Effectiveness of Airbags for Reducing Injury to Belted Drivers

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ABSTRACT

The combination of airbags and seat belts has been shown to be effective at reducing fatalities in crashes. Less is known however about the effectiveness of these restraints to reduce serious injury. The objective of this study is to determine the risk of injury associated with the inclusion of airbags into vehicles for belted drivers in frontal crashes. National Automotive Sampling System / Crahworthiness Data System (NASS/CDS) case years 1993-2007 were used in this analysis. An odds ratio analysis from a logistic regression model was conducted to determine which body regions benefitted from the inclusion of airbags. This study considered both moderate (AIS2+) and severe (AIS3+) injuries. The finding was that the inclusion of airbags did not significantly reduce the odds of head or chest injury. The presence of airbags increased the odds of lower extremity, upper extremity and spine injury. The face was shown to benefit from airbags. The depowering of airbags did not significantly change the odds of injury to any body region. This research approach presents distinct advantages over similar analyses. This research did not combine the results of the passenger and driver, which experience very different loading environments. Also, the face was analyzed independently of the head. This approach shows the benefit seen for the face and the lack of a significant benefit for the head. Our analysis also ensured that the comparison populations are similar in their occupant and crash characteristics. The confounding factors in the logistic regression model all exhibit statistically significant effects on the predicted odd ratio and increase the predictive power of the model. From this we were able to determine that the presence of an airbag did not significantly reduce the odds of moderate or serious injury for any body region except the face for belted drivers in frontal crashes.

INTRODUCTION

Previous research has reported that airbags have been effective at reducing the overall number of fatalities for occupants in frontal crashes. Airbags are especially effective for unbelted occupants in frontal collisions (Lund et al, 1994; Braver et al, 1997). However, with the national seat belt usage rate around 82% (NHTSA, 2007), it is the occupants who are restrained by both seat belts and airbags that represent the greatest proportion of all front seat occupants on American roads.

As part of the Intermodal Surface Transportation Efficiency Act (ISTEA), the United States Congress directed the National Highway Transportation Safety Administration (NHTSA) to prepare a series of reports on the effects that airbag mandates were having on the driving population. The most recent of these reports, presented in 2001, was based on the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS) for case years 1988-1997. NHTSA presented that there was no significant reduction of AIS2+ or AIS3+ injury occurrence rates for those protected by both airbags and seat belts as compared to those who were restrained only by belts when considering all body regions combined. The head, showed an increase in protection at both injury levels with the inclusion of an airbag. Also, the most recent report suggested that airbags actually reduced the effectiveness of protecting the chest for AIS3+ injuries, but still showed increased effectiveness for AIS2+ chest injuries; although the presented results were not shown to be significant (NHTSA, 2001).

A NASS/CDS study for case years 1995-2000 by McGwin et al (2003) investigated the relative risk of AIS2+ injuries for drivers with airbags and seat belts vs. seat belts alone. The relative risk values were corrected for confounding factors including gender, seat track position, occupant location, delta-V, age, and vehicle curb weight. The results showed no significant increase in effectiveness for head or chest protection with the deployment of an airbag. The relative risk point estimates suggested that these body regions may benefit from airbag deployment; however, the injurious data sample size may not have been sufficient to provide significant results. Overall, the data suggested that airbag deployment in conjunction with a belted occupant did not provide an increased protection against AIS2+ injuries, although none of the results showed significance.

This study presents a comprehensive perspective on injury protection associated with airbags for all body regions. The results will provide further insight and help resolve the conflicting findings of previously mentioned research by including a larger sample population and by combining investigations concerning different injury thresholds.

Objective

The objective is to estimate the effectiveness of airbags in reducing moderate and serious injuries for belted drivers exposed to frontal crashes.

