OCCUPANT INJURY IN LONGITUDINAL BARRIER COLLISIONS: EFFECTS OF RESTRAINTS

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ABSTRACT

Longitudinal barriers, such as guardrails, are designed to prevent a vehicle that leaves the roadway from impacting a more dangerous object while minimizing risk of injury to the vehicle occupants. Current full-scale test procedures for these devices do not consider the effect of occupant restraints such as seat belts and airbags. The purpose of this study was to determine the extent to which restraints are used or deployed in longitudinal barrier collisions and their subsequent effect on occupant injury in these collisions. Analyzing national crash data from 1996 through 2005, airbag deployment in longitudinal barrier crashes was found to be 40 percent for all involved vehicles and 68 percent when considering only airbag-equipped vehicles. Seat belt usage rates were approximately 60 and 80 percent for non-airbag-equipped and airbag-equipped vehicles, respectively. Compared to fully restrained occupants, relative risk of injury for no airbag/belted, airbag/unbelted, and no airbag/unbelted occupants was 1.6, 7, and 11.7, respectively. Despite these large differences in relative risk, however, 95 percent of the occupants in the analyzed data were either uninjured or sustained minor injury, which reinforces the overall effectiveness of these roadside devices.

Keywords: Injury, Longitudinal Barriers, Advanced Restraints, Airbags

INTRODUCTION

Longitudinal barriers, such as guardrails, are designed to safely prevent a vehicle that leaves the roadway from impacting a more dangerous roadside object. Performance of these roadside devices is tested using controlled, full-scale crash tests that are evaluated based on the ability of the barrier to withstand the vehicle impact, safe redirection of the vehicle after the impact, and vehicle-based measures of occupant risk [1]. Current occupant risk measures are based on the flail space model [2]. The flail space model, developed in the 1980's, does not account for occupant restraints such as seat belts or airbags. Although the overall benefits of airbags are well established for frontal collisions [3][4], little is known with regard to their performance in longitudinal barrier collisions.

Previous researchers [5][6] have investigated occupant injury in longitudinal barrier collisions prior to the widespread implementation of airbags. In 1997, Council et al. [7] examined state accident data to determine the effect of airbags on average injury severity in collisions with various roadside objects and safety devices. Airbags were found to decrease the average severity of roadside object collisions, but in most cases the decrease was not statistically significant due to small sample sizes. In addition, the study included data from years only through 1994, which is prior to the widespread implementation of airbags. The study did not examine occupant injury patterns. More recently, Grzebieta et al. [8] performed several full-scale crash tests with a small car impacting various roadside barriers to examine airbag performance and driver injury potential. The researchers demonstrated that advanced vehicle restraints, including airbags and seat belt pretensioners, can fire under certain barrier impact conditions. In terms of investigation of injury, however, the study is limited by the number of impact conditions and the use of a single vehicle type.

OBJECTIVE

The purpose of this study is (1) to determine the extent to which occupant restraints are used or deployed in real-world longitudinal barrier collisions and (2) to examine the effects of vehicle restraints on occupant injury and injury patterns in these collision types.

METHODS

Data from the National Automotive Sampling System / Crashworthiness Data System (NASS/CDS) was used to determine occupant restraint usage and deployment rates as well as resulting injury patterns in longitudinal barrier collisions. NASS/CDS provides detailed information, including restraint performance and occupant injury, for a random sample of approximately 5,000 U.S. crashes every year. To be included in the NASS/CDS database, a crash must be police reported, result in property damage or personal injury, and involve at least one vehicle towed due to damage. Our analysis included a 10-year NASS/CDS data set spanning 1996 to 2005 to provide an accurate representation of the current vehicle fleet while maintaining a relatively homogenous set of barriers (the most recent roadside barrier test procedures [1] became effective in 1993). Cases were selected from NASS/CDS based on the following criteria: (1) single event crash where a single passenger vehicle impacts a longitudinal barrier, (2) the front of the vehicle is damaged, (3) the occupant is seated in the front left or front right seating position, (4) the occupant belt and airbag status is known, (5) the occupant is not ejected from the vehicle. Inclusion of single event crashes ensures that the longitudinal barrier caused (or did not cause) the deployment of the airbag. For the purpose of this study, a longitudinal barrier includes concrete barriers, metal beam guardrails, and cable barriers.

The occupant injury severity was described using the Abbreviated Injury Severity (AIS) scale [9], which methodically rates injury on a discrete 0 to 6 scale based on threat to life. In NASS/CDS, each injury an occupant acquires is rated based on this scale and the greatest (most severe) of all the injuries is termed the maximum AIS (MAIS) score. Injury levels are summarized in Table 1.

