A PRELIMINARY ANALYSIS OF THE EFFECTIVENESS OF AIRBAG TECHNOLOGY IN REDUCING SEATBELT INJURIES

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ABSTRACT

Seatbelts have been shown to provide excellent protection for occupants of modern passenger cars. Yet, seatbelts have also been shown to cause some injuries, albeit generally less severe and not normally life threatening. Supplementary airbags in combination with seatbelt webbing clamps are expected to reduce seatbelt injuries by spreading the deceleration load on the torso and improving occupant kinematics during a crash. To date, however, there has been little scientific evidence in terms of field accident investigations to support this contention. The Monash University Accident Research Centre has undertaken several case-control studies of crashed vehicles equipped with airbags. Vehicle have been inspected and occupants interviewed using the National Accident Sampling System (NASS) format. Data were available for 140 belted drivers involved in frontal crashes (delta-Vs between 21 and 60 km/h), including 71 airbag and 69 control cases. The results showed indications of over-all benefits from the combination of airbags and webbing clamps, particularly in terms of a reduction in moderate and severe injuries and their associated costs. Indications of similar but smaller reductions were found when seatbelt injuries only were considered. As expected, airbags reduced chest injuries across a range of severities. However, an increase in minor shoulder injuries was found among the airbag cases. This may result from changes to the occupant kinematics during a crash that stem from the combination of seatbelt webbing clamps and supplementary airbags.

IT IS WELL DOCUMENTED that motor vehicle crashes create substantial trauma and cost for individuals and society. In Australia, a large part of these costs comes from occupant casualties, which represent around 70% of fatalities and serious injuries on our roads (Road Traffic Authority, 1988). In an effort to reduce these casualties, the road safety community and vehicle manufactures have invested considerable resources in the design, development and introduction of safety features in modern passenger cars, some following mandatory regulations (Heiman, 1988). These features, such as airbags and seatbelts, are designed to decrease the incidence, severity, or both, of injury stemming from road crashes.

The provision and use of seatbelts in modern passenger cars has had a significant affect on reducing injury and death on our roads. In Australia, seatbelt wearing rates are high, with around 95% of front seat and 80% of rear seat occupants wearing a seatbelt (Diamantopoulou, Dyte & Cameron, 1996). This is a result of legislation that was enacted in all Australian States and Territories by 1972, making the use of seatbelts compulsory for all passenger car occupants (Vulcan, 1973). Legislation introduced around the same time ensured that all new vehicles were fitted with a 3-point combination lap/sash seatbelt for the driver and the passengers in the outboard front and rear seats, as well as a lap only belt for the centre seats. Within nine months of the compulsory seatbelt wearing legislation, the State of Victoria experienced an 18% and 15% reduction in the number of vehicle occupants killed and injured, respectively, when the overall seatbelt wearing rate was only 70% (Vulcan, 1973). Since then, several Australian studies have reported reductions in occupant deaths of around 20% as a result of the compulsory seatbelt wearing laws (e.g. Foldvary & Lane, 1974). These reductions are usually attributed to fewer ejections from the vehicle and fewer occupants contacting internal components of the vehicle during a crash, such as the steering wheel, windscreen and instrument panel (Herbert et al., 1976).

Although it is well established that seatbelts provide excellent protection, it has long been recognised that forces applied by the seatbelt when restraining the occupant have to be carefully distributed to ensure minimal loading on the torso (Herbert et al., 1976). Indeed, several studies (e.g. Mackay, 1982; Dalmotas, 1980; Hobbs, 1978) have indicated that seatbelts can actually cause or contribute to minor and moderate injuries, especially to the abdomen, torso and neck (e.g. "whiplash"). The recent advance of supplementary airbags appears to offer a great deal of promise as a mechanism for reducing these injuries. For example, an airbag is expected to spread the deceleration load on the upper torso and abdomen over a wider surface than does a seatbelt alone (Grösch, 1985).

