DIFFERING PATTERNS OF HEAD AND FACIAL INJURY WITH AIR BAG AND/OR BELT RESTRAINED DRIVERS IN FRONTAL COLLISIONS

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Abstract

Air bag restraints without concomitant seat belt restraints may not offer adequate protection for drivers in frontal automobile collisions. The National Accident Sampling System data base was analyzed to determine the incidence of differing brain and facial injury patterns in frontal collisions for drivers using three different restraint types: a seat belt only; an air bag only; and a seat belt with an air bag. Analysis shows the probability of brain injuries and facial injuries to be higher for drivers protected only by air bags than for those restrained by only belt restraints. Laboratory sled tests conducted at the University of Virginia have identified the tendency of cadavers and dummies restrained only by an air bag to override the air bag and to contact the windshield. The National Accident Sampling System data confirms that actual collisions involving only air bag restraints also exhibit occupant contact with the windshield. The evidence suggests the need to emphasize the use of seat belts in conjunction with air bags and to develop a redesigned air bag that prevents windshield contact.

Introduction

Federal regulations in the United States require that all passenger cars manufactured after 1990 be equipped with automatic restraints. Two types of restraint systems have been used to meet the requirement: air bags that inflate automatically in frontal crashes, and seat belts that automatically fasten around occupants when they enter or start the car.

Increasingly, automobile manufacturers are offering air bags as the automatic restraint and by the 1997 model year all passenger cars will have air bags. Cars with air bags are also equipped with manual lap and shoulder belts to meet federal requirements for lateral and rollover crash protection and to provide additional restraint in frontal collisions. Air bags and lap/shoulder belts when used together have been reported to provide the most effective restraint protection available (IIHS, 1993). There has been concern that occupants might be less likely to use a manual lap/shoulder belt in vehicles with air bags than in cars that had only manual lap/shoulder belts, because they may erroneously assume that the air bag alone provides full or sufficient crash protection. (Williams et al., 1990).

Researchers at the University of Virginia noted a tendency during sled tests for unbelted dummies and cadavers to override the air bag and contact the windshield system during frontal decelerations. This observation led to an analysis of two separate databases maintained by the National Highway Safety Administration (NHTSA). The compliance test database was examined in order to determine the frequency of the override phenomenon in full-scale vehicle crash tests. The National Accident Sampling System (NASS) database was used to determine if air bag override of unbelted drivers occurred in real-life frontal collisions where an air bag deployment occurred. Specifically, the analysis examined the incidence of head contact with the windshield and the patterns of facial or head injury relative to the restraint type.

Laboratory Sled Tests

Hybrid III dummy and cadaver sled tests were conducted using a VIA Systems HITS-713 sled. The occupant restraints for each test were a production driver side air bag and a knee bolster. Occupant positioning and interior dimensions of the buck were modeled after mid-size vehicles. Two cadaver and one dummy test were conducted at both 32 km/h and 48 km/h. During the six sled tests, the pelvis of the occupant rose off of the seat and the upper torso and head passed over the top of the air bag. Head contact with the windshield/header region of the buck was noted on all tests. Based upon autopsy examinations and radiographic images, facial lacerations and cervical spine were identified injuries in three of the four subjects and attributed to head contact with the windshield.

NHTSA Compliance Test Database

In accordance with Federal Motor Vehicle Safety Standard 208, NHTSA conducts dynamic crash tests to assess the frontal crashworthiness of production automobiles. The test requires that the car, equipped with instrumented dummies in the driver's and passenger's seats, be driven into a full frontal barrier at 48 km/h (30 mph). NHTSA conducts about thirty full frontal dynamic crash tests per year. Since 1990, NHTSA has required that passive protection (i.e., motorized automatic seat belts and/or air bags) be used in the test.

To assess head contacts, the dummy head is coated with chalk prior to running each test. After the test, vehicle interior components are inspected for traces of chalk to determine if contact with the head occurred. Head injury potential, as estimated by the Head Injury Criteria (HIC) value, is also evaluated following each test. A HIC value greater than 1000 indicates a potentially injurious impact environment.