Table 1 Summary of the Abbreviated Injury Severity (AIS) Scale

AIS Value	Injury Description
0	No Injury
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximum/Fatal

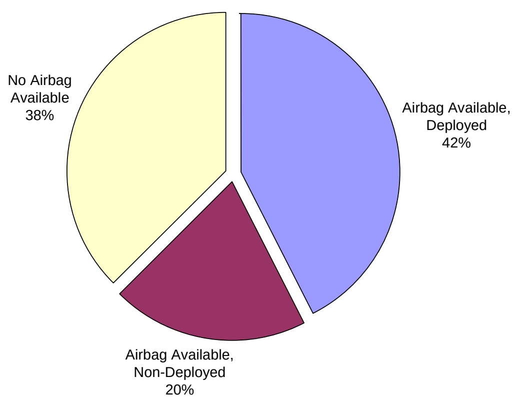
RESULTS

There were a total of 667 NASS/CDS cases suitable for analysis. For each case, the NASS/CDS database provides statistical weighting factors which must be applied to compute national estimates of the frequency with which this type of case occurs. After application of the NASS weights, these cases represent more than 350,000 occupants exposed to a longitudinal barrier collision. Table 2 shows the actual and weighted cases by restraint type. Figure 1 shows the distribution of airbag deployment and occupant belt usage rate using the weighted cases.

Table 2 Summary of Suitable Cases for Analysis

Belt Usage	Airbag Status	Actual		Weighted	
		Occupants	% of Total	Occupants	% of Total
Lap and Shoulder	Bag Deployed	211	31.6	135359	36.7
	Non-Deployed	109	16.3	56773	15.4
	Not Equipped	104	15.6	93104	25.3
No Belt	Bag Deployed	88	13.2	21316	5.8
	Non-Deployed	23	3.5	16799	4.6
	Not Equipped	132	19.8	45122	12.2

Based on the available data, airbag deployment occurs in approximately 40 percent of police-reported, tow-away longitudinal barrier collisions. If only longitudinal barrier collisions involving airbag-equipped vehicles, the airbag deployment rate becomes 68 percent. Lap and shoulder belt usage rates were 83 percent for vehicles equipped with airbags and 67 percent for vehicles not equipped with airbags. This data suggest that a majority of occupants exposed to a longitudinal barrier collision are restrained by a lap and shoulder belt and, if the vehicle is equipped with an airbag, the airbag is deployed more than half the time.



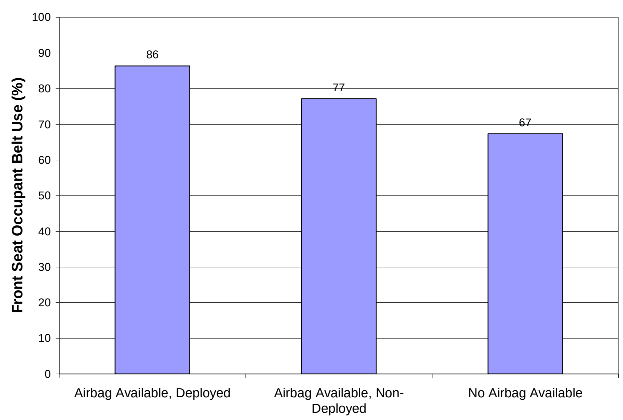


Figure 1 Airbag Deployment and Belt Use in Police-Reported, Tow-Away Longitudinal Barrier Crashes

A slightly smaller data set of 614 cases (342,837 weighted) was used for the injury analysis as detailed injury data was unknown in 53 cases. Four restraint conditions were considered: (1) airbag available, belted occupant, (2) airbag available, unbelted occupant, (3) no airbag, belted occupant, and (4) no airbag, unbelted occupant. For each restraint condition, the proportion of occupants injured to the MAIS 2 level or greater was computed and then normalized to determine relative risk. Figure 2 shows the relative risk of occupant injury in longitudinal barrier collisions for different restraint conditions. The data has been normalized against the airbag available, belted occupant restraint condition (e.g. the risk for this condition is set to unity). Again, the appropriate statistical weights, as assigned by NASS, have been applied to the data.

Compared to airbag available/belted occupants, occupants that are belted but do not have an airbag have 1.6 times the risk of MAIS 2 or greater injury. There is a seven-fold increase in risk for unbelted occupants that have an airbag available. For completely unrestrained occupants, the risk increases to roughly twelve-fold the baseline restraint condition. It should be noted that roughly 95 percent of the weighted injuries in the data set were minor or no injury (MAIS 1 or 0), providing an indication of the overall effectiveness of these devices.

