offer protection in crashes with delta-V’s above 35km/h. Using a computer algorithm, he calculated that some injuries would be eliminated if an airbag were used. His estimated savings are shown in Table 2.2.

Table 2.2 Injury savings estimated by Otte (1995)

No injury	+ 10.5%
MAIS 1	–11%
MAIS 2 and 3	–34%
MAIS 4 to 6	–50%
And MAIS 6	–0.2%.

Langwieder et al (1996) looked at 249 accidents in airbag-equipped cars. They observed a significant reduction in severe and fatal injuries to the belted and airbag-protected drivers.

They compared the degree of damage of non-airbag cars with airbag cars and noted that those drivers with airbags were far more rarely severely injured or killed particularly when high degrees of damage occur. A surprising finding was that the main types of AIS2+

injury sustained by drivers with airbags were injuries to the extremities especially the feet. Although head injuries occurred to airbag and seat belt protected drivers, the deploying airbag was not thought to be the main source of such injuries.

One further interesting finding in the study was that although neck injuries occurred to both belted and airbag-protected drivers and belted-only drivers, they were less likely to occur in the first group. They suggested that this was because the airbag has an overall effect in preventing an excessive range of forward movement in the neck (i.e. hyperflexion). This effect appeared to occur particularly when examining a sub-group of crashes with a collision severity between 15 and 30km/h. Belted-only drivers sustained higher numbers of AIS2+ injuries to the thorax. One issue with airbags was that in 42% of passenger airbag firings there was not a passenger seated so the firing was in fact unnecessary.

Furthermore, some of the injuries to occupants were thought to have occurred due to age and stature and this was particularly true of chest injuries, e.g. fractured ribs and sternum. They concluded that there was a need for optimisation of the belt and the airbag to form an ‘intelligent restraint safety *system*’ which could detect the presence of a passenger, a rear facing child seat, and proximity of drivers to the steering wheels. Variable inflation rates at 25-30 km/h to avoid some of the minor injuries sustained by premature firing were also postulated.

Morris et al (1996) examined injury patterns in European and Japanese airbag-deployed vehicles. In all, 186 frontal crashes were examined. The majority of the drivers in the crashes sustained AIS 1 injuries with the head/face being the most common body region injured. Some AIS2+ injuries occurred but these almost always occurred when the optimum deployment conditions were compromised in some way. The most common site of AIS2+ injuries in the study was the lower limb although several AIS2+ upper limb injuries were observed. This result in particular gives credence to US studies which had found similar upper limb injury outcomes in airbag-deployed vehicles. The authors attempted to differentiate between injury in vehicles fitted with larger airbags (40 litres +) and those under 40 litres. It was found that there were more injuries to the head/face, neck, chest and limbs in vehicles with the smaller airbags although the methodology used in differentiation of airbag size was somewhat arbitrary.

The issue of association between airbag deployment and forearm injuries was studied by McKendrew et al (1998). They examined forces generated by a deploying airbag and acting on the forearm, using cadavers as subjects. They found the thickness of subcutaneous tissue over the bone might have a padding effect when the airbag deploys, as bone density was not found to be a predictor of forearm fracture alone. One cadaver with good bone density but minimal subcutaneous tissue received a fracture to both forearms, compared to other cadavers with arms, which had lower bone density and higher tissue content.

Using a logistic regression model they concluded that the level of bone density and attenuation of force by subcutaneous tissue together were possible predictors of forearm fractures. The authors acknowledged that the study involved a small sample to examine predictors of injury using a logistic regression model. However from their results, they concluded that to protect against the incidence of fractures of forearms ‘padding’ of the airbag could contribute to a reduction in the incidence of this type of injury.

Lenard et al (1998) studied the injury distributions between a sample of airbag-deployed vehicles in frontal crashes and a larger sample of non-airbag equipped vehicles in frontal crashes in the UK. They found that airbag-equipped vehicles had relatively fewer head injuries and relatively more arm injuries.

2.5 COMMENT

Differences clearly exist between Australian (and European) SRS airbags with those fitted in North America, particularly with regard to deployment threshold, inflation rate and air bag volume. The review has shown that ADR 69 has generally led to an increase in restraint systems, involving both SRS airbags and improved seat belt restraint in Australia. In response to this new regulatory requirement (as well as increased consumer awareness, advocacy group pressure and legal consideration), manufacturers and importers of vehicles in this country have embraced the need for providing improved occupant protection by the widespread use of these devices. With other factors such as seat belt use, size, mass and structural properties of vehicle fleets, it is timely to evaluate the effectiveness of these systems in this country.

CHAPTER 3 METHODOLOGY

3.1 SAMPLING AND SELECTION CRITERIA

This study used a “vehicle based” entry criterion. Each case vehicle was required to have sustained sufficient damage in the crash to warrant a tow-away by a recovery truck from the scene of the crash. A case-control method was also applied in this study. Conventionally, a strict case-control design is a very powerful method for evaluating the effectiveness of measures such as airbags and is further advantaged in that statistical conclusions can be drawn from a minimal number of cases. However, the biggest disadvantage is that there is a requirement for a fairly strict matching between cases and controls to minimise the chances of contamination of the data. The case-control method applied in the study involved comparisons of vehicle models that were introduced either before or after the ADR 69 legislation. The intention was that the study would sample approximately equal numbers of cases with and without airbags in order to compare the injury outcomes of the occupants of these two vehicle populations.

3.2 ACCIDENT NOTIFICATIONS

On an annual basis, all registered tow-truck operators in the Eastern states of Australia were sent a package containing an explanatory letter, an A4 size poster and multiple copies of a B5 peel-and-stick notice explaining the purpose of the study, the types of vehicles involved that were of interest to MUARC and a free-phone telephone number which was manned with an operator or an answering machine 24 hours per day. As an incentive for tow-truck operators to call, a $30 “spotters fee” was offered to the first caller who notified MUARC of a suitable crash for follow-up. Generally, the callers were instructed to provide MUARC with details of the crash, the destination of the damaged vehicle(s) and name and contact number of the driver and/or owner. Deployment of the airbag (if fitted) and any unusual circumstances were always confirmed prior to proceeding with vehicle inspection.

3.3 OCCUPANT CONSENT

Ethical considerations demanded that the case only proceeded beyond the initial notification if the owner and occupants of the vehicle and the repair shop or salvage yard agreed to participate in the study. This was prescribed by the ethics committee of Monash University and is a standard scientific requirement for studies involving human participants. The first step after notification was to contact the owner and secure their written agreement to participate in the study. For the most part, this was achieved using facsimile correspondence although appropriate forms had to be mailed out and returned before the case could proceed on some occasions. In the event of occupants spending time in hospital following the crash, approval was necessary from the treating hospital for access to the patient and the medical record.

3.4 INJURY DATA

Injury data were gathered on each occupant known to have been injured in the collision. This was achieved from an inspection of medical and coronial records of those seriously injured or killed or from a structured telephone interview by a trained nurse for those not requiring hospital treatment. In the case of seriously injured occupants, the casualty notes for the occupant were obtained from the Emergency department of the relevant hospital.

These notes were usually completed by Resident Medical Officers or Emergency Consultants. Occasionally, in the case of seriously injured occupants who required further surgery or a lengthy stay in hospital, it was necessary to obtain notes from the appropriate ward. When the occupants were fatally injured, post-mortem reports were obtained from the Coroner's Office.

Individual injuries sustained by occupants in the study were coded according to the Abbreviated Injury Scale (AIS), 1990 revision. This scale, which was first developed in 1969, is a measure of the severity of individual trauma-based injuries. Although injuries are rated in terms of severity, the scale is not based on the actual long-term outcome to the occupant, although an outcome impairment scale is now available. The injuries that can be coded according to this system range from a simple bruise through to decapitation. In addition to allocating each injury a six-digit code to represent the injury descriptor, the injury is given a one-digit severity score according to the following protocol:

1 = Minor
2 = Moderate
3 = Serious
4 = Severe
5 = Critical (survival uncertain)
6 = Maximum (currently untreatable)
9 = Unknown

Such coding of the data facilitates retrieval for analysis purposes. In particular, it enables a systematic body region analysis because the scale is divided into 9 sections, each of which represents a particular body region in which injuries are coded. These are shown in Table 3.1.

Table 3.1 Abbreviated Injury Scale Body Regions

AIS Numerical Descriptor	AIS Section Descriptor	Body Regions Included
1	Head	Cranium, brain
2	Face	Eye, ear, lips
3	Neck	Neck, throat
4	Thorax	Thoracic contents, including rib-cage
5	Abdomen/Pelvic Contents	Abdominal/pelvic organs
6	Spine	Spinal column/cord
7	Upper extremities	Upper limbs including shoulder
8	Lower extremities	Lower limbs including pelvis
9	External	Integumentary system, including burns

3.4.1 Maximum Abbreviated Injury Score (MAIS)

The Maximum Abbreviated Injury Score (MAIS) is the highest severity code AIS injury sustained by the occupant in the collision (the lowest possible being '0' and the highest possible being '6'). This injury can be inflicted on any part of the body. An occupant can sustain more than one injury at the same maximum level; for example, if an occupant sustains several AIS 1 injuries but no injuries classified as higher than this, then the MAIS is still 1. This method of classifying injury severity was more often used in preference to other means of classifying injury severity since some degree of consistency can be attained.

3.4.2 Injury Severity Score (ISS)

The Injury Severity Score (ISS) is the sum of squares of the highest AIS code in each of the three most severely injured ISS body regions. The six body regions used in the ISS are:

1 Head or neck

2 Face

3 Chest

4 Abdominal or pelvic contents

5 Extremities or pelvic girdle

6 External

The ISS body regions do not necessarily coincide with the sections used in the AIS. For example the AIS spine section is divided into three ISS body regions: cervical in ISS Head or neck, thoracic in ISS Chest, and lumbar in ISS Abdominal or Pelvic contents. ISS scores normally range from 1 to 75. A score of 75 results in one of two ways, either with three AIS 5 injuries or with at least one AIS 6 injury. Any injury coded AIS 6 is automatically assigned an ISS of 75. The following example is provided to help in understanding ISS calculations.

Table 3.2 Example of coding for Injury Severity Score (ISS)

ISS Body Region	Injury	AIS Code	Highest AIS	AIS^2
Head or neck	Cerebral contusion	140604.3	3	9
Face	Ear laceration	210600.1	1	
Chest	3-4 Rib fractures	450220.2	2	
Abdomen or pelvic contents	Retro. Haemorrhage	543800.3	3	9
Extremities or pelvic girdle	Fractured femur	851800.3	3	9
External	General abrasions	910200.1	1	
			Total ISS	27

3.4.3 The Concept of HARM

Harm in this study is defined as a metric for quantifying injury costs from road trauma involving both a frequency and a unit cost component. In its most general form, it is used as a measure of the total cost of the road trauma. However, Harm can also be broken down by type of road user, body region injured and severity of the injury sustained.

The Harm metric has been used in a number of studies at MUARC as a means of estimating societal benefits from the introduction of new countermeasures (MUARC, 1992) as well as a means for quantifying the financial benefits to society in evaluation studies (eg Fildes et al, 1996).

Injury costs used in this analysis to compute Harm to vehicle occupants are derived from estimates reported earlier (MUARC, 1992). These costs were determined using the human capital method and included treatment, rehabilitation, loss of productivity and wages, pain and suffering allowances and administration costs. They were based on figures originally published by Steadman and Bryan (1988), and have been updated to current values (BTE 2000).

3.5 VEHICLE INSPECTION PROCEDURES

The procedure of crash injury data collection in the study involved the collation of information about both the occupant and the vehicle involved in the crash. The vehicles were usually examined at tow-truck storage yards, auction-houses and panel-beating shops within a few days of the accident. An inspection was performed on each vehicle in accordance with standard international practice that was developed in the United States (National Accident Sampling System-NHTSA, 1989, General Motors, Detroit). A standard proforma specifically designed for the collection of data was used. Altogether information was recorded on around 300 aspects of each individual vehicle and both the exterior and the interior of the vehicle were inspected in detail. The vehicles were also photographed extensively, both internally and externally.

Agreement to help when called upon was provided by the Victorian Police and they were an invaluable source of information and support during the study.

3.5.1 Vehicle Exterior

The data collected on the vehicle exterior included information on the performance of car components such as doors, door latches, pillars, vehicle glazing, bonnet hinges and latches and certain contents of the engine bay (e.g. fuel lines). Where possible, the crush-damage profile of the vehicle was measured so that collision severity measures could be attained. Other variables such as vehicle make, model and variant were also recorded. The collision severity measures used in this study were Delta-V and Equivalent Barrier Speed (EBS).

