

## Airbag Effectiveness in Real World Crashes

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### Abstract

This paper presents results from a sample of 383 belted drivers and 129 belted front seat passengers involved in frontal crashes. Of the drivers 253 vehicles were involved in crashes where the airbag deployed and 130 vehicles were non-airbag equipped. For the front seat passengers, 28 vehicles were also equipped with passenger airbags, with 25 deployed in crashes. The two groups were matched in terms of crash severity. Vehicles were inspected and occupants interviewed according to the National Accident Sampling System (NASS). Analysis of the data identified an overall reduction in the number of injuries sustained by drivers in the airbag-equipped vehicles for all frontal crashes. At the more serious injury levels (AIS 2+), reductions were noted to the head, face neck and chest in drivers in airbag equipped vehicles. Cost analysis using Harm as an outcome measure found that the mean Harm per driver (\$AUD) was 60% higher in non-airbag equipped vehicles compared with airbag equipped vehicles. It would appear from these findings that airbags in frontal crashes are contributing to the reduction in driver injuries and also cost to society.

Airbags in Australia act as supplementary restraint systems and were introduced to prevent head strikes to the steering wheel by belted drivers. However these findings suggest that airbags also seem to have a positive affect on protecting the chest and neck from injury. This study is the most extensive study of airbag performance in Australia to date.

**Keywords:** Airbags, Injury, Harm, Frontal Crashes.

### INTRODUCTION

In Australia, airbags are seen predominantly 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 restrain the occupant in the vehicle and prevent the occupant from having harsh contacts with interior surfaces of the vehicles. The airbag acts to cushion any impact with vehicle structure and has positive internal pressure, 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. 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% [2]. 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 Australian Design Rule (ADR) 69 specifications for the Hybrid III anthropomorphic dummy in Table 1.

**Table 1:** Full frontal test criteria specified in Australian Design Rule 69

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

### Field Studies of Supplementary Restraint System (SRS) Airbag Deployments

There have been a number of studies conducted both in Europe and Australasia, which have examined SRS airbag performance in field studies. In Germany, Otte [3] 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 the thorax, nosebleeds and burns to the 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.

Langwieder, Hummel and Muller [4] looked at 249 accidents in airbag-equipped cars. They observed a significant reduction in severe and fatal injuries to belted and airbag-protected drivers. They also found that the main types of AIS2+ injury sustained by drivers with airbags were injuries to the extremities especially the feet. 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.

Morris, Thomas, Brett, Bruno-Foret, Thomas, Otte and Ono [5] 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.

Morris, Fildes, Digges, Dalmotas and Langwieder [6] 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 the head, chest, abdomen and lower limb and benefits were found for head and abdomen but dis-benefits were found in the 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 in the seat-belt and airbag-protected drivers compared to the seat-belt protected only drivers.

Lenard, Frampton and Thomas [7] 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.

Deery, Morris, Fildes and Newstead [8] examined a group of 140 belted drivers involved in frontal impacts of which 71 were involved in crashes in which the airbag had deployed and 69 were involved in crashes with vehicles not fitted with airbags. Their analyses revealed significant reductions in the cost of injury and a strong indication of a reduction in overall injury severity among the airbag cases. Indications of airbag benefits were also found in terms of a reduction in the probability of sustaining a moderate and severe injury. Some evidence was found for an increase in minor injuries among the airbag cases. They concluded that as expected, airbag technology seemed to be reducing head, face and chest injuries, particularly those of at least moderate severity.

## **METHODOLOGY**

The data in this study were obtained from a sample of crashes that were investigated as part of an on-going study of driver injury and vehicle crash performance by the Monash University Accident Research Centre.

This study examines injuries that were sustained by a sample of drivers involved in frontal impacts in which the Principal Direction of Force (PDoF) was within 60-degrees of head-on. Vehicles were examined at recovery-garages, scrap-yards and panel-beating shops in Victoria, New South Wales, Queensland and Tasmania (depending on accident location) within a few days of the accident. This study used a "vehicle based" entry criterion. All vehicles in the study were towed away from the scenes of the crash and to further meet the study criteria, vehicles sustained at least \$6,000 repair costs, although in the majority of cases, the vehicles were totally non-repairable (write-off).

An inspection was performed on each vehicle in accordance with the US National Accident Sampling System (NASS) procedure [9] for retrospective examination of crash-damaged vehicles. Only drivers who wore their seat-belts were included in the study. Determination of seat-belt usage was achieved with a high degree of certainty and accuracy.