Fildes et al. (1992) estimated the injury savings if all Australian passenger cars were fitted with a driver's airbag as a supplement to a 3-point lap/sash seatbelt. They reported an expected reduction in road trauma of 15% annually if Australia's entire passenger car fleet was fitted with a full-size driver airbag. Some of these reductions were assumed to come from fewer head and face contacts with the vehicle interior, such as the steering assembly, instrument panel and windscreen. It was also assumed that injury benefits from airbags would be attained by reducing the number and severity of chest contacts with the seatbelt.

It should be noted that, because of Australia's unique driving environment (e.g. high seatbelt wearing rates), airbag systems tend to be designed differently to those overseas (Fildes et al., 1996). For example, the airbag deployment threshold is usually set lower than those overseas (around 25 km/h in Australia, depending on the manufacturer) so that the airbag deploys only when a crash is of such severity that the seatbelts alone can not afford complete protection. Furthermore, the rate at which the airbag inflates tends to be lower in Australia. This means that fundamentally different airbag systems are used in Australian vehicles, especially when compared with those that are developed for unrestrained occupants overseas. In particular, Australian airbags are designed to offer supplementary protection to that provided by the seatbelt.

In addition to offering a driver's airbag, the first generation of Australian manufactured "airbag cars" were notable for their seatbelt design. In particular, webbing clamps were installed on the seatbelts fitted at the front seating positions. These webbing clamps are believed to represent a significant improvement over the conventional emergency locking retractor design (ELR) that had been fitted to the 3-point lap/sash seatbelt systems of vehicles manufactured since 1975 (Herbert et al., 1976). Webbing clamps are positioned on top of the retractor to reduce the pay-out of the webbing as the seatbelt is loaded during the early stages of a crash. This restricted pay-out is believed to offer benefits in terms of providing more controlled occupant kinematics and reduce the risk of the occupant striking the steering wheel or instrument panel.

In conclusion, seatbelts have been shown to provide excellent benefits to occupants of modern passenger cars. Nonetheless, they have also been shown to cause some injuries, albeit generally less severe and not normally life threatening. Supplementary airbags in combination with seatbelt webbing clamps are expected to reduce seatbelt injuries by spreading the deceleration load on the torso and improving occupant kinematics during a crash. However, to date, there is little scientific evidence in terms of field accident investigations to support this contention of a reduction in seatbelt injuries. This study utilised data from airbag equipped cars involved in real-world crashes to examine whether or not airbags in combination with webbing clamps have reduced seatbelt injuries among the occupants of these modern passenger cars.

METHOD

DATA SOURCES - The Monash University Accident Research Centre (MUARC) is currently undertaking research aimed at evaluating the effectiveness of airbags fitted to popular Australian passenger car involved in real world crashes. These studies use a case-control design: cases comprise crashed vehicles where the airbag was deployed and controls comprise similar crashed cars without an airbag fitted.

Two data bases were available for the analyses reported here. The first involved General Motors-Holden Commodores, for which a preliminary analysis of airbag effectiveness was recently reported (Fildes et al., 1996). The second study, undertaken for the Federal Office of Road Safety, involves a range of popular Australian passenger cars other than Holden Commodores. In both studies, the cases comprise recent model crashed cars (manufactured after 1993) fitted with a driver airbag that deployed during the crash. The controls comprise either non-airbag models with a similar body structure or non-airbag options of the same models that were involved in similar severity crashes.

The data from these studies were aggregated for the analyses reported here. Only driver data were considered because of a low number of cases with front passenger airbags. For inclusion in the study, the cases had to meet several criteria. First, the vehicle had to be involved in the type of crash where the airbag is expected to provide maximum benefits. For example, only frontal crashes with a velocity change (delta-V) between 21 and 60 km/h were considered. Indeed, research in the U.S. suggests that, generally, airbags are only likely to provide benefits from their deployment threshold up to 60 km/h (MUARC, 1992; Fildes et al., 1992). Second, the driver had to wearing a seatbelt. This is determined retrospectively at the time the vehicle is inspected and is based on evidence of seatbelt loading, such as movement of the B-pillar bolt or cover, or markings on the seatbelt webbing and hardware (the inspection procedure is described in some detail below).