Delta-V is defined as the change in velocity from the moment of impact until the study vehicle separated from its impacting source (MUARC, 1992). Delta-V makes use of the damage profile in order to calculate velocity change at the time of the impact. Delta-V can only be calculated when the vehicle collides with a stationary object such as a tree, pole or lamp-post or with another vehicle whose damage profile can also be measured.

Equivalent Barrier Speed (EBS) is defined as the speed in the case vehicle at which equal energy would be absorbed in a frontal energy impact into a test barrier; i.e. an estimation of the velocity change at impact that would be required of a crash test if it were to re-create the same amount of crush that occurred in the real crash with a vehicle of equal mass and stiffness. Calculation of EBS also requires measurement of the crush profile of the damage, but only of the vehicle being studied. Delta-V was used in preference to EBS but there were circumstances in which Delta-V could not be calculated and EBS was used.

It should be remembered that a vehicle crash is a complex event and the resulting damage takes on a variety of dimensions. In order to describe the damage pattern in a manner that is universally agreed and readily recognised, the Society of Automotive Engineers (SAE) devised a descriptive coding method, which conveys the essential features of the collision damage in a seven-digit code. This method of coding is fully described in a booklet entitled 'SAE Recommended Practice J224b'. The code is known as the Collision Deformation Classification or CDC. The CDC is also required to calculate both the EBS and the Delta-V. Neither of these measures of collision severity can be calculated without the CDC. The code describes the nature and location of direct contact to the vehicle. A CDC is allocated for each collision the vehicle sustains. The CDC is an alphanumeric code, the first two digits and the last digit are numbers and digits three to six are letters. Digits 1, 2, 6 and 7 define the nature of the damage while digits 3, 4 and 5 define the location. The first two digits describe the principal direction of force of the impact (PDoF) and this is determined by the super-imposition of a clock-face onto the vehicle. The PDoF is thus split into twelve 30 degree sectors as on the clock-face so that a PDoF of 12 o'clock implies that the impact was applied longitudinally to the front of the vehicle i.e. head-on, while a PDoF of 6 o'clock implies that the impact was applied longitudinally to the rear of the vehicle. The third digit describes the side of the vehicle most damaged by the direction force of the impact.

F = front

B = back

L = leftside

R = rightside

T = top

B = bottom

X = unclassified

The fourth digit describes the horizontal location of the direct contact damage. The vehicle width is split into 3 bands and the vehicle length is also split into 3 bands. This digit identifies whether the damage is to the front, middle or back of the vehicle in the case of a side impact (or any combination of these e.g. front and middle, middle and back or fully distributed across the length of the vehicle), or to the left, centre or right in the case of a frontal or rear impact (or any combination of these e.g. right plus centre, left plus centre or fully distributed across the width).

This digit can be as follows:

Front/Rear Impacts	**Side Impacts**
R=Right	F=Front
L=Left	P=Passenger
C=Centre	B=Back
D=Distributed	D=Distributed
Y=Left and Centre	Y=Front and Passenger
Z=Right and Centre	Z=Back and Passenger

The fifth digit describes the vertical distribution and location of the direct contact damage. The height of the vehicle is split into three bands or combinations, namely:

G = Glass Level and Above
M = Middle Section Only
L = Lower Section Only
E = Middle & Lower Level
H = Middle & Glass Level
A = All Three Levels

The sixth digit describes the nature of the impact type once its location has been described. The codes for these are:

W = Wide Impact (wider than 41cm)
S = Sideswipe
A = Under-run Impact
N = Narrow Impact (narrower than 41cm)
O = Rollover/Overturn
E = Corner Impact

The seventh digit describes the extent of the direct damage in relation to the side of the vehicle damage (i.e. the 'crush'). This code can be between 1 and 9. A zonal system is used for this damage profile: suppose the width of the car is split into 9 zones of equal width, then a zone 9 impact suggests that the impact 'crush' was extensive enough to penetrate into the 9th zone If the impact is to the front of the vehicle and the bumper is only slightly dented without extensive rearward crush, then the zone damage is usually 1.

The determination of both Delta-V and EBS were made by combining data on the damage crush profile with the CDC and the mass of the vehicle. Delta-V and EBS are then calculated by using a computer algorithm known as Calspan Reproduction of Accident Speeds on the Highway version 3 (CRASH3), which is essentially a direct application of the principles of linear momentum. It should be stressed that both Delta-V and EBS are relatively accurate measures of collision severity but neither are exact measures.

3.5.2 Vehicle Interior

The data collected on the interior of the vehicle included information on seats and seat performance, steering wheel and steering column movement, measurement of any intrusion or deformations of the passenger survival cell, information on seat belt usage and identification of specific occupant contacts within the vehicle.

Data were also collected regarding the occupant’s seated position in the vehicle and also seat belt usage. Determination of seat belt usage in this study could be achieved with a high degree of certainty. Evidence of usage can normally be derived from either markings left on the restraint system after the collision or by the pattern of injuries sustained by the vehicle occupant. When restraining forces act upon the occupant in the collision, the belt webbing is impressed against the D-ring and buckle tongue, which are usually coated in plastic. In these circumstances, the weave of the belt leaves an imprint on the plastic, which is visible to the naked eye.

Occasionally, scuffing of the plastic coating occurs such that the plastic is transferred to the webbing itself. Marks can also be left on the webbing due to the webbing moving against the occupant's clothing and/or seat. Occasionally, in the absence of belt transfer marks or injury to the wearer, belt usage can be ascertained by other means. For example, the belt mechanism occasionally jams while the belt is spooled out or it pulls the cover off the B-pillar or distorts the D-ring mount. Furthermore, the belt itself is occasionally cut by rescue services in order to release the occupant, a clear indicator of usage.

3.6 COMPLETED CASES AND EXAMPLE CASES

Completion of a ‘case’ involved the amalgamation and processing of information attained. This process is described below. Furthermore, one example of the crashes involved in this study is described below.

3.6.1 Case Studies

Data from the two sources (i.e. vehicle and occupant) were combined to generate a report or 'case'. The medical information was combined with the vehicle damage details so that an assessment could be made of the origin of the injuries. Generally, occupant motion in the collision could be predicted from the pattern of damage to the vehicle. If motion was apparent, then occupant contacts along the line of motion were also generally conspicuous and injuries could therefore be attributed to interaction of the occupant with these contacts. For each individual injury, a contact source could be allocated on the basis of occupant motion (kinematics), evidence of vehicle contact deduced at the time of the inspection and occasional corroborative evidence taken from the occupant interview.

The case compilation involved a comprehensive description of the vehicle damage together with details of the calculated collision severity (EBS and Delta-V), and a detailed description of the occupant injuries matched to contact sources. In some circumstances, the injury contact source is unknown, as there is no forensic or other evidence to assist in source determination, and is coded accordingly.

3.6.2 Typical Case Scenario

It is useful to consider the typical procedures for examining the mechanisms of injury in car crashes. In a frontal impact, in addition to evaluating the vehicle damage for assessing collision severity (for comparison with other impacts), an investigator from MUARC would examine the vehicle interior, along the lines described above.

Case Example

Figure 1 shows an offset frontal impact. This vehicle collided head-on with another car, which crossed over the centre line of the road for an unknown reason. The EBS was calculated to be approximately 50 km/h and the damage is consistent with an impact with another car at approximately 12 o'clock to the front of the car (assuming a head-on impact is 12 o'clock, a side impact is 3 or 9 o’clock and a rear impact is 6 o'clock etc).

Figure 3.1 Offset Frontal Impact -Collision Direction of Force is 12 o'clock

In the above example (Figure 3.1), evaluation of the seat belt system showed that there was discernible evidence of use by the driver (evidenced by markings to the tongue, belt-webbing and the D-ring). The contact sources suggested that the driver contacted the steering wheel (evidenced by some distortion to the wheel rim) and the facia (evidenced by cracks and indentations to the plastic facia cladding). This is an example of 'classical' restrained occupant motion or kinematics in a frontal crash. When the medical reports were received, the occupant was found to have sustained a contusion to the forehead (steering-wheel contact) together with bruising to the rib cage (seat belt), a fractured right patella (facia contact) and an abrasion to the left patella (facia contact). He also sustained a fracture to the right ankle for which a contact was not ascertained (although contact with the intruding wheel-well was suspected).

CHAPTER 4 RESULTS

4.1 GENERAL CRASH AND OCCUPANT CHARACTERISTICS

4.1.1 Driver and Passenger Characteristics

In total, 476 vehicles were included in the study. These included 476 drivers and 141 front left passengers. Table 4.1 shows the mean age, weight and height of these vehicle occupants. Sixty four percent of drivers were males and 28% females (8% missing data) and for the front left seat passengers 44% were male and 50% female (6% missing data).

Table 4.1 Characteristics of drivers and front left seat passengers in frontal crashes

Mean	Drivers (n=438)*	Front left passengers (n=133)*
Age	39 years (range 17-81 years)	36 years (range 3-97 years)
Height	174cms (range 125-202cms)	167cms (range 91-194cms)
Weight	77kgs (range 42-175kgs)	68kgs (range 23-120kgs)

*numbers for which driver characteristics were known

4.1.2 Crash Characteristics

All crashes included in the study were ‘frontal’ crashes (within 60-degrees of head-on) with the Principal Direction of Force ranging between 10 o’clock and 2 o’clock with the majority occurring at 12 o’clock (52%). Figure 4.1 shows the breakdown in terms of crash direction. The main object struck in the crash was found to be a passenger car or car derivative (50%) and pole/tree the second most common object 19% (see Table 4.2).

Table 4.2 Object Struck

Object struck	Frequency (n=476)	Percentage
Passenger car or derivative	237	50%
Tree/Pole	91	19%
Other vehicle	43	9%
Truck / bus	25	5%
Other roadside object	22	5%
Van	17	4%
Wall	10	2%
4WD	9	2%
Barrier	6	1%
Other/unknown	16	3%