Delta-V was calculated to assess collision severity in this study. Delta-V was calculated in 54% of cases. A median test, used to compare the delta-V in the airbag-equipped and non-airbag equipped vehicles, revealed no statistical difference in the delta-V distributions. For the remaining cases where delta-V could not be calculated, a comparison was made of the extent of the frontal deformation (static crush) between the tow groups. The vehicles were also found to be comparable in this respect Vehicle age was also considered; non-airbag vehicles were found to be 3 years older than airbag-equipped vehicles, which is as expected.

Ethical considerations demanded that the vehicle was included in the study only if the owner and occupants of the vehicle and the repair shop or salvage yard agreed to participate in the study.

Injury data were gathered on each consenting driver 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 for those not requiring hospital treatment by a nurse trained in interview techniques. Injuries were coded according to the Abbreviated Injury Scale (1998 revision). This scale classifies injuries in terms of threat to life on a 6-point scale as follows;

- 1 = minor
- 2 = moderate
- 3 = serious
- 4 = severe
- 5 = critical
- 6 = maximum (currently untreatable injuries)

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, covering treatment, rehabilitation, emergency services and pain and suffering allowances. In its most general form, it is used as a measure of the total cost of road trauma.

## RESULTS

Cases were selected using a baseline curb weight between 1000kgs and 2000kgs (mean for airbag-equipped vehicles = 1441kgs, mean for non-airbag vehicles = 1364kgs) and a delta-V distribution (where calculable) between 10 and 65km/h. A total of 383 belted drivers involved in a crash were included for analysis. 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.

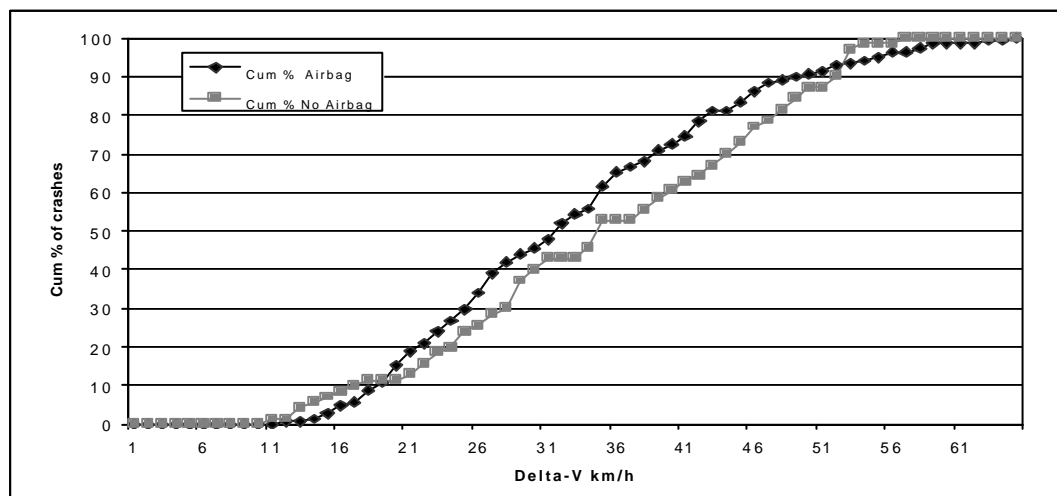
There were no significant differences in occupant characteristics (age, weight, sex and height), Table 2 or crash severity (as measured by delta-V) between the airbag cases and non-airbag cases.

**Table 2;** Characteristics for belted drivers in airbag and non-airbag frontal crashes

Mean	Airbag cases (n=253)	Non-airbag cases (n=130)
Sex	71% males 29% females	66% males 34% females
Age	39 years (range 17-80 years)	40 years (range 17-81 years)
Height	174 cm (range 152-193cm)	167 cm (range 125-201 cm)
Weight	77 kg (range 45-175 kg)	77kg (range 48-120 kg)

The mean delta-V for the airbag cases was 33km/h and non-airbag cases was 37km/h (p=0.20, independent 2 tailed t-test). A chi-squared analysis of cases in both groups with delta-V severities of <40km/h and >40km/h also suggest that there was no significant difference between the two samples at the 5% level ( $\chi^2=3.2$ , df=1, p=n.s.) Having established that the two sample groups were matched, as far, as was practical, it was hypothesised that any differences in injury outcomes in this study could be attributed to the effects of the airbag. Figure 1 gives the distribution of crashes in terms of collision severity.