On the basis of these criteria, 140 cases were retained for use in this study, comprising 71 airbag and 69 control vehicles. Cases were excluded because: (a) the driver was not wearing a seatbelt or seatbelt usage could not be ascertained (25% of excluded cases), or

(b) delta-V could not be calculated or was calculated to be less than 21 km/h or greater than 60 km/h (75% of excluded cases). Delta-V can not be reliably calculated when the second vehicle involved in the crash is unavailable for inspection. Given this relatively large loss of cases, it may be feasible to use equivalent barrier speed (EBS) as a measure of crash severity in the future, as EBS can often be calculated without inspection of the second vehicle.

VEHICLE INSPECTIONS AND OCCUPANT INJURY - All crashed vehicles were inspected by a mechanical engineer using the National Accident Sampling System (NASS) inspection proforma, modified where necessary to suite Australian conditions. This system provides detailed information on impact direction, vehicle damage (deformations and intrusions), occupant contacts and impact speed. Impact speed, or delta-V, was defined as the change in velocity from the moment of impact until the study vehicle separated from its impacting source (MUARC, 1992). Delta-V values were calculated by computer software (Crash 3), made available from the National Highway Traffics & Safety Administration (NHTSA) in the U.S. The assessment and classification of injures was undertaken by State Registered Nurses, trained in the collection of injury information using the NASS system.

RESULTS

BACKGROUND AND DEMOGRAPHIC VARIABLES - Table 1 summarises some descriptive statistics calculated for the airbag and control samples. There were no significant differences between the two groups in terms of the type of frontal crashes, with around 50% oblique frontal crashes in both groups ($\chi^2(2) = 0.35$, $p > .05$). The age and sex of the drivers of the airbag and control vehicles were also similar ($\chi^2(1) = 0.15$, $p > .05$, and $\chi^2(4) = 2.7$, $p > .05$, respectively). The mean number of kilometres travelled was significantly higher for the control vehicles ($t(89) = 3.91$, $p < .01$), simply because they tended to be an older fleet at the time of inspection with higher exposure. This was not considered to be a problem for these analyses.

IMPACT VELOCITY - Figure 1 shows the delta-V distribution for the airbag and control cases. These distributions were quite similar ($\chi^2(3) = 0.60$, $p > .05$), as were the mean delta-V values of both groups (airbag mean = 37.3 km/h; control mean = 38.9 km/h). These results suggest that the two samples were similar with respect to crash severity.

OVERALL AIRBAG BENEFITS AND SEATBELT INJURIES ONLY - Table 2 shows the mean Injury Severity Score (ISS) and injury cost, and the proportion of drivers injured (or probability of injury) for all injuries and seatbelt injuries only among the airbag and control cases. ISS is an over-all measure of injury severity and is calculated as the sum of the three highest AIS injury severity scores squared[1], with the three injuries having to occur in different body regions. The cost of injuries was calculated based on the Harm approach that was initially developed to enable the savings from road-safety countermeasures to be established (Malliaris, Hitchcock & Hedlund, 1982). It was later extended to permit a systematic body region and contact source analysis (MUARC, 1992). In this context, the cost of injury refers to their total financial cost, including costs to the community, treatment and rehabilitation costs, lost

[1] AIS severity scores range from 1 (minor) to 6 (untreatable).

productivity, and some pain and suffering allowances (no property damage costs are included).

Prior to examining differences between the groups in ISS and the cost of injury, skewness in their distributions were reduced through logarithmic transformation, a common approach for dealing with skewed data (Tabachnick & Fidell, 1989).