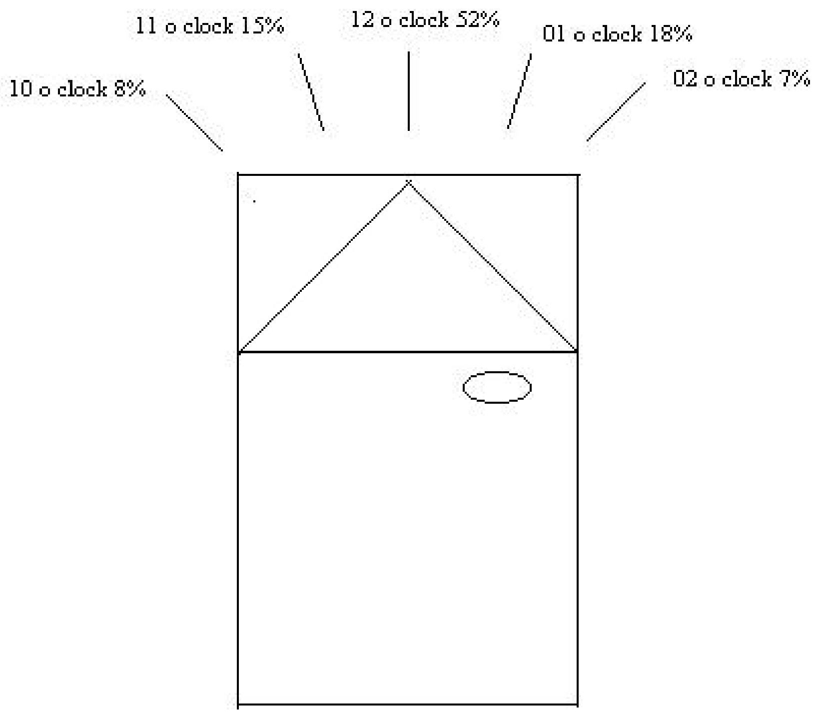


Figure 4.1 Distribution of the principal direction of force for frontal crashes

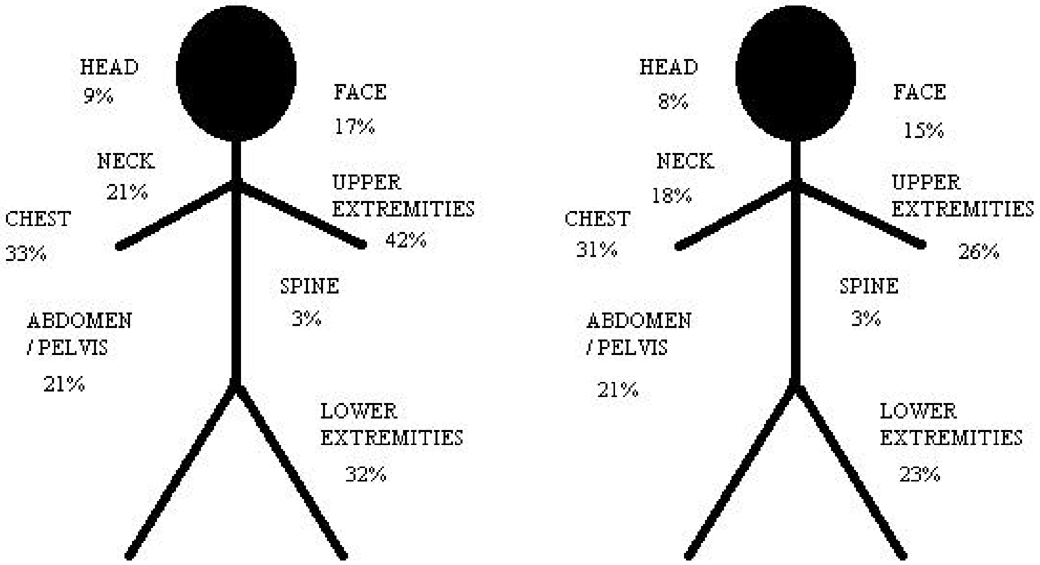
The crash severity was calculated in each case using the Crash3 algorithm where appropriate. Delta-V and equivalent barrier speed (EBS) were used as outcome measures. The mean delta-V for all crashes was found to be 36km/h, (median 34 km/h, range 6-93 km/h) and the mean EBS was found to be 35 km/h, (median 34 km/h, range 6-127 km/h).

4.1.3 Seat belt Use

Seat belt usage could be determined with a great degree of accuracy in most cases. The drivers had a 95% seat belt usage rate with 5% definitely not using them at the time of the crash. For the front left passengers 97% wore a seat belt at the time of the crash, 3% did not. The usage rate in both cases includes drivers who probably or almost certainly wore their seat belts for which usage could not be determined with 100% accuracy.

4.1.4 Injury Characteristics

Out of all of the drivers 335 (70%) sustained an injury resulting from the crash as did 92 (65%) of the front left seat passengers. As shown in Figure 4.2, the extremities and the chest were the most commonly injured body regions in the study. Of interest is the fact that drivers sustained more upper extremity and lower extremity injuries than the front left seat passengers. Contact with the deploying airbag would probably account for increased numbers of upper extremity injuries whilst lower extremity injuries are more likely to be a function of offset crashes influencing driver outcomes. Another factor could be the influence of control pedals situated on the driver's side. With the exception of these injuries, the distribution of injured body regions was comparable between drivers and front left seat passengers. Contact sources for these injuries are considered in detail later in this report.



Drivers (n=476) **Front Left Seat Passengers (n=141)**

Figure 4.2 AIS 1+ injuries to body regions sustained by front seat occupants (several occupants received more than one AIS 1+ injury)

4.2 BELTED DRIVERS IN FRONTAL CRASHES WITH AND WITHOUT DRIVER SIDE AIRBAGS

4.2.1 Driver Characteristics

This section considers differences in outcomes between belted drivers only in the study. Unbelted drivers were excluded from this analysis since it was postulated that non-belt wearing would influence injury outcomes. The total number of drivers wearing a seat belt in the crashes included in this study was 432, with 291 (67%) involved in a crash where the airbag deployed and 141 (33%) where there was either no airbag fitted or the airbag did not deploy. The characteristics of both groups of drivers are detailed in Table 4.3. As can be seen from the table, statistical analysis revealed that the two groups were very evenly matched in terms of the more important parameters (age, weight, sex and height). Therefore, it could be established with some certainty that differences in injury outcomes between the two groups could not be attributable to differences in these characteristics.

Table 4.3 Characteristics of belted drivers in airbag and non-airbag frontal crashes

Characteristics	Airbag cases (n=291)		Non-airbag cases (n=141)	
Sex*†	184 (63%) males	79 (27%) females	89 (62%) males	46 (32%) females
Age*	Mean 39 years (17-80 years)		Mean 39 years (17-81 years)	
Height*	Mean 174cms (152-193cms)		Mean 174cms (125-201cms)	
Weight*	Mean 77kgs (48-120kgs)		Mean 77kgs (45-175kgs)	

*no statistically significant difference between airbag cases and non-airbag cases
†cases where sex of occupant could not be determined excluded in this analysis

4.2.2 Crash Severity

The mean delta-V, where calculated, was found to be 33km/h (SD 13) for the airbag case group and 40 km/h (SD 17) for the non-airbag case group (p<0.0001, independent T test, 2 tailed). The mean equivalent barrier speed was found to be 33km/h (SD 14) for the airbag cases and 41km/h (SD19) for the non-airbag cases (p<0.0001, independent T test, 2 tailed). The range of calculated delta-V and equivalent barrier speeds are detailed in Figures 4.3 and 4.4. This result is of importance to this analysis since differences in injury outcomes could be in part attributable to differences in collision severity.

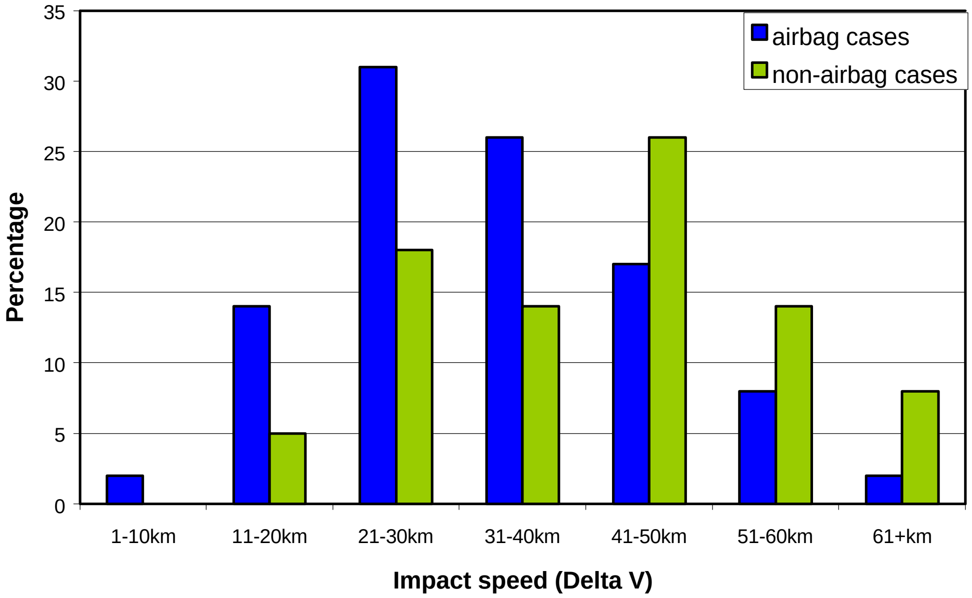


Figure 4.3 Delta-V distribution for airbag and non-airbag frontal crashes

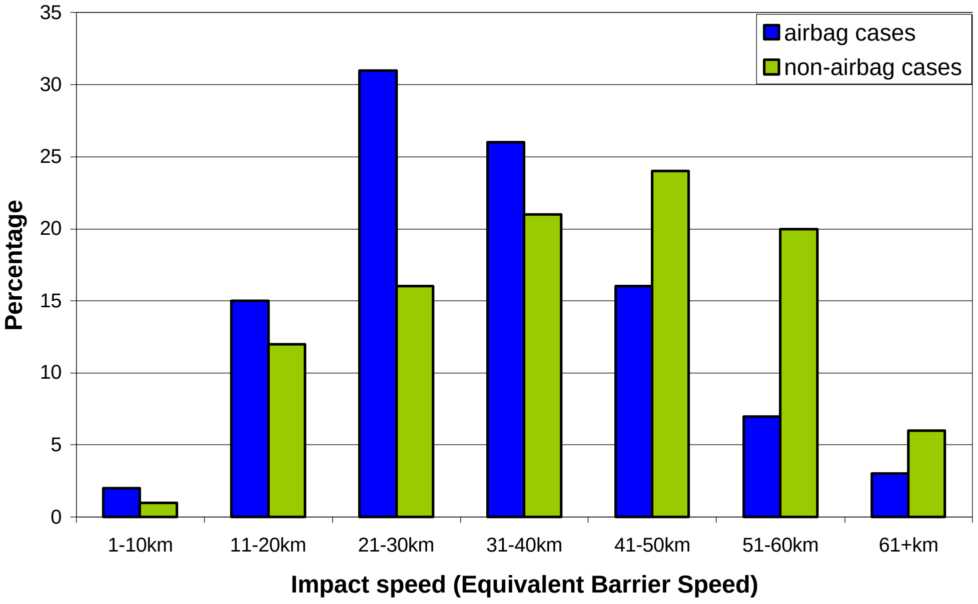
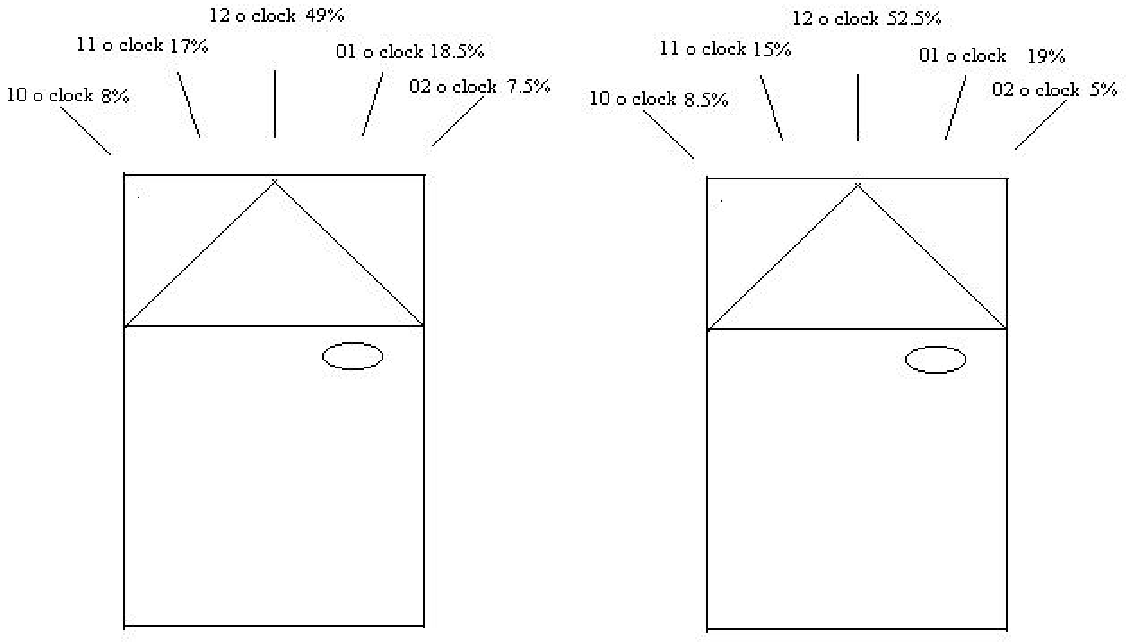


Figure 4.4 Distribution of equivalent barrier speeds for airbag and non-airbag frontal crashes

Further analysis revealed that there was no significant difference between the groups in the Principle Direction of Force (PdoF) of the crash (Figure 4.5) In both groups, the majority of crashes had a PdoF of 12 o'clock (or 0-degrees). Similarly, the objects struck during the crash did not differ significantly between the two groups (Chi squared test - Table 4.4).