Table 1 - Vehicle and Driver Dummy Compliance Test Results

Model and Year	Restraint	HIC	Head Contacts
'91 Honda Accord	Belt	247	none
'91 Honda Accord	Airbag	480	windshield
'88 Chevy Berreta	Belt	543	steering wheel
'92 Chevy Berreta	Airbag	172	air bag only
'89 Pontiac Bonneville	Belt	578	steering wheel
'92 Pontiac Bonneville	Airbag	222	air bag only
'90 Chevy Caprice	Belt	632	steering wheel
'91 Chevy Caprice	Airbag	267	header/windshield
'87 Chrysler LeBaron	Belt	691	steering wheel
'91 Chrysler LeBaron	Airbag	306	air bag only
'90 Subaru Legacy	Belt	711	steering wheel
'93 Subaru Legacy	Airbag	617	header/windshield
'92 Toyota Paseo	Belt	442	none
'93 Toyota Paseo	Airbag	389	air bag only
'91 Ford Probe	Belt	270	none
'93 Ford Probe	Airbag	315	header/windshield
'88 Honda Prelude	Belt	452	none
'93 Honda Prelude	Airbag	420	header/windshield
'91 Saturn SL2	Belt	636	steering wheel
'93 Saturn SL2	Airbag	317	air bag only
'88 Dodge Shadow	Belt	647	steering wheel
'91 Dodge Shadow	Air bag	201	air bag only

There are several car models that were tested with only automatic seat belt restraints in one year and with only air bags in a subsequent year. Although other design changes may have been implemented between production years, the model pairs remain comparable in size and weight. Table 1 lists these cars, the type of restraint, the HIC value of the driver side dummy, and the head contact regions.

The results of tests conducted using either automatic seat belts or air bags show that both restraint systems provide sufficient protection if viewed in terms of the driver's HIC. Although each dummy's HIC was below 1000, the air bag equipped cars generally had a lower HIC than those with belt restraints.

NHTSA has conducted a total of 156 compliance tests since 1988 in which only an air bag or only a belt was used as the restraint. The trend of lower HIC values for the air bag equipped vehicles identified in Table 1 remains true when all of the compliance tests are considered. In addition, the increased incidence of header/windshield contacts for the air bag restraint relative to the belt restraint was also consistent (Table 2).

Table 2 - FMVSS 208 Compliance Test Results
for Air bag or Seat Belt Restraints

Restraint Type	Number of Tests	Steering Wheel Contact	Header/Windshield Contact
Air bag only	73	0	38
Seat belt only	83	24	2

Compliance tests indicate that replacing a seat belt with an air bag reduces head-to-steering wheel contacts at the expense of increasing head-to-windshield/header contacts. Furthermore, steering wheel contacts appear to be more severe than the header/windshield contacts, as indicated by the HIC values.

The National Accident Sampling System (NASS) database was examined to determine if occupants using only air bag restraints in frontal crashes exhibited different patterns of facial and head injuries than belted occupants. Contacts to the windshield/header region of the vehicle were also compared between restraint systems.

NASS Data Base

The National Accident Sampling System data base was established by NHTSA in the late 1970's in order to produce a national traffic accident data base to evaluate highway safety needs. The system consists of 24 teams of accident researchers, who are located across the country. These teams investigate approximately 5,000 accidents yearly. Since accidents selected in NASS are a probability sample of all accidents occurring in the survey year, the data from these accidents are weighted to produce national estimates.

In order for an accident to qualify for investigation by a NASS researcher, it must meet several criteria. The accident must involve a motor vehicle in transport on a public trafficway that has been towed from the accident scene. The accident must be reported to the police, resulting in the filing of a Police Accident Report (PAR) that is sent to the state for inclusion in the state accident statistics. Finally, the accident must involve property damage or personal injury.