Table 1 - Descriptive statistics of belted airbag and no airbag drivers involved in frontal crashes

Variable	Airbag (n = 71)	Control (n=69)
1. Crash type		
Full frontal	16.9%	20.3%
Pure offset	32.4%	29.0%
Oblique offset	50.7%	50.7%
2. Driver sex		
Male	72.1%	75.0%
Female	27.9%	25.0%
3. Driver age		
≤17 years	0.0%	1.5%
18 - 25 years	20.3%	16.9%
26 - 55 years	65.2%	69.2%
55 - 75 years	14.5%	10.8%
76+ years	0.0%	1.5%
4. Mean kilometres travelled	19,483	51,687

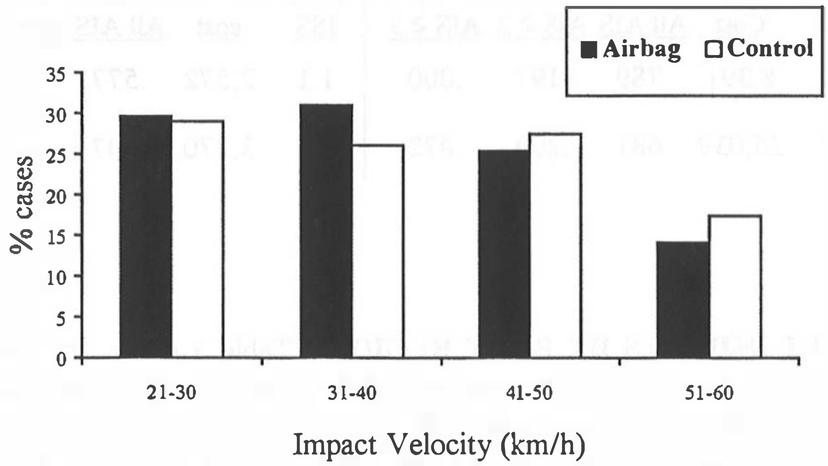

Fig. 1 - Impact velocity (delta-V) among belted drivers of airbag and no airbag vehicles in frontal crashes

All injuries - Injury costs and ISS (logarithmically transformed) were subject to separate one-way analysis of variance. These analyses showed consistent trends but failed to reveal statistically significant differences between the airbag and control groups ($F(1,138) < .16$, $p > .05$). Thus, the differences in Table 3 should be considered indicative only at this stage, although the addition of more cases would likely yield statistically significant results.

In terms of the proportion of injuries at each level of severity (or probability of injury), chi-square analyses revealed that a smaller proportion of drivers in the airbag group received a serious injury compared to drivers of control vehicles (i.e. AIS $\geq$ 3), $\chi^2(1) = 5.33$, $P < .05$.

Seatbelt injuries - The analyses above were repeated for seatbelt injuries only. The results were similar to those for all injuries, with non-significant differences for injury costs and ISS ($F(1,138) < .12$, $p > .05$). Furthermore, the proportion of drivers in the airbag and control vehicles receiving an injury at each level of severity was not significantly different, $\chi^2(1) < 2.09$, $p < .05$).

It should be noted that the probability of injury (any AIS level) is higher among the airbag cases for both all injuries and seatbelt injuries only. However, this is confined to AIS 1 injuries, suggesting that the airbag and webbing clamp combination is causing some minor injuries (e.g. bruises and abrasions) but preventing more serious injuries (e.g. fractures and dislocations). Indeed, there is a higher probability of moderate and serious injury (AIS $\geq$ 2 and 3) among the control cases.

Table 2 - Mean ISS, cost of injury ($1995), and the probability of injury for all injuries and seatbelt injuries only among the airbag and control cases

	All injuries					Seatbelt injuries only				
Group	Mean ISS	Mean Cost	Prob. All AIS	Prob. AIS ≥ 2	Prob. AIS ≥ 3	Mean ISS	Mean cost	Prob. All AIS	Prob. AIS ≥ 2	Prob. AIS ≥ 3
Airbag	2.3	8,391	.789	.197	.000	1.1	2,572	.577	.099	.000
Control	3.5	25,039	.681	.290	.072	1.4	3,370	.507	.145	.029

SEATBELT INJURIES BY BODY REGION - Table 3 shows the proportion of airbag and control cases receiving a seatbelt injury in each body region. None of the differences were statistically significant (all $\chi^2(1) < 2.3$, $p > .05$). Nonetheless, of particular interest was the finding that a lower proportion of drivers of airbag vehicles appeared to sustain chest injuries from the seatbelt at each level of severity. It is likely that this finding would be statistically robust with the addition of more cases. However, a greater proportion of drivers in airbag vehicles did sustain minor shoulder injuries from the seatbelt. These injuries are examined in more detail below.