Table 4.4 Object struck in airbag and non-airbag frontal crashes

Object struck	Airbag cases (n=291)	Non-airbag cases (n=140)
Car / ute	144 (50%)	72 (51%)
Tree	33 (11%)	13 (9%)
Pole	26 (9%)	14 (10%)
Other vehicle	22 (8%)	18 (13%)
Truck / bus	12 (4%)	8 (6%)
Van	12 (4%)	4 (4%)
4WD	8 (3%)	1 (1%)
Other roadside object	14 (5%)	6 (4%)
Wall	6 (2%)	2 (1%)
Other object	7 (3%)	0
Barrier	3 (1%)	2 (1%)



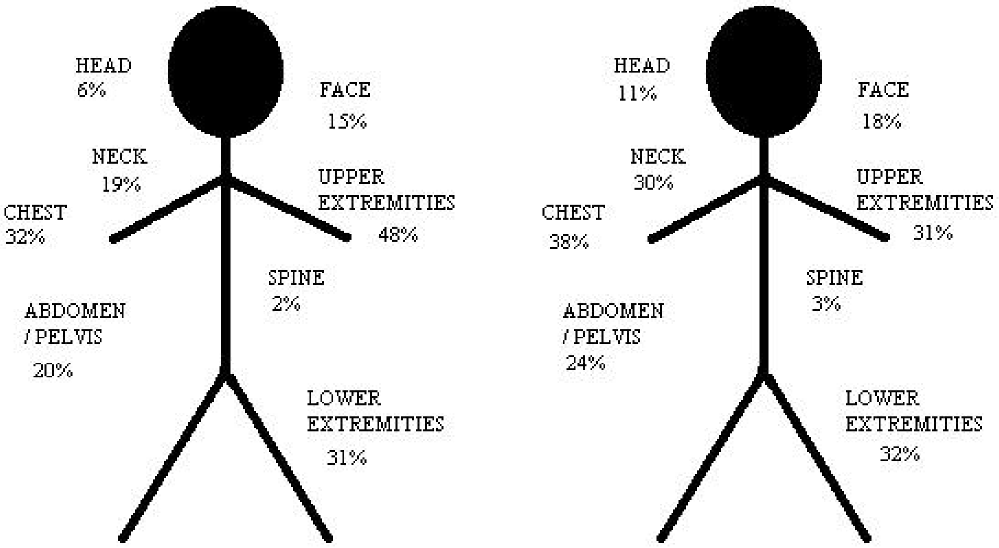
Airbag cases (n=291) **Non-airbag cases (n=141)**

Figure 4.5 Principal direction of force for airbag and non-airbag frontal crashes

4.2.3 Injuries

A total of 217 (75%) drivers in the airbag study group sustained an injury, 50 (17%) did not and injury outcomes were unknown in 24 cases. A total of 90 (64%) drivers in the non-airbag study group sustained an injury, 42 (30%) did not and injury outcomes were unknown in 9 cases. The distribution of injuries to body regions is detailed in Figure 4.6.

Analysis of the data revealed that there was a significantly lower number of neck injuries sustained by drivers in the airbag group compared to the non-airbag group (χ^2=7.78, df=1, $p<0.005$) (Table 4.5). Furthermore, significantly more upper extremity injuries occurred in the airbag group (χ^2=12.53, df=1, $p<0.001$) compared with the non-airbag group. There were also differences in injury outcomes that whilst not statistically significant, revealed a trend according to driver group; for example, head injuries were less frequently sustained by the airbag-group whilst this group also sustained less numbers of chest injuries.



Airbag cases (n=291) **Non-airbag cases (n=141)**

Figure 4.6 Distribution of AIS 1+ injuries in belted drivers in airbag and non-airbag frontal crashes

Table 4.5 AIS 1+ injuries in belted drivers in airbag and non-airbag frontal crashes

Body region	Airbag cases (n=291)	Non-airbag cases (n=141)	Significance
Head	6%	11%	ns
Face	15%	18%	ns
Neck	19%	30%	<0.005*
Chest	32%	38%	ns
Abdomen / pelvis	20%	24%	ns
Spine	2%	3%	ns
Upper extremity	48%	31%	<0.001*
Lower extremity	31%	32%	ns

*Chi squared test

The Maximum Abbreviated Injury Severity (MAIS) score for each group was also compared. Drivers in the non-airbag group were more likely to sustain no injury compared with the airbag group. However, drivers in the airbag group were more likely to sustain injuries at the MAIS 1 injury level compared with the non-airbag group. Furthermore, drivers in the non-airbag group were more likely to sustain injuries at the MAIS 2 and 3 level compared to the airbag group. A very small percentage of MAIS 6 injuries were observed in the non-airbag group but these were not observed in the airbag group.

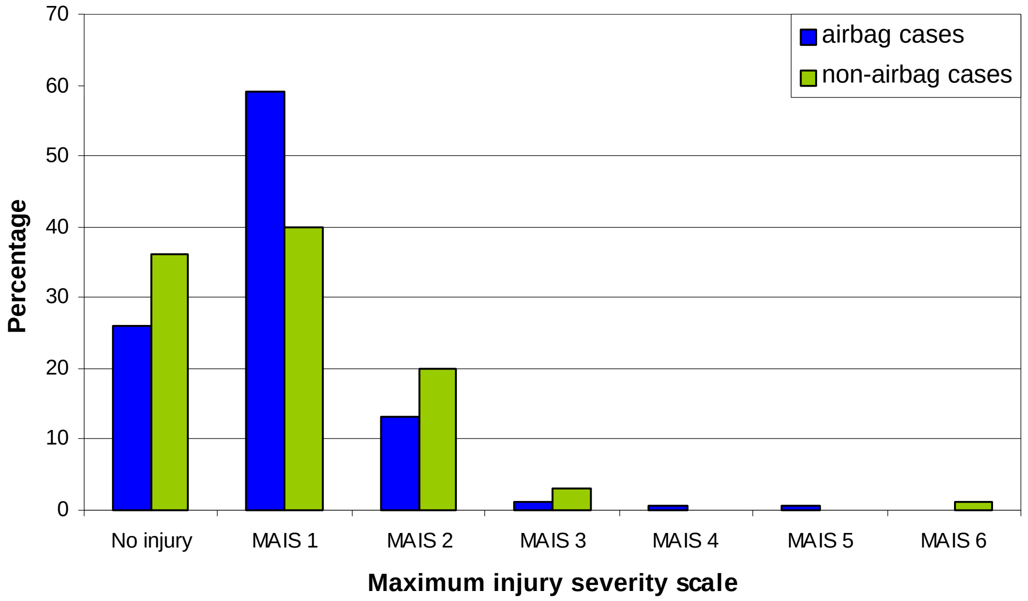


Figure 4.7 Maximum abbreviated injury scale for belted drivers in airbag and non-airbag frontal crashes

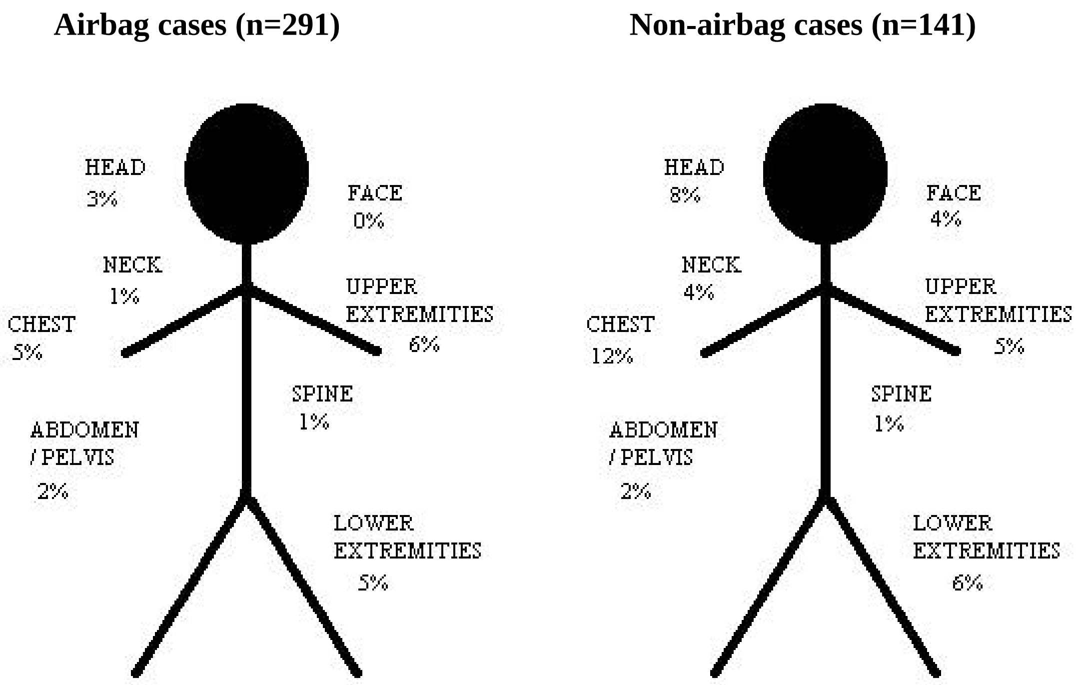
Table 4.6 shows comparisons of injuries at higher severity (MAIS 2+) levels. In this analysis, statistically significant reductions in injuries to the head, face, neck and chest are observed in the airbag group, which can in part be attributed to the airbag deployment. As expected, injuries to other body regions do not differ.

Table 4.6 MAIS 2+ injuries to all body regions for belted drivers in airbag and non-airbag frontal crashes

Body region	Airbag cases (n=291)	Non-airbag cases (n=141)	Significance
Head	3%	8%	<0.02
Face	0%	4%	<0.004**
Neck	1%	4%	<0.07
Chest	5%	12%	<0.006*
Abdomen / pelvis	2%	2%	ns
Spine	1%	1%	ns
Upper extremity	6%	5%	ns
Lower extremity	5%	6%	ns

* Chi squared test ** Fishers exact

The distribution of driver injuries at the MAIS 2+ level is illustrated in Figure 4.8.



Airbag cases (n=291)

Non-airbag cases (n=141)

Figure 4.8 Distribution of AIS 2+ injuries in belted drivers in airbag and non-airbag frontal crashes

Overall, significantly fewer MAIS 2+ injuries were sustained by the airbag group compared to the non-airbag group, although higher numbers of MAIS 1 injuries were sustained by the same group (χ^2=11.6, df=1, p<0.001).

Contact sources for all injuries and MAIS 2+ injuries were determined and grouped accordingly. The main contact sources for injury to both groups were the seat belts, steering assembly, instrument panels, deceleration forces and airbags for the airbag group (Table 4.7).

There were no significant differences between the two groups in terms of contact source for their injuries. A trend in fewer steering column contacts was noted in the airbag group (χ^2=3.63, df=1, p<.06). Furthermore, there were obviously several injuries sustained in the airbag group due to contact with the airbag itself. It was interesting to observe that higher numbers of AIS 2+ injuries due to interaction with the seat belt were sustained by the non-airbag group. This would suggest that the airbag does offer additional retardation and distribution of crash forces over a wider area than the head and face alone.

An interesting observation in the airbag group is that whilst there were several injuries attributable to interaction with the airbag (almost always minor abrasions and ‘burn’ injuries due to contact with the vent-holes), some AIS 2+ injuries did occur. These were almost exclusively fractures to the forearm that occurred due to direct contact with the airbag at the moment of deployment. Such injuries are considered in more detail in the discussion.

Table 4.7 Contact sources for body regions injured for belted drivers.

Source of Injury	Airbag cases (n= 291)		Non-airbag cases (n=141)	
	All AIS	AIS 2+	All AIS	AIS 2+
Seat belts	45%	10%	47%	19%
Airbag	28%	3%	Nil	nil
Instrument panel	22%	7%	24%	12%
Steering assembly	13%	6%	19%	13%
Deceleration	11%	1.5%	15%	5%
Floor and toe pan	9%	5%	11%	8.5%
Front screen and header	3%	0.5%	1.5%	1%
Side window and frame	2%	0.5%	2%	1%
Doors and fittings	2%	1.5%	2%	1.5%
A pillar	1%	1%	Nil	nil
Roof side rail	1%	nil	Nil	nil
B-pillar	0.5%	nil	Nil	nil
Roof surface	0.5%	0.5%	1%	1%
Exterior other object/vehicle	0.5%	0.5	1%	nil
Other occupant	0.5%	nil	Nil	nil
Seat	nil	nil	1%	1%

4.2.4 Harm Analysis

The mean sum Harm for drivers in the airbag group was found to be $30,000 and for the non-airbag group $50,000, (these figures have been interpolated to reflect the threefold increase in Harm costs since 1985, as calculated by The Bureau of Transport Economics in 2000, (Steadman and Bryan 1988, BTE 2000)).