A NASS accident report includes information on the vehicle, the occupants, and the site of the crash. A complete description of the accident scene including weather conditions and the road surface is given. A full assessment of the interior and exterior vehicle damage is also reported. Occupant information provided by the NASS report includes a physical description of the occupant, areas of contact between the occupant and vehicle interior, the injuries suffered by the occupant, and blood alcohol levels. The restraint system, if any, and the seat position are also reported. By surveying tire marks, vehicle damage, and other accident scene information, investigators can estimate the change in vehicle speed due to impact (delta V).

NASS Data Weighting

Because the accidents selected in NASS are a probability sample of all accidents occurring in the survey year, the data from these accidents are weighted to produce national estimates. Accidents are grouped into one of several strata based on severity, vehicle type, and police jurisdiction. Each strata is assigned a weight reflecting the accident's probability of being selected. The sum of the weights for all NASS cases in a year is an estimate of the total number of accidents which occurred during the year in the United States. If restricted to an accident stratum, the sum is an estimate of the total number of that type of accident which occurred in that year.

NASS Search Criteria

The NASS database has recorded air bag related information since 1991. The search in this study was limited to the years 1991 and 1992, since the data for 1993 is not yet publicly available. Despite the inclusion of air bag accidents in the database, relatively few accidents involving air bags were recorded in comparison with those involving belts. In addition, nearly half of all air bag cases reported an unknown delta V. Since the change in velocity was found to correlate strongly with injury probability for all restraint types, all cases with an unknown delta V were omitted from the analysis.

Restraint Systems - The 1991-1992 NASS databases were examined to compare the head and facial injuries suffered by drivers restrained by one of three restraint systems. NASS accident cases were grouped into datasets as follows:

1. Air bag only (AIRBAG dataset)
2. Seat belt only (BELT dataset)
3. Air bag with seat belt (AIRBAG & BELT dataset)

Vehicle Parameters - The NASS database search was further refined by considering only those cases meeting the following criteria:

1. Delta V of the vehicle was known to be over 19 km/h. This criteria was imposed in order to examine only those instances in which the air bag deployed properly. A velocity of 19 km/h was considered the threshold for air bag deployment. Although there were some NASS cases in which an air bag deployed at a delta V less than 19 km/h, choosing a lower delta V threshold value would have skewed the data set to include proportionally more BELT cases than desired, since there were as many air bag deployments as nondeployments for delta V's less than 19 km/h. Over 19 km/h, however, there were very few nondeployments.

2. The injury analysis of the vehicle occupants was limited to drivers only. Data for collisions involving driver side air bags far outnumbered those involving passenger side air bags. In addition, the scope of this study was limited to head injuries brought about by overriding the driver side air bag and steering wheel.

3. Since the study focused on protection afforded to the occupant with a functionally operational restraint system, the air bag analysis examined only those accidents in which the air bag deployed.

4. The search was limited to passenger cars and light trucks.

5. Since the air bag restraint system is most beneficial in frontal collisions, accidents with principal directions of force between 11 and 1 o'clock were examined. According to NASS figures, this crash configuration comprises over 60% of all accidents.

Injury Classification - NASS contains coded information on several types of injuries. The severity of each injury is classified by the Abbreviated Injury Scale (AIS). For this study, the following injuries were examined:

1. Brain Injuries (AIS ≥ 2)
2. Brain Injuries (AIS ≥ 3)
3. Facial Lacerations
4. Facial Abrasions
5. Facial Contusions
6. Facial Fractures
7. Facial Injuries (Lacerations, Abrasions, Contusions, and Fractures combined)
8. Neck/Cervical Spine Injuries

Although laceration, abrasion, and contusion injuries rate low on the AIS scale, the AIS rating system only addresses mortality and does not account for morbidity associated with the injuries. In particular, facial injuries can result in cosmetic deformities and disfigurement. Furthermore, the facial injuries were used in this study to indicate occupant kinematics (i.e., windshield contact) not controlled by the restraint system.