Table 3 - Seatbelt injuries by body region among belted drivers of airbag and no airbag vehicles

	Airbag (n = 71)			Control (n =69)		
Body region	All AIS	AIS ≥ 2	AIS ≥ 3	All AIS	AIS ≥ 2	AIS ≥ 3
Head	nil	nil	nil	nil	nil	nil
Face	nil	nil	nil	nil	nil	nil
Neck	2.9%	nil	nil	1.4%	nil	nil
Chest	32.4%	5.6%	nil	39.1%	13.0%	2.9%l
Abdomen/pelvis	26.8%	nil	nil	26.1%	1.4%	nil
Spine	2.8%	2.8%	nil	2.9%	1.4%	nil
Shoulder	18.3%	1.4%	nil	11.6%	1.4%	nil
Arm/hand	1.4%	nil	nil	1.4%	nil	nil
Lower extremity	1.4%	nil	nil	1.4%	nil	nil

Note: AIS scores range from 1 to 6; 1 = minor, 2 = moderate, 3 = serious, 4 = severe, 5 = critical, 6 = maximum (untreatable); Multiple injuries included (one per body region).

SHOULDER INJURIES FROM THE SEATBELT - A more detailed examination of the cases with shoulder injuries was undertaken. One airbag and one control case sustained a moderate shoulder injury (AIS 2), namely, a fractured clavicle. The remaining injuries to drivers of both airbag and control vehicles were minor (AIS 1) contusions to the shoulder. There was strong evidence of high seatbelt loadings among the large majority of these cases, indicated by deformation of the B-pillar bolt and cover (see Appendix A). However, contrary to expectation, this was the case regardless of whether or not an airbag was present. The majority of these drivers were male and weighed in excess of 70 kgs. In fact, the mean weight of drivers receiving a shoulder injury from the seatbelt was 79 kgs. This is higher than both the mean weight (76 kgs) among the rest of the sample (i.e. no shoulder injury from the seatbelt) and the weight (75 kgs) of the 50th percentile American male (Cesari & Bouquet, 1983). For those injured, an airbag in combination with a seatbelt webbing clamp does not appear to be reducing or spreading the deceleration load on the torso during a crash.

It should be noted that 30 (43%) of the control vehicles were equipped with webbing clamps on the seatbelts fitted at the front seating positions. As noted earlier, webbing clamps alone are expected to provide injury benefits. Indeed, analyses comparing seatbelt injuries among the control vehicles with and without webbing clamps indicated some injury benefits that could be attributed to the webbing clamps. For example, the control cases with webbing clamps, in comparison to the controls without webbing clamps, had a lower ISS (mean = 1.2 versus mean = 1.6) and Harm (mean = $3,035 versus $3,627) and fewer shoulder injuries of any severity (6.7% versus 15.4%) and chest injuries of at least a moderate severity (15.4% versus 10.0%). None of these differences were statistically significant, probably due to the minimal number of cases available for analysis at this time. Nevertheless, they indicate that the analyses of the benefits of airbags in combination with webbing clamps reported above are conservative because the webbing clamps fitted to almost half of the control cases appear to have provided benefits.

DISCUSSION

The results of these preliminary analyses suggest that supplementary airbags in combination with seatbelt webbing clamps appear to be effective, reducing **all** injuries to drivers of passenger cars in Australia. A reduction in average cost of injury of almost $17,000 was observed among the airbag cases. In comparison to the controls, a greater proportion of drivers of airbag vehicles received minor injuries (e.g. bruises and abrasions), but a lower proportion received moderate and serious injuries. In other words, airbag technology appears to be preventing moderate and severe injuries. It must be emphasised that most of these results were not statistically significant due to a relatively low number of cases and thus should be considered indicative only at this stage. Nonetheless, the addition of more cases would likely yield statistically significant airbag benefits.