4.2.5 Injury Severity Score

The ISS scores are presented in Table 4.8 for all belted drivers involved in a crash (n=432) and for those belted drivers injured in the crash (n=307). There is a significant difference in the mean ISS scores between the airbag and non-airbag groups (independent t-test). Drivers in the non-airbag group scored higher on the ISS scale when compared with drivers in the airbag group and this could be explained in part by greater numbers of drivers in the non-airbag group sustaining injuries particularly at the AIS 2 level.

Table 4.8 Injury severity score for belted drivers in airbag and non-airbag frontal crashes

Drivers	Airbag cases (mean ISS)	Non-airbag cases (mean ISS)	Significance (t-test)
All belted drivers (n=432)	2.12	3.49	<0.04
Injured belted drivers (n=307)	2.6	5.1	<0.004

The differences between the airbag and the non-airbag group that have been observed in the above analyses could, in part, be explained by differences in collision severity (as measured by Delta-V and EBS) between the two groups. Although collision severity is not always a predictor of injury outcomes there is almost always some association between the two. Collision severity would be the only other significant factor (other than airbag deployment) on injury outcomes in this study. However, as was shown earlier, there were no statistically significant differences in terms of occupant characteristics between the two groups. Therefore, it was postulated that in order to attain a more accurate picture of the effects of airbags, there was a requirement for a further comparison between two groups of drivers involved in crashes of equal severity. This is explored in the next section.

4.3 BELTED DRIVERS IN FRONTAL CRASHES WITH AND WITHOUT DRIVER AIRBAGS: COMPARATIVE SAMPLE GROUPS

4.3.1 Driver Characteristics

Cases for this analysis were selected using a baseline kerb-weight between 1000kgs and 2000kgs and a delta-V distribution between 10 and 65kph. A total of 383 belted drivers involved in frontal crashes were available for the analyses in this section. There were 253 belted drivers involved in crashes where the airbag deployed and 130 belted drivers involved in crashes where an airbag was not equipped or not deployed.

Again, as in Section 4.2, there were no significant differences in age, weight and height between the airbag cases and non-airbag cases. However, in this sample, the mean collision severity between the two groups did not differ significantly; mean delta-V for the airbag cases was 33.3 km/h and non-airbag cases was 35.6km/h (p=0.2, independent 2 tailed t test). Figure 4.9 shows the cumulative distribution according to delta-V. A median test of this distribution also showed that there was no statistically significant difference between the two groups (χ^2= 1.21, df=1, p=ns).

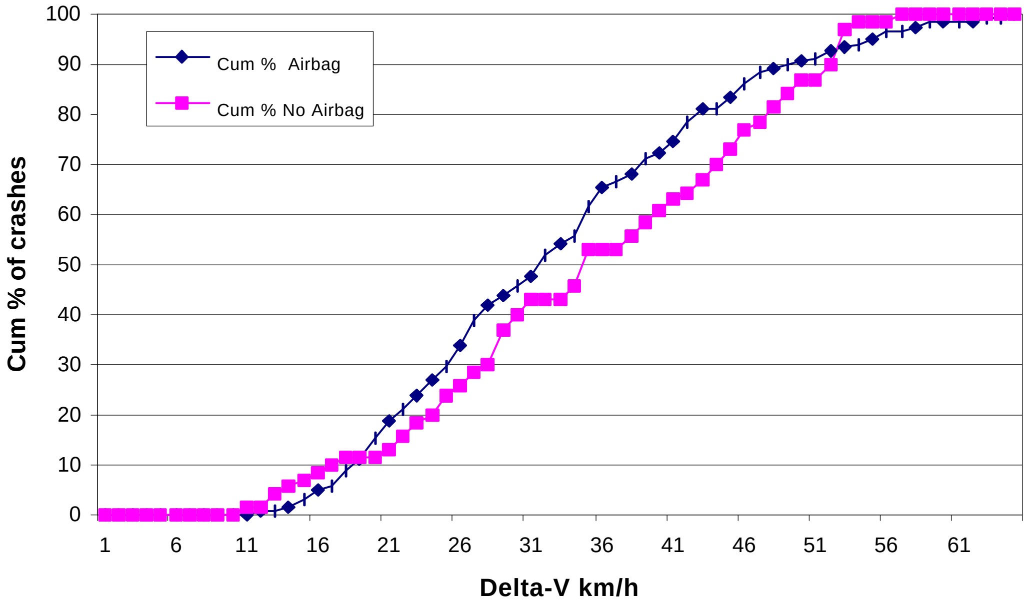


Figure 4.9 Cumulative distribution of delta-V for airbag and non-airbag frontal crashes in a comparative sample

4.3.2 Injury Outcomes

The injury analysis for all AIS levels of injury showed a significant reduction in neck injuries (χ^2 7.2, df1, p<0.007) and a trend in the reduction of head injuries in the airbag group (χ^2=3.2, df 1, p=0.07) (Table 4.9). However it was noted that significantly higher numbers of upper extremity injuries occurred within the airbag group compared to the non-airbag group (χ^2=15.54, df =1, p<0.001). Figure 4.10 gives the distribution of all AIS level injuries sustained by belted drivers in the airbag and non-airbag groups.

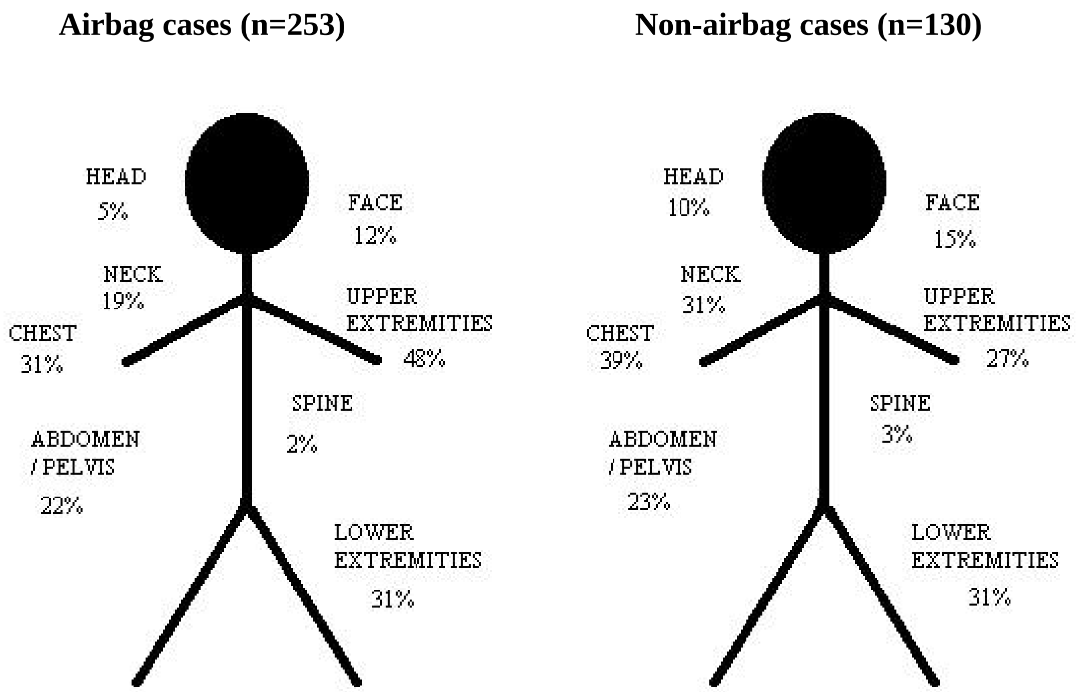


Figure 4.10 Distribution of AIS 1+ injuries in belted drivers in airbag and non-airbag frontal crashes in a comparative sample

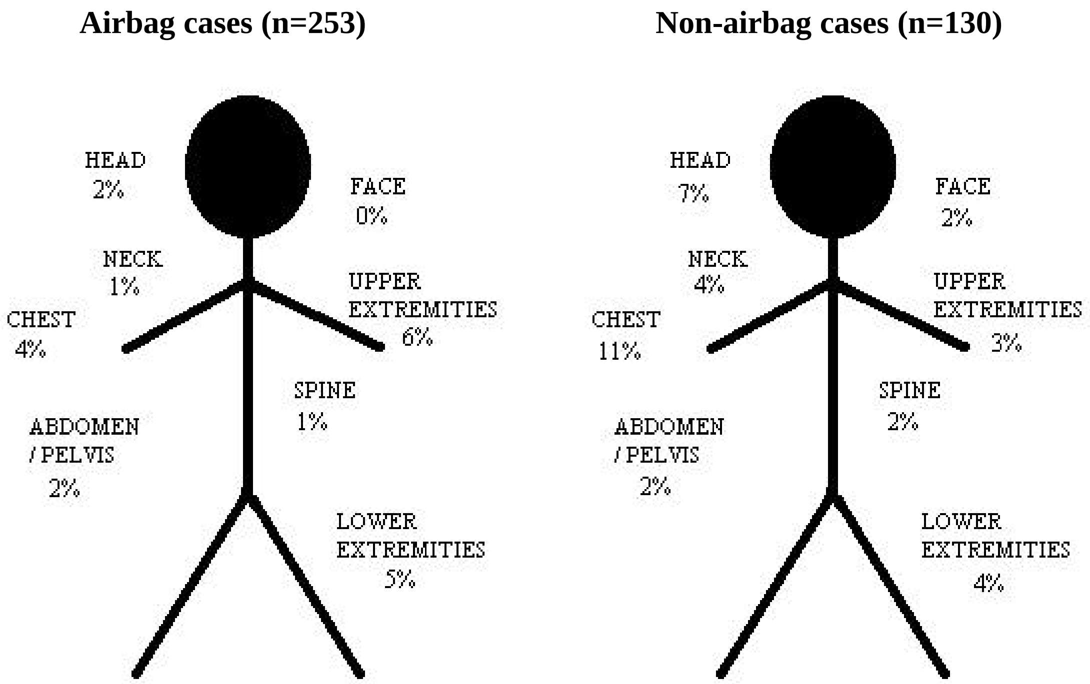
Other trends in injury reductions were observed, particularly to the face and the chest. Therefore, whilst it cannot be stated with certainty that airbags are significantly reducing injuries to most body regions, there are definite injury reductions to the targeted body regions.

Table 4.9 AIS 1+ injuries to body regions for belted drivers in airbag and non-airbag frontal crashes in a comparative sample group

Body region	Airbag cases (n=253)	Non-airbag cases (n=130)	Significance
Head	5%	10%	0.07
Face	12%	15%	ns
Neck	19%	31%	0.007*
Chest	31%	39%	ns
Abdomen / pelvis	22%	23%	ns
Spine	2%	3%	ns
Upper extremity	48%	27%	<0.001*
Lower extremity	31%	31%	ns

* Chi squared test

For injuries sustained at the AIS 2+ level there was a significant reduction in head and chest injuries to belted drivers in the airbag group ($\chi^2=5.8$, df =1, $p<0.02$; and $\chi^2=5.97$, df=1, $p<0.01$) (Table 4.10). It was also found that neck injuries at this level were lower in the airbag group compared to the non-airbag group (p<0.05, Fishers exact test). It should be observed that higher numbers of upper extremity injuries at the AIS 2+ level were observed in the airbag group. Figure 4.11 shows the distribution of injuries at the AIS 2+ level to both drivers in the airbag and the non-airbag groups.



Airbag cases (n=253) **Non-airbag cases (n=130)**

Figure 4.11 Distribution of AIS 2+ injuries in belted drivers in airbag and non-airbag frontal crashes in a comparative sample group

Table 4.10 AIS 2+ injuries to body regions for belted drivers in airbag and non-airbag frontal crashes in a comparative sample group

Body region	Airbag cases (n=253)	Non-airbag cases (n=130)	Significance
Head	2%	7%	<0.02*
Face	0%	2%	Ns
Neck	1%	4%	<0.05**
Chest	4%	11%	<0.01*
Abdomen / pelvis	2%	2%	Ns
Spine	1%	2%	Ns
Upper extremity	6%	3%	Ns
Lower extremity	5%	4%	Ns

* Chi squared test ** Fishers exact test

The non-significant number of upper extremity injuries sustained at the AIS 2+ level would indicate that drivers in the airbag group are sustaining numerous minor injuries to this body region. Figure 4.12 shows the MAIS injury distribution for the two groups of drivers.