METHODS

The research presented here is based on NASS/CDS for case years 1993-2007. This case year range included cases affected by the depowering of airbags or the inclusion of advanced airbags. The analysis includes only frontal collisions (PDOF: +/- 30º off the longitudinal axis of the vehicle), where the driver was belted. Rollover events were excluded. All injuries were categorized using the Abbreviated Injury Scale (AIS). AIS ranks injury severity by threat to life using a six-level scale where 0 = no injury and 6=fatal injury (AAAM, 1998). The airbag conditions that were investigated include belted drivers in vehicles with and without frontal airbags available, belted drivers exposed and not exposed to a deployed frontal airbag, and belted drivers exposed and not exposed to a deployed, depowered frontal airbag as compared to a deployed first generation airbag. The results are presented where a point estimate with a value of 1 represents equal odds of injury to a given body region, with or without the airbag restraint condition of interest. A point estimate of less than 1 represents a decrease in the odds of injury with the airbag condition, and a point estimate of greater than 1 represents an increase in the odds of injury with the airbag condition. Instances where the range of the confidence intervals includes a value of 1 indicate a statistically insignificant relationship. The odds ratio is defined in Equation 1:

$$OddsRatio = \frac{\left[p_{Airbag+Belts} \Big/ \left(1 - p_{Airbag+Belts}\right) \right]}{\left[p_{Belts\_Only} \Big/ \left(1 - p_{Belts\_Only}\right) \right]} \quad \text{Equation 1}$$

The odds ratios were computed using a logistic regression model. The SAS statistical software was used to compute the point estimates for the odds ratios and the 95th percentile confidence limits (SAS, Cary, N.C.). Along with the airbag restraint condition, occupant age and delta-V were included as continuous variables and vehicle type (defined as light truck, car, or mini-van) as a categorical variable in the logistic regression model for the computation of the odds ratio. The jackknife variance calculation method was used to compute confidence intervals due to its conservative nature. The stratified and cluster sample design employed by NASS/CDS has been accounted for in the computation of confidence intervals.

RESULTS

The distributions in Table 1 show the number of injuries for each body region based on the restraint condition with weights applied. This table includes only cases that met the inclusion criteria described above. The subsequent odds ratios are based on this data.

Table 1. Number of AIS2+ and AIS3+ injured by body regions for belted drivers with and without the presence of an airbag (Un-Wgtd=Unweighted Cases, Wgtd=Weighted Cases)

	AIS2+				AIS3+			
	Seat Belts Only		Belts & Airbags		Seat Belts Only		Belts & Airbags	
	Un-Wgtd	Wgtd	Un-Wgtd	Wgtd	Un-Wgtd	Wgtd	Un-Wgtd	Wgtd
Head	314	26,033	425	52,815	139	10,056	136	15,045
Chest	338	32,885	491	49,864	211	12,864	308	21,269
Lower Ext.	434	49,175	1,227	199,526	182	10,085	489	33,953
Upper Ext.	303	43,537	764	106,793	90	7,302	283	29,838
Abdomen	122	5,759	192	14,567	48	1,623	75	5,421
Face	179	13,595	80	11,294	45	3,398	14	991
Spine	96	6,243	213	23,015	33	1,627	66	3,283
Occupant Exposure	**5,271**	**2,662,390**	**12,562**	**5,774,866**	**5,271**	**2,662,390**	**12,562**	**5,774,866**

As shown in Table 2, belted drivers in vehicles with an available airbag showed lower odds of injury to the face as compared to drivers with belts alone for AIS2+ (0.20x; CI:0.1-0.4x) and AIS3+ (0.1x; CI:0.02-0.2x) injury levels; this was the only body region that experienced a reduction in risk. The spine (2.8x; CI:1.4-5.9x) and upper extremity (2.0x; CI:1.2-3.5x) showed an increase in the odds of injury when an airbag was available at the AIS2+ injury level and the lower extremity injury odds increased (2.6x; CI:1.3-5.2x) for the AIS3+ injury level. The chest, head and abdomen showed no significant difference in the odds of injury at either injury level when restrained by seat belts and an available airbag as compared to seat belts alone.