Similar, but smaller, airbag benefits were observed when seatbelt injuries only were considered. The probability of a moderate and serious injury from the seatbelt was lower for the airbag cases than the controls. Furthermore, seatbelt injuries to the chest of at least a moderate severity (AIS $\geq$ 2) were reduced by almost 100% among the airbag cases. Again, these differences were not statistically. Nevertheless, these results probably provide a conservative estimate of the benefits of the combination of airbags and seatbelt webbing clamps. This is because almost half the vehicles in the control group were fitted with webbing clamps that alone provide injury savings.

There appeared to be a trade-off between a reduction in minor chest injuries and an increase in minor shoulder injuries from the seatbelt among the airbag cases. One possible explanation of these results is that a webbing clamp on the seatbelt in combination with an airbag alters the occupant kinematics during a crash, increasing the likelihood of bruising and abrasions to the shoulder. Del Nevo (1991) found that webbing clamps alone were effective in reducing the forward displacement and upper torso excursion of a Hybrid III test dummy (50th percentile male) in sled tests, but induced relatively high seat belt loadings. On the other hand, chest acceleration and compression were reduced by these seatbelt-occupant dynamics. These results are consistent with the findings of this study, with strong evidence of relatively high seatbelt loadings among those cases receiving shoulder injuries from the seatbelt (e.g. deformation of the B-pillar bolt and cover). For these cases, an airbag in combination with a webbing clamp reduces the overall deceleration load on the torso during a crash and provides a decrease in the loading on the chest but an increase in the loading on the shoulder. Although the injuries from these seatbelt loadings tend to be of minor severity, they require monitoring in the future. They also suggest that there may be scope to improve the restraint systems of modern passenger cars further.

CONCLUSION

The results of these preliminary analyses are encouraging for occupants of Australian passenger cars equipped with a driver's airbags and a seatbelt webbing clamp. Although not statistically significant, there were indications of a reduction in seatbelt injuries among the airbag cases compared to the controls. As expected, airbags in combination with webbing clamps reduced moderate and severe chest injuries caused by the seatbelt. However, there appears to be a trade-off between a reduction in minor injuries to the chest and an increase in minor shoulder injuries from the seatbelt. This may result from changes to the occupant kinematics during a crash that stem from the combination of seatbelt webbing clamps and supplementary airbags, particularly for heavier occupants.

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APPENDIX A

Table A.1 - Observations of cases with shoulder injuries[1] from the seatbelt

	Delta-V (km/h)	Age	Sex	Weight (Kgs)	Seatbelt System	Observations
Airbag	32	46	M	88	WC	B-pillar bolt moved and fractured cover
	24	42	M	67	WC	B-pillar cover detached
	53	56	F	58	WC	B-pillar cover detached
	28	42	F	59	WC	B-pillar bolt moved
	39	47	M	76	WC	no observable changes
	42	24	M	82	WC	B-pillar bolt moved and cover detached
	25	63	M	83	WC	B-pillar bolt moved and cover detached
	34	30	M	72	WC	B-pillar bolt moved and cover detached
	34	36	M	110	WC	B-pillar bolt moved and cover detached
	28	34	M	80	WC	B-pillar bolt moved and cover detached
	46	32	F	79	WC	B-pillar bolt moved and cover detached
	52	27	F	70	WC	B-pillar bolt moved and cover detached
	35	26	M	98	WC	B-pillar bolt moved and cover detached
Control	45	25	M	74	ELR	B-pillar bolt moved and cover detached
	46	34	M	87	ELR	B-pillar bolt moved and cover detached
	39	28	M	82	ELR	B-pillar bolt moved and cover detached
	44	62	M	90	ELR	B-pillar bolt moved and cover detached
	44	51	M	72	ELR	B-pillar bolt moved and cover detached
	22	49	M	64	ELR	B-pillar bolt moved and cover detached
	41	33	F	90	WC	B-pillar bolt moved and cover detached
	52	29	M	83	WC	B-pillar bolt moved and cover detached

[1] All injuries were minor AIS 1 injuries, such as bruises and abrasions
Note: WC = webbing clamp; ELR = emergency locking retractor