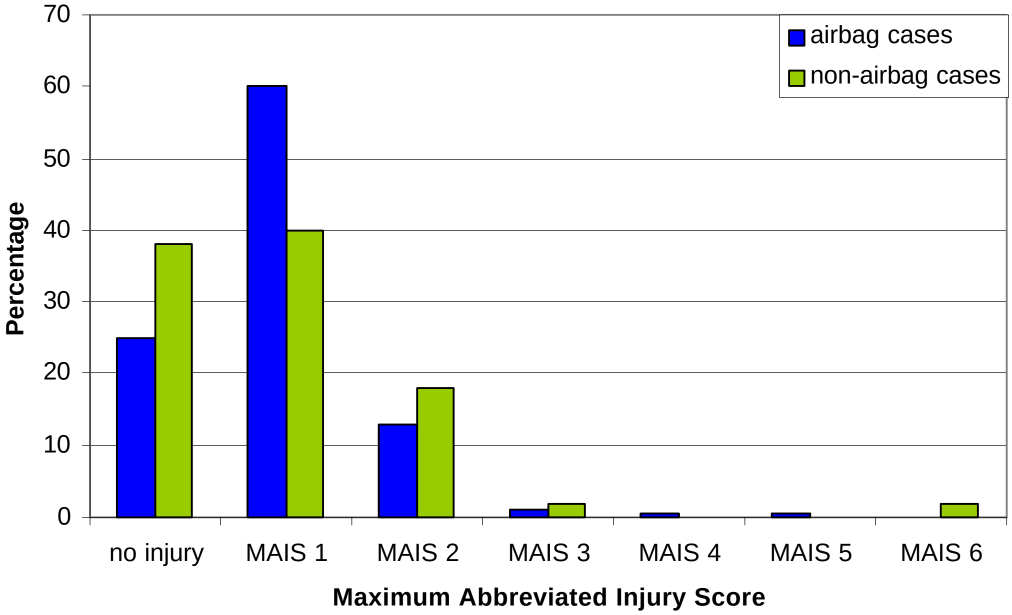


Figure 4.12 Distribution of MAIS for belted drivers in airbag and non-airbag frontal crashes in a comparative sample group

As can be seen from Figure 4.12, the same trends in MAIS injury distributions that were observed in the first analysis are apparent. Drivers in the airbag group were more likely to sustain injuries at the MAIS 1 injury level compared with the non-airbag group. Furthermore, drivers in the non-airbag group were more likely to sustain injuries at the MAIS 2 and 3 level compared to the airbag group. A very small percentage of MAIS 6 injuries were observed in the non-airbag group but these were not observed in the airbag group.

4.3.3 Injury Severity Score and Harm Analysis

Table 4.11 shows the analysis of the comparison between mean injury severity scores (ISS) and mean Harm for all belted drivers in the study. Whilst the mean ISS scores do not differ significantly, there is a large discrepancy in the mean Harm between the two groups. This analysis suggests that whilst the outcomes in terms of threat to life do not differ, there are significant implications in terms of the difference in injury costs.

Table 4.11 Mean injury severity score and Harm for all belted drivers in airbag and non-airbag frontal crashes in a comparative sample group

Belted drivers	Number of cases	Mean ISS	Mean Harm ($ 000s)*
Airbag cases	253	2	25.2
Non-airbag cases	130	3.2	40.8

* These figures have been interpolated to reflect the threefold increase in Harm costs since 1985 as calculated by BTE in 2000 (Steadman and Bryan 1988, BTE 2000).

Table 4.12 compares injury outcomes amongst *injured* belted drivers. As can be seen from the table, the mean Harm for injured belted drivers in non-airbag vehicles is of the order of twice the Harm of drivers in airbag vehicles. This analysis suggests that injured drivers in non-airbag vehicles sustain more impairing types of injuries that involve higher cost implications. If this table is viewed in association with table 4.10, then it can be seen more clearly that the drivers of non-airbag vehicles are sustaining more injuries to the head, chest and neck and these are injuries which have significant cost implications as measured by Harm.

Table 4.12 Mean injury severity score and harm for injured belted drivers in airbag and non-airbag frontal crashes in a comparative sample group

Belted drivers	Number of cases	Mean ISS	Mean Harm ($ 000s)*
Airbag cases	190	2.35	33.5
Non-airbag cases	80	4.9	66.0

* These figures have been interpolated to reflect the threefold increase in Harm costs since 1985 as calculated by BTE in 2000 (Steadman and Bryan 1988, BTE 2000).

4.3.4 Contact Sources for Injury

Table 4.13 shows the contact sources for injured drivers in the study. A number of issues arise from this analysis. Firstly, there is the issue of seat belts as a contact source for AIS 2+ injuries in the non-airbag group. As can be seen from the table, AIS 2+ injuries are more likely to occur amongst this group and this in part may be explained in terms of a general reduction in AIS 2+ injuries particularly to the chest. On occasions, the restraining effect of the seat belt webbing can be sufficient to cause fracturing of the ribs and sternum and sometimes also the scapular. However, the fact that this was found to occur less frequently in the airbag group would suggest that the airbag has additional restraint capabilities beyond simply protecting the head from harsh contacts with the steering wheel. This is despite the fact that the 'early' design of airbags such as those found in vehicles included in this study did not generally make provision for chest injury reduction. In effect, the deploying airbag would appear to work in conjunction with the seat belt to distribute the crash-load over a wider area of the chest thus reducing the risk of concentrated load, which would normally cause fracture. This is clearly an encouraging aspect of the Supplementary Restraint System's effectiveness. Then there is the issue of contacts with the steering assembly itself. One of the main functions of the airbag is to prevent harsh contacts between the head/face and the steering wheel. This analysis shows that there is a general reduction in injuries caused by the steering wheel but the effect is not heavily pronounced. Injuries do still happen through interaction with the steering wheel and this raises the question of deployment timing (discussed in more detail in a later section). A further issue of note is that the airbag itself can cause injury and this is particularly true for upper extremity injuries. Moderately serious upper extremity injuries can arise in one of two ways. Firstly, the upper extremity may be in the proximity of the deploying airbag itself. Secondly the upper extremity can be 'flung' as result of interaction with the deploying airbag and can contact the 'A'-pillar or header-rail leading to fracture of the bones of the hand, wrist or arm. Both these injury mechanisms were observed in this study. Finally the deploying airbag was observed to prevent some injuries due to inertial forces alone and this was particularly true for neck injuries. This is also discussed more fully in a later section.

Table 4.13 Contact sources for injuries in belted drivers in comparative airbag and non-airbag frontal crashes

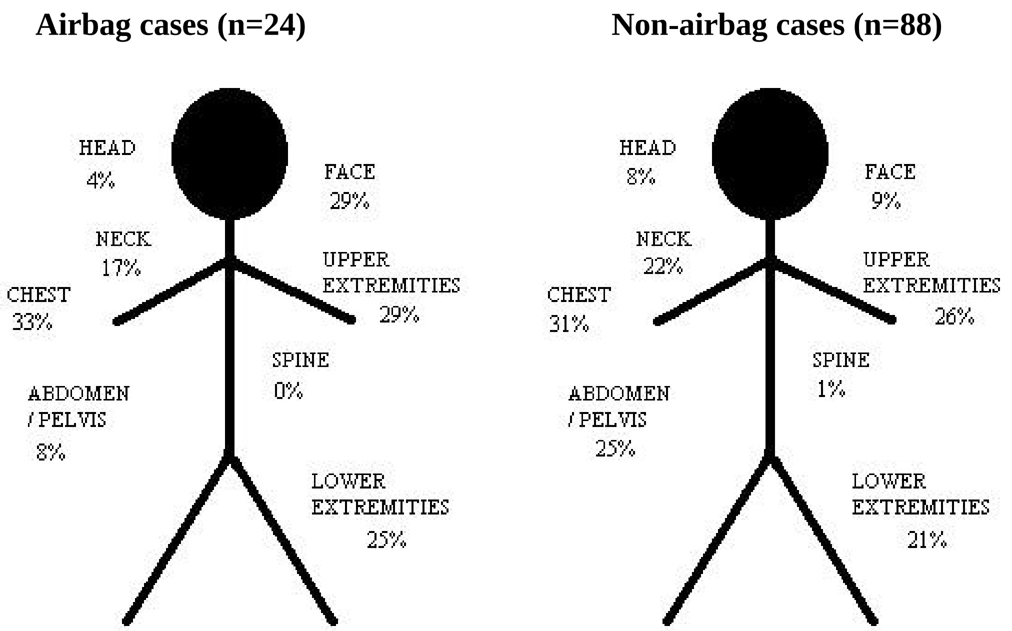
Source of Injury	**Airbag cases (n=253)** **All AIS**	 **AIS 2+**	**Non-airbag cases (n=130)** **All AIS**	 **AIS 2+**
Seat belts	44%	10%	47%	18%
Airbag	28%	3%	nil	nil
Instrument panel	22%	6%	22%	9%
Steering assembly	13%	6%	16%	10%
Deceleration	12%	1.5%	15%	6%
Floor and toe pan	9%	5%	9%	5%
Front screen and header	3%	Nil	2%	1%
Side window and frame	2%	0.5	2%	1%
Doors and fittings	2%	1.5%	2%	1%
A pillar	1%	0.5%	nil	nil
Roof side rail	1%	Nil	nil	nil
B-pillar	0.5%	Nil	nil	nil
Roof surface	nil	Nil	1%	1%
Exterior other object/car	nil	Nil	1.5%	1.5%
Other occupant	0.5%	Nil	nil	nil
Seat	nil	Nil	1%	1%

4.4 FRONT LEFT SEAT PASSENGERS

4.4.1 Belted Front Left Seat Passengers

In this section, the effects of the deploying passenger airbag on the front left seat passenger are analysed. In total, there were 112 front left seat passengers in a comparative sample group of crashes. Twenty-four (21%) were involved in frontal crashes where the passenger airbag deployed and 88 passengers (79%) were involved in frontal crashes where there was no airbag fitted in the passenger side. There were no differences between sex, age, and weight although height differed between the airbag and non-airbag group of passengers.

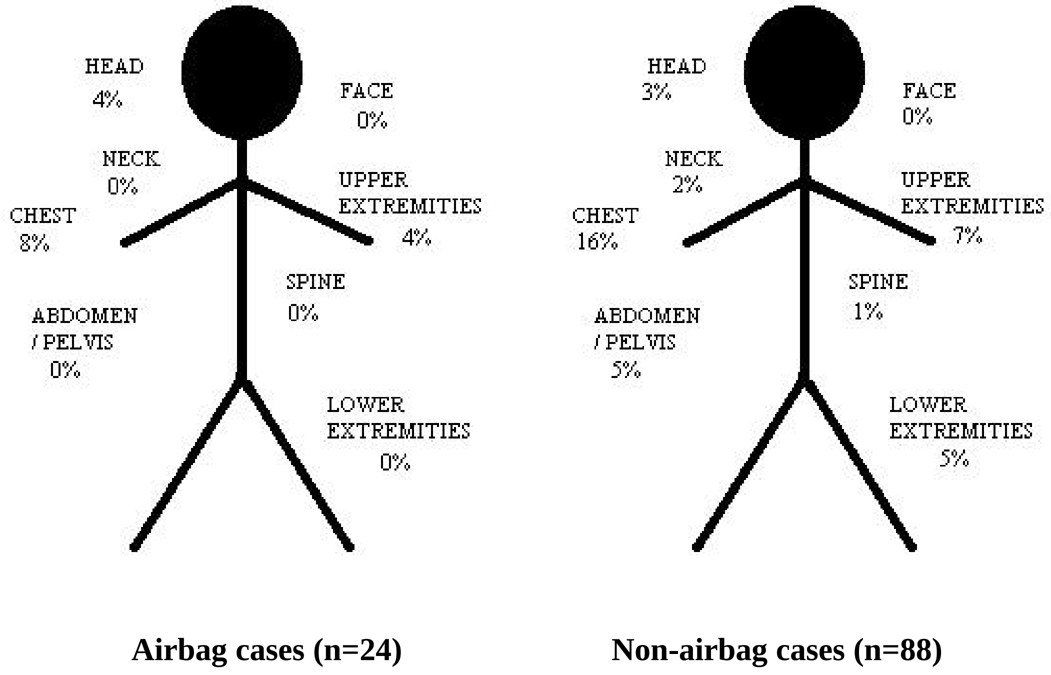
In total 18 passengers in the airbag group and 53 passengers in the non-airbag group sustained injuries following the crash. The main body regions injured were the chest, upper and lower extremities and neck in both groups of passengers. However the airbag group had higher numbers of facial injuries and the non-airbag group a higher number of abdominal injuries (Figure 4.13). The injury analysis for all levels of injury showed an increase in facial injuries sustained by the airbag group (p=0.2, Fishers exact) and a trend in the reduction of abdominal injuries (χ^2 =3.11, df 1, p= 0.08).