**Figure 1:** Delta-V distribution for airbag and non-airbag cases



## Injury outcomes

The first analysis in this study demonstrates differences in injury outcomes between the two groups of drivers, (Table 3). Of interest is that there was a significant reduction in neck injuries ( $\chi^2 = 7.2$ ,  $df=1$ ,  $p<0.007$ ) and a trend in the reduction of head injuries in the airbag group ( $\chi^2 = 3.2$ ,  $df =1$ ,  $p=<0.07$ ). However it was noted that significantly higher numbers of upper extremity injuries occurred within the airbag group compared to the non airbag group ( $\chi^2 = 15.54$ ,  $df =1$ ,  $p<0.001$ ).

The reduction in head injury rates is an important finding since the airbags were originally designed to prevent contact between the head and the steering wheel. The relative risk of sustaining an injury in an airbag-deployed vehicle compared to a non-airbag vehicle was also calculated using logistic regression. This involved controlling for vehicle mass and Equivalent Barrier Speed (EBS) by including them as factors in the regression. EBS was used in this analysis in preference to Delta-V as more cases were available for the overall analysis.

These results, whilst in most cases are not statistically significant, show trends that wholly support the chi-square analyses. It is suggested that statistical significance was not attained because of the general lack of cases in the analysis along with the loss of statistical power caused by inclusion of the adjustment factors. It is further suggested that increased case numbers would provide robust support for the chi-square analyses since the adjusted relative risk estimates show a positive effect in injury reduction for the same body regions as are found in the chi-square analyses.

**Table 3; All injuries to body regions for belted drivers**

Body region	Airbag cases (n=253)	Non airbag cases (n=130)	Significance	Adjusted Relative Risk Estimate	Significance
Head	5%	10%	<0.07	0.561	0.236
Face	12%	15%	Ns	1.291	0.471
Neck	19%	31%	<0.007*	0.505	0.011
Chest	31%	39%	Ns	0.973	0.914
Abdomen / pelvis	22%	23%	Ns	1.218	0.506
Spine	2%	3%	Ns	0.924	0.919
Upper extremity	48%	27%	<0.001*	2.703	0.000
Lower extremity	31%	31%	Ns	1.470	0.145

\*Chi squared test

For injuries sustained at the AIS2+ 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  $\chi^2 = 5.97$ ,  $df=1$ ,  $p<0.01$ ). It was also found that neck injuries at this level were also 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 AIS2+ level were observed in the airbag group. The relative risk of sustaining an AIS2+ injury in an airbag-deployed vehicle compared to a non-airbag vehicle was also calculated using logistic regression using the technique described above. Again, the results, whilst in most cases are not statistically significant, show trends that wholly support the chi-square analyses. It is again suggested that statistical significance was not attained because of the general lack of cases in the analysis along with the loss of statistical power caused by inclusion of the adjustment factors. It is further suggested that increased case numbers would provide robust support for the chi-square analyses since the adjusted relative risk estimates show a positive effect in injury reduction for the same body regions as are found in the chi-square analyses.

Table 4 shows the distribution and statistical comparison of injuries at the AIS2+ level to both drivers in the airbag and the non-airbag groups.

**Table 4:** AIS2+ injuries to body regions for belted drivers

Body region	Airbag cases (n=253)	Non airbag cases (n=130)	Significance	Adjusted Relative Risk Estimate	Significance
Head	2%	7%	<0.02*	0.445	0.233
Face	0%	2%	ns	0.000	0.853
Neck	1%	4%	<0.05**	0.220	0.107
Chest	4%	11%	<0.01*	0.509	0.163
Abdomen / pelvis	2%	2%	ns	1.302	0.793
Spine	1%	2%	ns	0.999	0.999
Upper extremity	6%	3%	ns	2.842	0.123
Lower extremity	5%	4%	ns	1.930	0.354

\* Chi squared test \*\* Fisher's exact test

The non-significant number of upper extremity injuries sustained at the AIS2+ level would indicate that drivers in the airbag group are sustaining numerous minor injuries to this body region.