Occupant Contacts - To verify if air bag override occurred, occupant contact with the header/windshield region of the car was examined. The incidence of head contacts was determined by assuming that all header/windshield contacts resulted from contact with the occupant's head or facial region.

NASS Results

Using the aforementioned criteria and weighting factors, the injuries and contacts were determined for each of the restraint systems (Table 3). The total number of cases for each restraint meeting the search criteria is designated as N. The subset of injuries or contacts within the total set of restraint cases is n. The weighted ratio of the number of injuries or contacts over the total number of cases is also provided.

Data Analysis

For the NASS analysis, the BELT dataset was used as the control group. Significant changes in the probability of injury brought about by either the addition of an airbag (i.e., AIRBAG & BELT dataset) or the exchange of the belt for an airbag (i.e., AIRBAG dataset) were determined. Only statistically significant injuries at the 95% level of confidence have been considered in this analysis.

Table 3 - Percent of Drivers Sustaining Head Injuries (NASS Results)

Injury / Contact	Air bag Only (N = 39)	Air bag and Belt (N = 59)	Belt Only (N = 1178)
Brain Injuries ($AIS \geq 2$)	n = 12 Wght % = 25.0	n = 4 Wght % = 0.6	n = 135 Wght % = 4.0
Facial Lacerations	n = 11 Wght % = 30.8	n = 9 Wght % = 6.6	n = 254 Wght % = 10.0
Facial Abrasions	n = 4 Wght % = 2.4	n = 10 Wght % = 11.7	n = 149 Wght % = 7.1
Facial Contusions	n = 10 Wght % = 19.0	n = 8 Wght % = 3.2	n = 236 Wght % = 14.7
Facial Fractures	n = 3 Wght % = 2.3	n = 0 Wght % = 0.0	n = 92 Wght % = 3.0
Facial Injuries	n = 21 Wght % = 48.6	n = 16 Wght % = 19.7	n = 448 Wght % = 25.5
Windshield Contact	n = 15 Wght % = 62.5	n = 14 Wght % = 18.9	n = 239 Wght % = 14.1

Using the Generalized Linear Interactive Modeling (GLIM) software package, a logistic regression model was fit to the NASS injury data in order to estimate the probability of injury. All factors that could potentially correlate with the observed injuries were initially included as variables in the model: vehicle weight; delta V; vehicle wheelbase; model type; driver height; driver weight; driver age; driver sex; and restraint type. The general form of the models is:

$$\log\left(\frac{p}{1-p}\right) = b_1 + b_2 * x_2 + \ldots\ b_n * x \qquad (1)$$

where p is the predicted probability of being injured given the factors $x_1, x_2, \ldots x_n$. The coefficients $b_1, b_2, \ldots b_n$ and the associated standard errors were estimated using the principles of maximum likelihood.

The model indicated that the only significant predictors of injury were the vehicle's delta V and the type of restraint system. Therefore, the revised model took the form

$$p = \frac{e^{b_r + b_v \Delta V}}{1 + e^{b_r + b_v \Delta V}} \quad (2)$$

The coefficient b_r is associated with the categorical restraint type (i.e., BELT, AIRBAG, AIRBAG & BELT) and the b_v coefficient corresponds to the delta V (ΔV).

Using the revised model, estimates and standard errors of the coefficients were reevaluated. A 95% confidence interval for the estimates was characterized as

$$\text{estimate} \pm 1.96 \text{ standard error} \quad (3)$$

If zero was contained in the confidence interval then the estimate was not considered to be significant.

The AIRBAG and AIRBAG & BELT datasets did not contain sufficient data to fit the probability model over a sufficiently large range of velocities. In particular, most of the AIRBAG cases had velocities concentrated in the vicinity of 19 km/h to 32 km/h. The BELT cases, however, provided a data set of more than 1000 observations distributed over a wide range of velocities. Therefore, it was necessary to assume that the role delta V played in the models for the AIRBAG and AIRBAG & BELT datasets was the same as the role it played in the BELT dataset. In other words, the probability of injury for the cases involving air bags increased with delta V at the same rate that it did in the cases for the seat belt alone.