Airbag cases (n=24)

Non-airbag cases (n=88)

Figure 4.13 Distribution of AIS 1+ injuries in belted front left seat passengers

With regard to injuries sustained at the AIS 2+ level, the main body regions injured were the chest and the upper extremities in the non-airbag group (Figure 4.14). There were no significant differences between the airbag and non-airbag group, which is possibly an effect of the small sample size within the two groups.



Airbag cases (n=24)

Non-airbag cases (n=88)

Figure 4.14 Distribution of AIS 2+ injuries in belted front left seat passengers

The Maximum Abbreviated Injury Severity score sustained by the passengers for both groups was 4, with the majority sustaining injuries at the MAIS 1 and 2 levels (Figure 4.15).

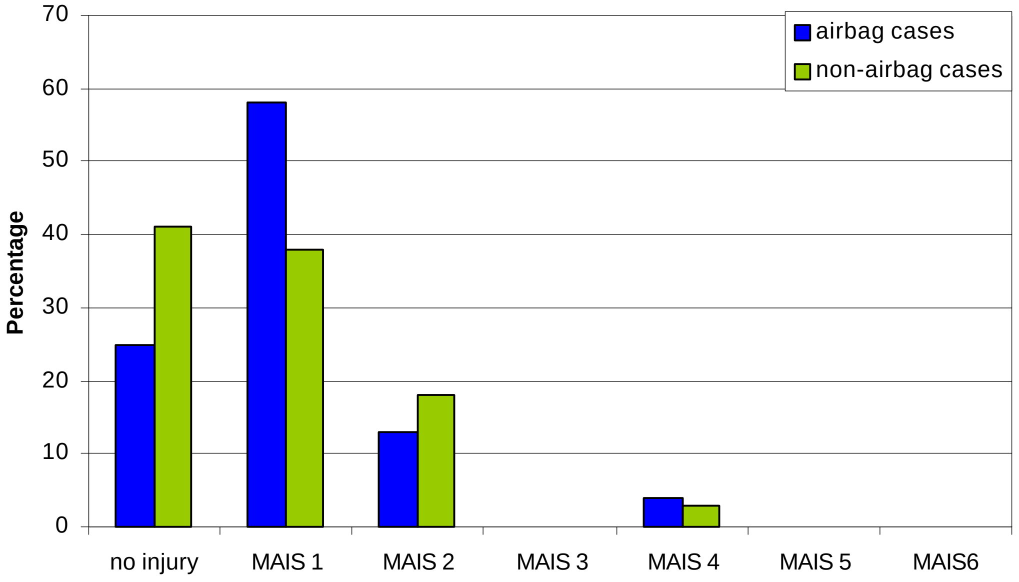


Figure 4.15 Distribution of MAIS in belted front left seat passengers

Of interest in this analysis is the fact that passengers in the non-airbag group sustained fewer MAIS 1 injuries and were more likely to sustain no injuries (i.e. MAIS 0) given the same crash conditions. Thirteen percent of passengers in airbag vehicles sustained injury at the MAIS 2 level compared to 18% in the non-airbag group and this is a reflection particularly of fewer chest, abdominal/pelvic and lower extremity injuries being sustained by passengers at the AIS 2+ level in the airbag group.

4.4.2 Contact Source

The main contact sources are shown in table 4.14. As can be seen from the table, the main source of injury for both airbag and non-airbag cases proved to be the seat belt. As with drivers, the airbag proved to be a source of injury at the AIS 1 level but no injuries of AIS 2 or above were observed due to interaction with the airbag which is an encouraging finding. The airbag appeared to have prevented some injuries that occur due to deceleration since this injury source (particularly for neck injuries) was observed to occur twice as frequently in the non-airbag cases. Another frequent source of contact for both groups was the instrument panel. The fact that this contact source occurred more frequently in the airbag group could be explained by the fact that the passenger airbag does not serve any purpose with regard to preventing injuries to the lower extremity at both minor and more serious injury severity levels.

Table 4.14 Contact source for injury for belted front left seat passengers

Source of Injury	Airbag cases (n= 24)		Non-airbag cases (n=88)	
	All AIS	AIS 2+	All AIS	AIS 2+
Seat belts	38%	4%	43%	3%
Airbag	33%	Nil	Nil	nil
Instrument panel	25%	4%	18%	1%
Steering assembly	4%	Nil	Nil	nil
Deceleration	8%	Nil	16%	1%
Floor and toe pan	nil	Nil	5%	2%
Side window and frame	4%	4%	1%	nil
A pillar	nil	Nil	1%	nil
B-pillar	nil	Nil	1%	1%
Exterior other object/vehicle	4%	Nil	Nil	nil
Other occupant	nil	Nil	1%	nil
Seat	nil	Nil	2%	nil

4.4.3 Injury Severity Score and Harm Analysis

The mean ISS was low for both passenger groups which would be expected with very few injuries sustained above the MAIS 2 level (Table 4.15). The mean Harm for all passengers was also calculated which differed by a nominal amount.

Table 4.15 Mean ISS and Harm for belted front left seat passengers

Passengers	Number of cases	Mean ISS	Mean Harm ($1000s)*
Airbag cases	24	2	22.45
Non-airbag cases	88	2.42	25.23

* These figures have been interpolated to reflect the threefold increase in Harm costs since 1985 as calculated by BTE in 2000 (Steadman and Bryan 1988, BTE 2000).

CHAPTER 5 DISCUSSION

Australian manufacturers seem to have readily adopted the driver airbag and improved restraint systems in order to comply with the ADR 69 frontal regulations. Airbags along with many other such safety mechanisms incorporated in vehicles today all have their origins within the crash-test laboratory. For this reason, the development and testing of such devices is usually performed on dummies in very limited crash configurations. As is well known, dummies do not always replicate human response in the event of a crash and at best, they only represent a certain percentage of the population at risk. Therefore, studies of real-world crashes such as this are the only method of obtaining some degree of insight into true crash performance when real people are involved. It is important to remember that the results of a study such as this represent reality. Real-world studies should not need to validate biomechanical testing and development in the crash-test laboratory; rather the converse should apply. Therefore it is very encouraging to find that airbags as Supplementary Restraint Systems (SRSs) in Australian vehicles work effectively to reduce injuries to a number of body regions. This issue is discussed in detail below.

5.1 INJURY REDUCTIONS

Occupants in airbag vehicles suffered substantially fewer severe injuries than their non-airbag counterparts in similar crashes (50% fewer multiple injuries, ISS). For AIS 2+ (severe) injuries, drivers in airbag crashes sustained significantly fewer head injuries (2% versus 7%), neck injuries (1% versus 4%) and chest injuries (4% versus 11%). The data revealed a higher number of upper extremity injuries at the AIS 2+ level to drivers in the airbag vehicles (6%) compared to the drivers in non-airbag crashes (3%) but this difference was not statistically significant. In some respects, such differences in upper extremity injury outcomes are in accordance with intuitive expectations. Furthermore it is a finding that has been observed in other worldwide studies. The issue of injury reductions to individual body regions is discussed in turn below.

An overall reduction in AIS 1+ injuries was also observed in crashes where the airbag deployed compared to crashes where there was no airbag fitted or did not deploy. Drivers in crashes involving airbag deployment were more likely to sustain injuries at the MAIS 1 level compared to the non-airbag group of drivers who were more likely than drivers in airbag deployed vehicles to sustain MAIS 2+ injuries. Other authors (Morris et al 1998, Lenard et al 1998, Deery et al 1999) have found similar reductions in injury trends. It should be noted that the airbags in such studies were similar in terms of size and deployment thresholds.

When comparable samples of drivers were studied, those in airbag vehicles had fewer head injuries (5% c.f. 10%) and neck injuries (19% c.f. 31%) than those in non-airbag vehicles. However, for upper extremity injuries, drivers in the airbag vehicles sustained more injuries than drivers in non-airbag vehicles (48% c.f. 31%).

An important consideration in this study is that the data comprise a range of vehicle makes and models which will have different structures as well as different airbag and restraint systems. Hence the level of crash performance optimisation is likely to be different for each vehicle model. A limitation is that vehicle models cannot be separated out in the analysis since the number of cases would diminish and it would be difficult to draw sustainable conclusions.

Another issue is that the basic structural design of many vehicles included in the study dates back in some cases to the late 1980s. The level of airbag and restraint optimisation will be limited by this fact. A more modern ‘clean-sheet’ design would be expected to achieve improved crash performance beyond those reported here and future research may be beneficial.

5.1.1 Head Injuries

Drivers in airbag deployed vehicles sustained injuries at the AIS 1+ and AIS 2+ level less frequently than the drivers in the non-airbag deployed crashes. This is an encouraging and positive finding. Typical head injuries sustained at the AIS 2+ level were short periods of loss of consciousness with some associated retrograde amnesia. However not all of these drivers were found to have sustained a corresponding focal brain injury. Nevertheless prevention of diffuse brain injuries is equally if not more important. Langwieder et al (1996) also observed head injuries occurring in belted drivers in airbag deployed crashes but the cause of such injuries was not thought to be the deploying airbag in the vast majority of cases.

The most severe head injury for the drivers in airbag crashes was found to be a severe diffuse type injury. The driver who sustained this injury also sustained spinal fractures, substantial abdominal injuries and lower limb fractures, and had an ISS of 33. This driver was involved in a high energy crash with a pole, which generated severe intrusion of the passenger compartment. It was generally considered that the driver sustained a head contact directly with the pole. This particular case demonstrates that the airbag should not be seen as a ‘universal panacea’. To a certain degree, crashes are unique events and as such, there will always be a certain percentage of crashes that will compromise the limitations of most practical engineering countermeasures. This applies both to current airbag systems and also future generations of restraint technology.

Non-airbag drivers also tended to sustain diffuse type brain injuries at the AIS 2+ level. Most drivers sustaining these types of injuries had head contacts with the steering wheel and this injury mechanism obviously occurred more frequently among this group. The significant reduction in head injuries at the AIS 2+ level is a very positive finding. Furthermore the fact that a downward trend was evident of AIS 1+ injuries in drivers in the airbag deployed crash group is also positive. German et al (1998) showed similar findings particularly in the more severe crashes.

Such results have implications concerning the use of the Head Injury Criterion (HIC) as a predictor of head injury outcomes. Part of the development process of airbag systems in Australia and elsewhere has involved the use of this somewhat controversial injury criterion. Such development work has demonstrated that reductions in head accelerations are achievable through contact with the deploying airbag in laboratory testing. This study suggests that the laboratory development process translates into the real world and this would support the case for continued use of HIC as an injury criterion in the development of second generation airbag systems.

5.1.2 Chest Injury

The significant reduction of chest injuries at the AIS 2+ level was also a positive finding for drivers in airbag deployed crashes, compared to the non-airbag crash group of drivers (4% versus 11%). The more serious chest injuries that occurred in this study were typically fractures to the ribs and sternum at the AIS 2+ level whilst a large proportion of contusions and abrasions were sustained at the AIS 1+ and these usually occurred through interaction with the seat belt. Minor injury types accounted for high numbers of chest injuries identified at the AIS 1+ level in both driver groups (31% and 39%).

Contrary to the head injury findings, the types of chest injuries were actually quite similar between the two driver groups, albeit less frequent or severe to the drivers in airbag deployed crashes. Langweider (et al 1996) similarly reported that belted only drivers sustained a greater number of thoracic injures at the AIS 2+ level compared to the belted driver airbag group. It seems then that the airbag is effective at reducing the incidence of serious thoracic injury. It is suggestive that the airbag exerts general restraining forces on the driver torso and as such limits the load concentration of the seat belt thereby reducing the incidence of more serious chest injury. This would correspond with Eppinger's maxims for good restraint design (Eppinger, 1993). Additionally, it could be that chest injuries can occur due to interaction with the steering system even amongst restrained occupants of non-airbag vehicles and that the deploying airbag prevents this from happening. Evidence of this injury mechanism is not apparent during every vehicle inspection.

5.1.3 Facial injuries

Facial injuries at the AIS 1+ level in drivers in airbag deployed crashes again were found to have a downward trend compared to the non-airbag group. The minor injuries recorded for the drivers in the airbag group consisted mainly of abrasions, contusions and some lacerations. Importantly there were no facial injuries recorded at the AIS 2+ level for the same group of drivers. The AIS 2+ injuries for the non-airbag crash group were attributed to the steering wheel rim and were typically severe lacerative-type injuries. Thus, the issues raised for head injury reductions above also apply to facial injury and airbags.