### Injury Severity Score (ISS) and Harm Analysis

The ISS scores are presented in Tables 5 and 6 for all belted drivers involved in a crash (n=383) and for those belted drivers injured in the crash (n=270). When comparing between drivers, who are injured, there is a significant difference in the mean ISS scores between the airbag and non-airbag group (independent t-test). 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 5:** Mean injury severity score and Harm for all belted drivers

Belted drivers	Airbag group	No airbag
Number of cases	253	130
Mean ISS	10.4	9.1
Mean Harm (\$ 000s)	10.1	16.3

**Table 6:** Mean injury severity score and Harm for injured belted drivers.

Belted drivers	Airbag group	No airbag
Number of cases	190	80
Mean ISS	2.35	4.9
Mean Harm (\$ 000s)	13.4	26.4

### Injury Contact Sources

Contact sources for all injuries and AIS 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.

There were no real 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 ( $\chi^2$  3.63, df 1, p=0.06). Furthermore, there were obviously several injuries sustained in the airbag group due to contact with the airbag itself. It was interesting to observe that the non-airbag group sustained higher numbers of AIS2+ injuries due to interaction with the seat-belt. This would suggest that the airbag does offer additional driver restraint and distribution of crash forces over wider area than the head and face alone.

An interesting observation in the airbag group is that whilst there were several minor AIS 1 injuries attributable to interaction with the airbag 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.

## DISCUSSION

This study suggests that airbags as Supplementary Restraint Systems (SRSs) work effectively to prevent injuries to several body regions. Injury reductions were observed particularly in respect of the head, face

neck and chest but possibly at the expense of an increase in injuries to the upper extremity at both the AIS1+ and AIS2+ level. The most notable difference in injury outcomes was observed when comparing injuries to the neck. Generally speaking, injuries to the neck in this study were 'whiplash' type injuries. It was encouraging to find that airbags do offer some degree of protection with respect to neck injury outcome since whiplash injuries occur frequently in frontal impacts and can result in long-term if not permanent consequences to the afflicted [10, 11, 12]. If airbags are indeed preventing 'whiplash' type injuries, as this study would suggest, then this is a very positive if somewhat unexpected finding.

Laboratory crash-test results involving dummies predict reductions in head and face injury through action of the deploying airbag. These carefully controlled laboratory test conditions (e.g. 48.3 km/h into a rigid barrier) are rarely met in the real world, however, it is encouraging that such results as found in this study appear to support those predicted by the laboratory crash tests.

In this sample of crashes investigated, there were no individual cases where serious injury or death could be attributed to interaction with the deploying driver airbag. This study may therefore indicate that the less aggressive, more benign Supplementary Restraint Systems in Australia are more suited to driver protection providing that the seat-belt is worn in comparison the Primary Restraint Systems that are prevalent in the US. However, it should be considered that this study has only examined a sample of crashes. Derivation of data on all crashes in which a driver airbag has deployed would be impractical in a country the size of Australia. The possibility remains that there may be occult examples of serious injury through airbag interaction, which has not been investigated as part of this study.

One issue observed in this study is that of injuries to the upper extremity. In many respects, contact between the deploying airbag and the upper extremity is unavoidable because the upper extremity will nearly always be in the proximity of the airbag when it deploys. However, it should be observed that some upper extremity injuries are also caused by 'fling' of the upper extremity during airbag deployment into the A-pillar and roof rail, and this has been observed in other studies of injury outcomes in airbag vehicles.

The issue of Harm has been included in this study since this is a convincing means by which to evaluate the benefits of airbags. Assuming that the cost calculations involved in Harm calculations accurately reflect the real cost in terms of injury consequence, then it is clear that 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 sample that have been used in this study would be beneficial in further evaluations of cost-effectiveness in terms of Harm reduction.

There were some interesting findings in this study in terms of injury contact sources. For example, AIS 2+ injuries to the chest (generally rib and sternum fractures) and upper extremity (generally clavicle fractures) were found to be less common in crashes in which the airbag deployed. The reason for this is not entirely clear but it is suggested that the airbag may exert restraining forces on the occupant torso in a manner that is perhaps not well understood. However, as a consequence, it is possible that limitations of the load concentration of the seat belt as well as retarding excursion of the head/neck are achieved. More data would be valuable in exploring this issue further.

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 the performance of advanced belt technology, such as pretensioners, in conjunction with the airbag but follow-up studies are planned. In a similar vein, the attribution of injury reduction through airbag deployment should be considered in the light of such improvements to belt technology that are described above. A difficulty with a study of this type is to establish whether injury reductions are wholly attributable to the airbag or are as a result of the airbag in conjunction with improved belt technology. More data would also be valuable in this respect.

In conclusion this study is the most extensive study of airbag performance in Australia to date and has found that the fitting of airbags into vehicles has reduced the number of injuries and injury costs to Australian drivers and society.

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