In addition to the injury analysis, a logistic regression model was also used to estimate the probability of windshield contact for a given restraint system at a given vehicle velocity. Moreover, the likelihood of sustaining brain and facial injuries given windshield contact, the restraint type, and the crash velocity were also determined.

Injury Probability

Due to the lack of data, the probability of injury could not be evaluated for the neck/cervical spine and brain injuries (AIS $\geq$ 3) with any of the restraint systems.

Brain Injuries - Brain injuries (AIS ≥ 2) were significantly more probable in the AIRBAG dataset than the BELT or AIRBAG & BELT datasets (Figure 1). No statistically significant difference was identified between the two systems involving belts.

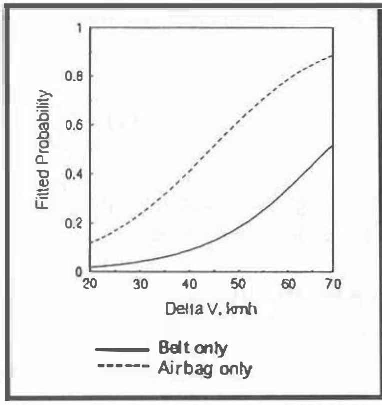

Figure 1. Brain Injuries AIS ≥ 2

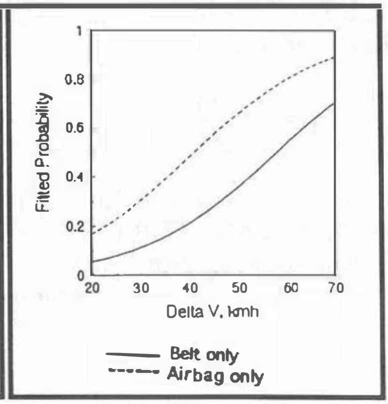

Figure 2. Facial Lacerations

Facial Lacerations - The probability of facial lacerations in the AIRBAG dataset exceeded those of the BELT and AIRBAG & BELT datasets over the total range of velocities investigated (Figure 2). The model, however, suggests that no statistically significant difference exists in the probability of facial lacerations between the BELT and AIRBAG & BELT datasets.

Facial Contusions - The probabilities of facial contusion in the BELT and AIRBAG datasets were not significantly different. The AIRBAG & BELT dataset, however, had a significantly lower probability of injury (Figure 3).

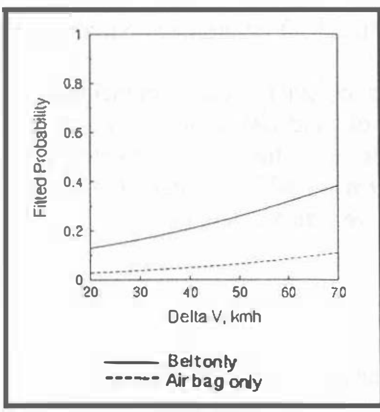

Figure 3. Facial Contusions

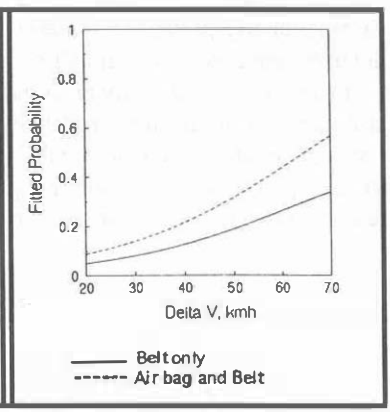

Figure 4. Facial Abrasions

Facial Abrasions - The probability of receiving an abrasion during an accident was the same for the BELT and the AIRBAG datasets (Figure 4). In accordance with previous reports (IIHS, 1993), however, the AIRBAG & BELT dataset had a significantly higher abrasion probability than the other two datasets. The control of the occupant's kinematics in the AIRBAG & BELT cases ensure that the occupant's face always contacts the air bag . The increase in the number of abrasions is believed to result directly from the air bag contact. In the AIRBAG cases, the occupant may largely miss the air bag and strike the windshield or, he may contact the air bag with a body region below the face.