5.1.4 Neck Injuries

Injuries to the neck in this study consisted mainly of 'whiplash' type injuries, which are a common occurrence in frontal impacts but which can be extremely debilitating in the long term (Kullgren 1997). A significant reduction in the number of neck injuries sustained by drivers in the airbag deployed crashes was recorded compared to drivers in the non-airbag crashes (19% versus 31% (AIS 1+) and 1% versus 4% (AIS 2+)). Langweider et al (1996) also noted a reduction of neck injuries in drivers involved in crashes where the airbag has deployed. However Otte (1995) found opposing evidence. He suggested that the airbag was thought to be causing a greater number of cervical distortions by inducing hyperextension movement in frontal crashes. Otte does not differentiate between gender and height and reports his findings as a general conclusion. However, previous research has suggested that differences in injury risk between males and females do exist.

The reported serious neck injuries found by Huelke and Reed (1996) were considered to be a function of airbags contacting the chin causing a powerful hyper-extensive movement of the cervical spine, although his study involved unbelted short-stature women positioned in the proximity of the aggressive deploying US airbag. The findings in this study however lends support to previous findings where the airbag has been shown to offer some degree of protection in respect to neck injury outcome (Morris and Thomas 1996, 1997, Morris et al 2000).

The implications of the results presented in this study are worthy of further consideration. Firstly, it is important to reiterate that whiplash injuries do occur in frontal impacts although it is acknowledged that the risk is slightly below that in rear impacts. However to date, all injury prevention techniques have been aimed specifically at reducing the risk in rear impacts (generally through improved seat and head restraint design).

Driver airbags were initially conceptualised as an attempt to reduce the risk of skull-brain injury in a frontal crash. The fact that they reduce the risk of neck injury is a clear bonus. The actual mechanism of neck injury in frontal crashes is worthy of consideration. Previously it has been assumed that hyperextension of the head and neck is the most important process in the generation of neck injury and this explains the development of active and integral head restraints, despite conflicting evidence about the overall effectiveness of head restraints generally. This study has perhaps supported the view that hyperflexion is also important. If this supposition is considered in the context of the seat-rebound theory (where hyperflexion becomes more important in rear impacts) it is suggested that hyperflexion as an injury mechanism should be considered in a future study if prevention of whiplash injuries is to be prioritised.

5.1.5 Upper extremity injuries

The majority of the injuries sustained by the drivers at the AIS 1+ level in the airbag crashes were contusions, abrasions and burns to the forearms, usually where there was direct contact with the deploying airbag. Libertiny et al (1995), Lenard et al (1998) and Huelke (1994) have reported similar findings. Lenard's study was based on data collected in the UK where the airbag is very much a Supplementary Restraint System airbag similar to those used in Australian vehicles. Huelke found AIS 2+ injuries to the hand and digits and a few forearm fractures in US vehicles, all of which could be attributed in some way to the airbag.

The AIS 2+ injuries in this current study were typically fractures to the carpal and metacarpal bones and fractures to the wrist or distal portion of the ulnar. These were similar to the types of injuries found in Huelke's study. There were other upper extremity fractures in this study but they were usually clavicle fractures that are typically associated with loading from the seat belt rather than being a by-product of airbag deployment.

The frequency of upper extremity injuries that occurred to drivers in airbag-deployed vehicles is not unexpected because of the typical positioning of the arms during driving. The close proximity of the forearms to the steering wheel ensures a direct contact with a deploying airbag during a crash. When the airbag deploys, it can generate a violent force in order to inflate at a rapid rate, albeit for only a few milliseconds. Nevertheless, such force may be sufficient to induce a fracture to the forearm. Often the airbag has begun deflating before the driver realises that it has been activated. Abrasions and 'burn' injuries to the driver's forearm can be generated from gases escaping from the vents in the airbag as it deflates.

However more severe injuries at the AIS 2+ level can also be caused by the arm being 'flung' from the driving position during the deployment phase. Such injuries can occur when the arm is flung by the sheer power of the airbag rapidly onto other hard interior surfaces such as the window, A-pillar, roof rail or door. The possible scenario here is that drivers tend to lose control of their vehicle during the crash sequence and cross their arms over the steering wheel creating a large surface area for the deploying airbag to contact causing 'fling'. One study in the US (McKendrew et al 1998) suggests that a reduction in forearm fractures due to airbag deployments can be achieved through padding of the airbag although it would depend on whether the fracture mechanism is related to the break-out velocity of the airbag as this has not yet been fully established.

Although AIS2+ upper extremity injuries can occur to drivers, the majority sustain either no or minor injuries to this body region. When it is considered that the threat-to-life incurred by upper extremity injuries is very small, then the trade-off associated with a reduction in head and face injuries would appear to be acceptable. Libertiny suggests that such a trade-off exists between minor or moderate airbag-induced injuries and the more serious life-threatening injuries that the airbags are preventing.

5.1.6 Injuries to Other Body Regions

Slight reductions in the numbers of injuries at the AIS1+ level to the abdomen/pelvis, spine and lower extremity were observed but these were not significant and were considered to be incidental. At the AIS2+ level, the difference in injury risk was even less clear-cut. However, there would be no reason to expect a reduction in such injuries since the Supplementary Restraint System airbag is not designed to protect these body regions.

Some previous work has found that lower extremity injuries have been more evident in drivers where the airbag has deployed in the crash (e.g. Morris et al 1996 and 1998). The reason for this finding in such previous studies has not been well explained although one suggestion is that the deploying airbag alters the kinematics of the driver in a manner that is not well understood by simple observations of the crash-dummy. However, this outcome was not evident in the present study.

The combination of seat belt use and airbag deployment in frontal crashes suggests that this combined safety feature is effective in reducing injury to drivers both at the AIS 1+ and AIS 2+ levels. This is supported by other studies mentioned in the literature search, however Langwieder et al (1996) suggest that there is a need for further improvement by optimising the belt and airbag to form an ‘intelligent restraint safety system’. There is currently some international research that is exploring the ‘intelligent restraint system’ option in more detail. The introduction of such advanced seat belt technology is expected to have a further positive effect on injury outcomes however data will not be available for some time. A further study that compares the effects of advanced/intelligent restraint systems to the data presented here will be necessary in the future.

5.2 HARM REDUCTIONS

Harm reduction was also analysed in this study to evaluate the capability of airbags and as such the effectiveness of ADR 69 in terms of reductions in injury cost. In these preliminary findings, assuming the cost calculations involved in Harm are an accurate reflection of the real cost of injury, then it is clear that cost savings are manifest in crashes where an airbag has deployed.

Amongst *injured* drivers, those involved in crashes without an airbag incurred almost twice the average cost of injury (average Harm) compared to injured drivers involved in crashes where the airbag deployed ($66,000 c.f. $33,500). This suggests that drivers in crashes where no airbag is deployed sustain injuries that are more debilitating in nature and consequently incur higher societal injury cost. In this study, debilitating injuries to the head, neck and chest were observed to both groups of drivers but they were more common amongst drivers in the non-airbag group.

Unfortunately, the Abbreviated Injury Scale does not take into account the disabilities that are associated with injuries since it is a threat-to-life scale. It would be interesting to consider disability and impairment in a future study. However, if costed thoroughly, Harm is a suitable proxy for impairment and long-term consequences. Historically, injury costs have essentially focussed more on direct institutional costs (medical, rehabilitation, lost wages, lost productivity, funeral expenses, emergency services, etc) than the more indirect costs incurred by the individual and his or her family. Encouragingly, though, more recent costing by the Bureau of Transport Economics and others has included a sizeable quality of life loss component, which helps to place more emphasis on injuries that may not be very life threatening but nevertheless cause considerable long-term consequences.

Given the significant reductions in head, face and neck injuries (which may all have severe pain and suffering associated with them and in the longer term, reductions in an individual's quality of life, airbags would seem to have a special benefit for the long-term consequences of road crashes. This is something worthy of further follow-up and evaluation.

5.3 PASSENGER AIRBAGS

The results in terms of injury outcomes to passengers are not clear cut for a number of reasons. Firstly, there were not many cases on which to base the analysis and therefore any conclusions drawn should be regarded as preliminary. There were several cases of passenger airbag deployment in this study, which occurred in the absence of a passenger. Whilst this has no obvious detrimental effect on other occupants of the vehicle including the driver, there are some cost implications particularly if the vehicle is repairable following the crash.

Eventually, Australia will see the introduction of 'smart airbags' and such systems may well make use of sensors that detect the presence or absence of a passenger. Therefore in time, technology may well prevent unnecessary deployments.

Secondly, it should be observed that the passenger airbag is not thought to be a device that vehicle manufacturers adopt to meet the ADR 69 requirement. Generally speaking, passengers contact the facia region of the vehicle interior in a minority of cases therefore it is not clear whether the passenger airbag will have a major impact on the prevention of injury in each deployment since injury may well not have occurred anyway. It would seem that passenger airbags are more an issue of equity and regulation, where a safety conscious driver wants to ensure at least equal protection for his or her passenger. However, it should be noted that during the development of the ADR 69 regulation, passenger head contacts with the instrument panel/facia occurred in 4 out of 7 vehicles tested by the Federal Office of Road Safety (Seyer, 1992). In more modern vehicles, passenger head contacts with the instrument panel/facia may be prevented through improved vehicle structural and restraint designs, although it could be argued that passenger airbags generally would be beneficial in reducing the likelihood of neck injuries through hyperflexion.

Some differences in injury patterns, however, were observed among passengers where a passenger airbag was fitted. The most substantial injury reductions at the AIS1+ level amongst passengers in airbag vehicles occurred to the head, neck and abdomen/pelvis. To counter this, increases in the numbers of facial injuries were observed to the passengers in the passenger airbag vehicles although such injuries were usually minor abrasions. At higher injury severities, no significant differences were observed possibly because of the sample size.

5.4 CONCLUSIONS

In a comparable sample of drivers in airbag and non-airbag vehicles, reductions in injury have been found for the head, face, neck and chest, especially involving severe injuries. There were no real differences in terms of injury outcomes to the abdomen/pelvis, spine and lower extremity among airbag and non-airbag injured occupants. An increase in injury outcome to the upper extremity was observed amongst drivers in airbag vehicles but this was the only detrimental event in the study and is consistent with findings from other international studies.

A Harm analysis was included in this study to evaluate the capability of airbags to reduce injury and long-term consequences, and hence the effectiveness of Australian Design Rule 69. Assuming that the cost calculations involved in Harm calculations accurately reflect the real cost in terms of injury consequence, then savings in terms of injury costs are achieved through airbag deployments. A follow-up study in Australia which takes into account mass data rather than the sampling method used in this study, would be beneficial in further evaluating the cost-effectiveness of the ADR 69 requirement.

There were some important findings here in terms of injury contact sources. Clearly the airbag prevented some of the more serious (AIS2+) injuries generated through interaction of the driver with the seat belt. Such injuries generally involve fractures of the ribs, sternum and clavicle. This suggests that the airbag exerts restraining forces on the occupant torso in a manner which is perhaps not well understood since dummy kinematics are not directly transferable to real people. However, limitations of the load concentration of the seat belt as well as retarding excursion of the head/neck are obviously achieved. It should not be overlooked that seat belt technology has also improved in recent times coincidental with the introduction of airbag technology. This study has not allowed for an evaluation of advanced belt technology such as pretensioners but follow-up studies are planned.

Whilst the deploying airbag has been shown to be effective in preventing more serious injury from occurring in frontal crashes, it should be reiterated that the airbag is only truly effective if the driver is also wearing a seat belt at the time of impact. Furthermore the airbag is only effective in a certain percentage of crashes and as such will not generally offer any added protection in the most severe crashes (i.e. Delta-V greater than 65km/h, Fildes et al, 1996).

This study is the most comprehensive evaluation of ADR 69 to date in Australia, relying on real-world in-depth accident data. The results offer a strong indication that the requirement has been successful at addressing some outstanding issues that remain for injury prevention for drivers involved in frontal impacts. It is acknowledged that manufacturers are now in the process of developing second generation airbags and it is important that evaluations of these systems are also undertaken through real-world studies such as this. This is particularly as laboratory crash tests of improved vehicle technology and enhanced legislation can never paint a true picture of the effectiveness of such advancements.

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