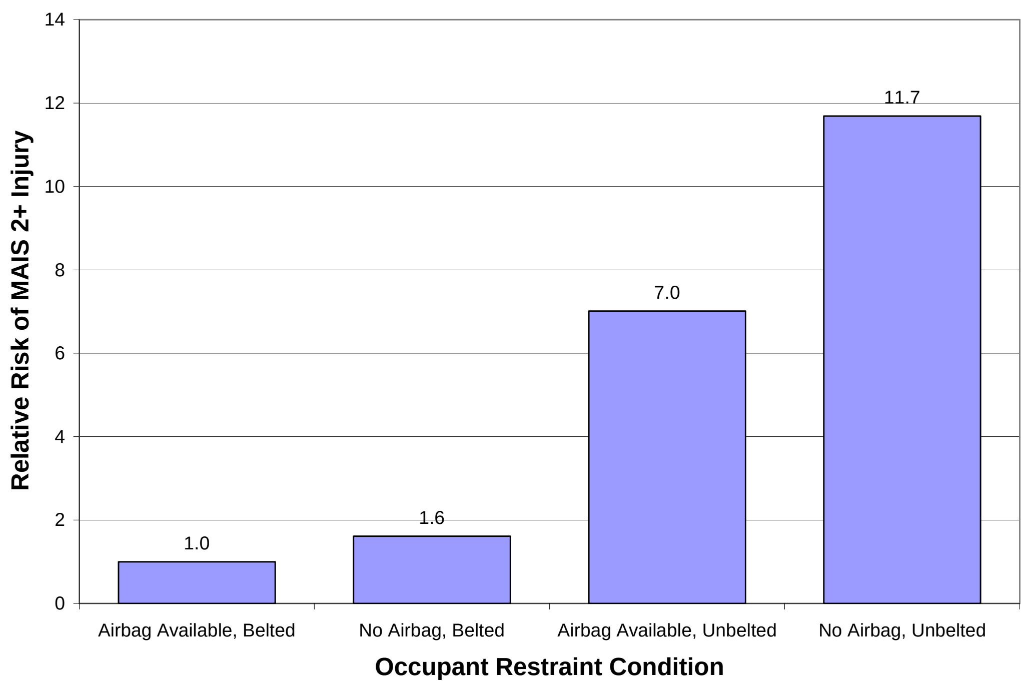


Figure 2 Occupant Relative Risk by Restraint Type Normalized to Belted Occupant with Airbag Available

Also note that Figure 2 does not account for confounding factors such as differences in crash severity or or occupant characteristics (e.g. age, gender, or weight,). In NASS/CDS, crash severity is quantified by the change in vehicle velocity during the crash. For longitudinal barrier collisions however, the vehicle change in velocity, or delta-v, is extremely difficult for NASS crash investigators to reliably estimate. Approximately two-thirds of these values are missing from the available data; thus, it was not possible to compare delta-v for the different restraint conditions. The mean age, weight, and gender distribution are summarized in Table 3. Values in the same column with the same symbol indicate no statistically significant difference based on an ANOVA comparison.

Table 3 Summary of Occupant Characteristics and ANOVA for Different Restraint Conditions

Restraint Condition	Mean Age (Yrs)	Mean Weight (kg)	% Male
Airbag Available, Belted	33.7*	71.1*	49.1
Airbag Available, Unbelted	31.4*	74.7* +	48.3
No Airbag, Belted	38.3	69.5*	70.6
No Airbag, Unbelted	22.7	78.9 +	58.2

No statistically significant difference was found in mean occupant age or weight between airbag-equipped restraint conditions. Their gender distribution is also similar. The completely unrestrained occupants are significantly younger than the other restraint groups while the no airbag/belted group is significantly older than the other groups. Because the occupant age, weight, and gender distribution are similar between belted and unbelted occupants where an airbag is available, this comparison has been chosen for further body region injury analysis. Figure 3 shows the relative risk of AIS 2 and greater injury by body region for occupants restrained by an airbag. Injury risk has again been normalized to the airbag available, belted restraint group. For unbelted occupants in airbag-equipped vehicles, there is approximately a twenty-fold greater risk of head and face, chest and abdominal, and lower extremity injury. Upper extremity risk is also greater, but to a much lesser extent.