Table 2. Odds ratio and confidence limits of AIS2+ and AIS3+ injuries for belted drivers in vehicles with airbags as compared to those in vehicles without airbags (weighted)

Body Region	AIS2+				AIS3+			
	Odds Ratio	- CI	+ CI		Odds Ratio	- CI	+ CI	
Lower Extremity	**2.053**	0.827	5.102		**2.646**	1.335	5.236	*
Spine	**2.833**	1.366	5.882	*	**1.572**	0.581	4.255	
Upper Extremity	**2.049**	1.208	3.472	*	**2.070**	0.675	6.369	
Chest	**0.948**	0.454	1.980		**1.667**	0.644	4.310	
Head	**0.948**	0.606	1.484		**0.625**	0.256	1.527	
Abdomen	**1.529**	0.751	3.195		**2.604**	0.887	7.634	
Face	**0.202**	0.101	0.404	*	**0.058**	0.015	0.228	*

As shown in Table 3, the face was the only body region to experience lower odds of injury with for belted drivers exposed to an airbag deployment (0.3x; CI:0.1-0.5x); similar to the result from Table 2. The upper extremity had greater odds of injury for the AIS2+ (3.3x; CI:2.0-5.3x) and AIS3+ (3.2x; CI:1.3-7.9x) injury levels. The abdomen also showed greater odds of injury with airbag deployment for the AIS2+ (2.2x; CI:1.1-4.2x) and AIS3+ (3.7x; CI:1.4-10.2x) injury levels. The spine, again, showed greater odds of injury for belted occupants exposed to a deployed airbag (2.1x; CI:1.1-4.0x) for AIS2+ injuries. The lower extremity (2.8x; CI:1.5-5.4x) and chest (2.4x; CI:1.02-5.8x) had greater odds of AIS3+ injuries when the belted driver was exposed to a deployed airbag. The risk of injury to the head was not significantly different for belted drivers with or without airbag deployment at either injury level.

Table 3. Odds ratio and confidence limits of AIS2+ and AIS3+ injuries for belted drivers exposed to airbag deployment as compared to those without airbag deployment (weighted)

Body Region	AIS2+				AIS3+			
	Odds Ratio	- CI	+ CI		Odds Ratio	- CI	+ CI	
Lower Extremity	**1.553**	0.469	5.155		**2.833**	1.488	5.376	*
Spine	**2.105**	1.111	4.000	*	**2.049**	0.842	5.000	
Upper Extremity	**3.268**	2.020	5.263	*	**3.165**	1.271	7.874	*
Chest	**1.302**	0.661	2.564		**2.439**	1.021	5.814	*
Head	**1.059**	0.752	1.493		**0.701**	0.393	1.252	
Abdomen	**2.151**	1.089	4.237	*	**3.731**	1.359	10.204	*
Face	**0.254**	0.126	0.515	*	**0.049**	0.009	0.275	*

The results shown in Table 4 show the injury odds ratios for belted drivers who are exposed to depowered airbag deployment vs. those exposed to first generation airbag deployment. The spine (2.2x; CI:1.1-4.6x) and chest (2.5x; CI:1.3-4.8x) had greater odds of an AIS2+ injury with a depowered airbag. None of the body regions show a significant reduction in odds based on the presence of a depowered airbag for the AIS2+ or AIS3+ injury levels.

Table 4. Odds ratio and confidence limits for AIS2+ and AIS3+ injuries for belted drivers exposed to depowered airbag deployment as compared to first generation airbag deployment (weighted)

Body Region	AIS2+				AIS3+			
	Odds Ratio	- CI	+ CI		Odds Ratio	- CI	+ CI	
Lower Extremity	**1.484**	0.943	2.334		**1.512**	0.913	2.502	
Spine	**2.204**	1.065	4.564	*	**1.582**	0.547	4.578	
Upper Extremity	**0.900**	0.523	1.546		**0.912**	0.566	1.470	
Chest	**2.532**	1.349	4.753	*	**2.313**	0.810	6.602	
Head	**1.037**	0.605	1.775		**0.574**	0.223	1.477	
Abdomen	**1.388**	0.643	2.996		**1.073**	0.236	4.889	
Face	**0.607**	0.213	1.731		**2.017**	0.152	26.746	

DISCUSSION

The previously discussed studies as well as the present study have examined both airbag availability and airbag deployment as methods for examining the changes in injury risk associated with this technology. The former provides a broad perspective on the role of airbag mandates and their effect on the epidemiology of crash injury. The latter provides a more focused perspective on the interaction between the airbag and the onset of injury. However, studies based on airbag deployment are biased toward the higher severity crashes necessary to deploy the airbag. McGwin et al included only cases with a delta-V ≥ 15kph to address this issue. However, this methodology ignores any association between low delta-V airbag deployment and injury risk. From the present analysis, it has been shown that both the presence and deployment of airbags are associated with lower AIS2+ and AIS3+ facial injury risk for the driver. On the other hand, airbag presence generally increases the odds of injury for the lower extremity, upper extremity and AIS2+ spinal injuries for drivers. The abdomen was particularly susceptible to the deployment of an airbag at both injury levels. There was also an increase in risk of AIS3+ chest injuries when exposed to an airbag deployment.

The NHTSA reports to Congress suggested that the head had significantly lower odds of serious and moderate injury when the driver was belted and an airbag was available, but only with respect to unbelted occupants. Interestingly, both NHTSA and McGwin et al included the face as part of the head body region in their analyses. In the results reported from this study, the face is the only body region that has lower odds of injury with the presence or deployment of an airbag. By not investigating the face independently, the general improvements with respect to facial injury were not noted in these previous analyses and possibly contributed to an overly optimistic view regarding airbags and head injury.

The latest NHTSA report to Congress noted a reduction in effectiveness for belted occupants with airbags (46%) as compared to those without airbags (57%) with respect to serious upper extremity injury. The McGwin et al study did not show a significant difference in effectiveness for the upper extremity at the AIS2+ injury level. The present study has shown an increase in the odds of AIS2+ and AIS3+ upper extremity injury when exposed to a deployed airbag for belted drivers. Interestingly, Table 4 shows depowered airbags provide no significant reduction in the odds of upper extremity injury as compared to earlier, first generation airbags. Hardy et al (2001) found a lower risk of airbag induced forearm injury for cadavers exposed to depowered airbags. Jernigan et al (2005) showed a change in the distribution of upper extremity injuries with depowered airbag deployment; specifically, a lower risk of upper extremity fracture with depowered airbags, yet a higher risk of dislocation. Overall, this contributed to a higher percentage of ASI2+ upper extremity injuries when compared to the overall exposure to crashes. The lower extremity was shown to be adversely affected for the AIS3+ injury level when an occupant is exposed to a deployed airbag. However, the results were not significant at the AIS2+ level, agreeing with the conclusions of McGwin et al. Estrada et al (2004) suggested that an increase in odds of injury to the lower extremity with airbag exposure may be attributed to a change in kinematics of the occupant by which an airbag interaction induces the pelvis to submarine under the lap belt, increasing the possibility of interior contacts. It is possible that this same kinematic response was also responsible for the increased risk of abdominal injury when exposed to a deployed airbag. This submarining response may cause the lap belt to disengage the pelvis and result in increased abdominal pressurization from the lap belt or steering wheel rim.

The spine seems to be adversely effected by the presence and deployment of an airbag at the AIS2+ injury level. No significant result was given for the AIS3+ level. This suggests that the airbag is more effective at protecting against the more severe injury types, including cord lacerations, however, the airbag is less effective at protecting against moderate injuries, such as vertebral fractures and brachial plexus injuries (AAAM, 1998). When exposed to airbag deployment, belted drivers are not significantly more protected against serious or moderate thoracic injury. This is consistent with the results reported by McGwin for AIS2+ injuries. However, the latest NHTSA report to Congress showed increased protection against AIS2+ injuries and a decrease in effectiveness for AIS3+ thoracic injuries when comparing belted occupants with (35%) and without (58%) airbag deployment; however, these results were not significant. The present study also suggests no increase in thoracic protection with depowered airbags and an increase in thoracic injury risk for the AIS2+ injury level.

CONCLUSIONS

For belted drivers, airbags do not appear to provide better protection for most body regions, with the exception of the face. Furthermore, the abdomen, lower extremities, and upper extremities appear to be adversely affected by airbag technologies. However, airbags have previously been shown to reduce fatalities, thus suggesting that they are still an integral part of occupant protection systems.

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