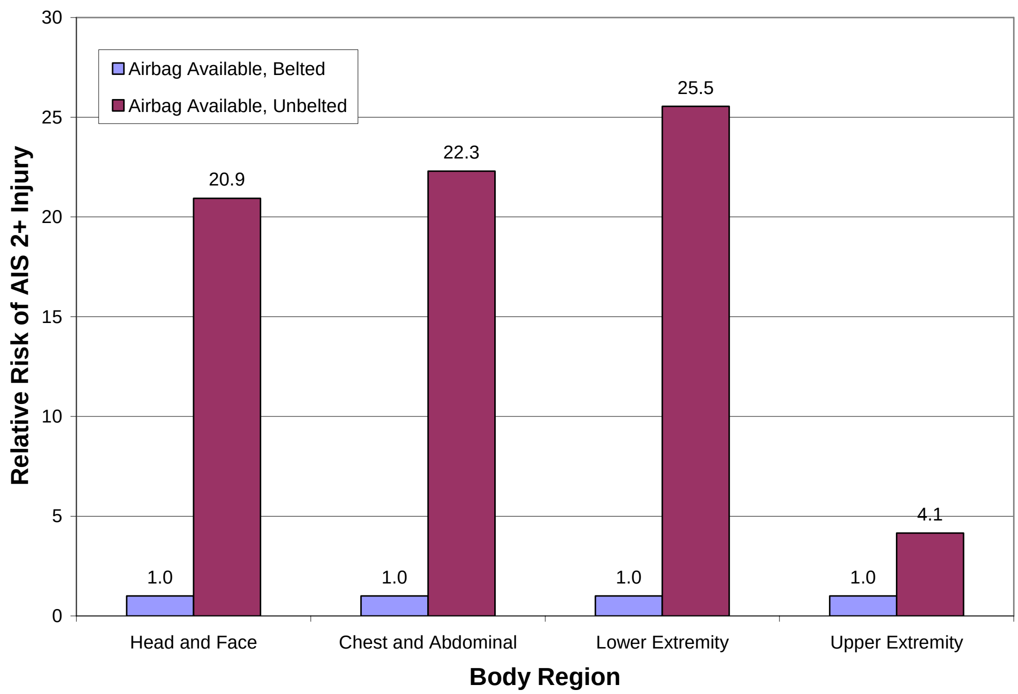


Figure 3 Injured Body Region Comparison: Belted vs. Unbelted, Airbag Restrained Occupants

DISCUSSION

Restraint usage and deployment in longitudinal barrier collisions has been characterized for the current vehicle fleet. Seat belt usage rates for occupants involved in single vehicle, tow-away longitudinal barrier crashes (airbag-equipped vehicles) was 83 percent, which is comparable to the 2005 national average of 82 percent [10]. For airbag-equipped vehicles, frontal airbag deployment occurred in 2 out of 3 tow-away longitudinal barrier collisions. These results confirm that airbag deployment is not a rare event in tow-away longitudinal barrier collisions and that a majority of occupants wear safety belts. Although the flail space model continues to be used to evaluate occupant risk in full-scale roadside hardware tests, it does not account for either of these occupant restraint types.

As expected, relative risk was greater for both unbelted occupants and occupants in vehicles not equipped with airbags. Belted, non-airbag-restrained occupants have a 50 percent higher risk of MAIS

2+ injury than belted, airbag-restrained occupants. For unbelted occupants with and without an airbag, this risk was found to increase to 7 and 12 times, respectively. There were some differences in occupant characteristics between the groups with the exception of the airbag/belted and airbag/unbelted groups. Although statistically significant in most cases, these differences are not likely to explain all the variation in relative risk, especially in the case of both unbelted restraint groups. For unbelted occupants in airbag-equipped vehicles, a roughly twenty-fold greater risk of head and face, chest and abdominal, and lower extremity injury was found compared to their belted counterparts. On the other hand, the risk of upper extremity injury increased by only 40% suggesting that belt use does not equally affect all body regions. One limitation of the data is the general lack of delta-v estimates for these collisions. Also, the delta-v values that are provided are of low confidence (NASS/CDS has a qualitative indication of each estimated delta-v based on input from the investigator), which is typical for longitudinal barrier collisions. The lack of data and low confidence for the known values prevented an analysis of delta-v across restraint groups.

CONCLUSIONS

This study has investigated occupant restraint use and airbag deployment in longitudinal barrier collisions. In real world longitudinal barrier collisions, airbags were found to deploy in 40 percent of all tow-away longitudinal barrier collisions and roughly 68 percent of all collisions when the vehicle was equipped with an airbag. Seat belt usage rates in longitudinal barrier collisions were found to be 83 percent in airbag-equipped vehicles. When compared with fully restrained occupants (belt and airbag), the injury risk was found to be 1.6, 7, and 11.7 higher for no airbag/belted, airbag/unbelted, and no airbag/unbelted occupants, respectively. Unbelted occupants in airbag-equipped vehicles were found to have a twenty-fold increase in head/face, chest/abdomen, and lower extremity injury than their belted counterparts. Despite these large differences in relative risk, 95 percent of the occupants in the analyzed data were either uninjured or sustained minor injury, which reinforces the overall effectiveness of these roadside devices.

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