Facial Fractures - For facial fractures, no statistical significance was identified among any of the three probability models.

Facial Injuries - An aggregate estimate of the probability of receiving a facial injury was obtained by combining the data for all injury types except brain injuries. Consistent with the individual probability models, the BELT and the AIRBAG & BELT systems demonstrated no statistically significant differences in the probability of facial injury. The AIRBAG system, however, resulted in more facial injuries than either of the other two restraint systems.

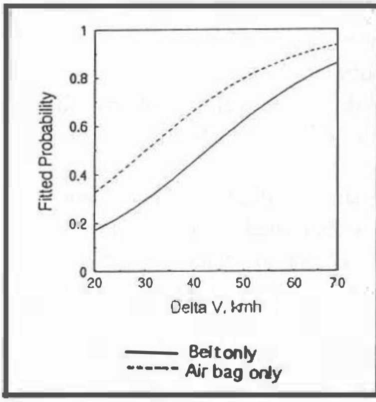

Figure 5. Facial Injuries

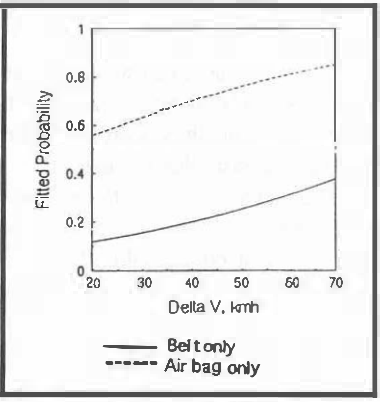

Figure 6. Windshield Contact

Windshield Contact - The likelihood of the occupant contacting the windshield/header was greatest for drivers restrained by only the AIRBAG system (Figure 6). Furthermore, Figure 7 indicates that head-to-windshield contacts are much more severe with the AIRBAG system when measured by brain injuries of AIS ≥ 2. The probability of facial injuries given windshield contact was relatively high regardless of the restraint system. In Figure 8, there is no significant difference in the probability of facial injury among any of the three restraint systems.

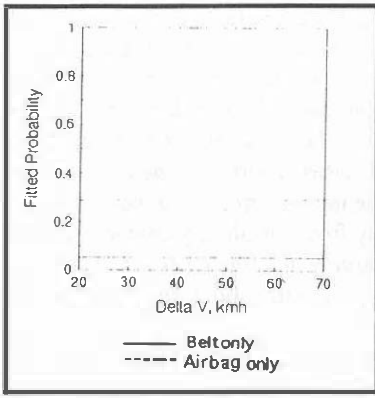

Figure 7. Brain Injuries given Windshield Contact

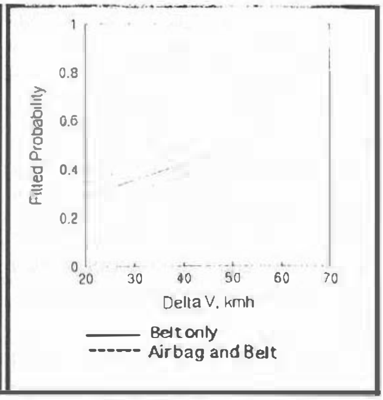

Figure 8. Facial Injuries given Windshield Contact

Conclusions

Laboratory sled tests and real-world crash statistics indicate that drivers have a higher probability of receiving a brain injury (AIS $\geq$ 2) or a facial injury if they are restrained by only an air bag than by only a seat belt. Moreover, occupant contact with the header/windshield of the vehicle occurs more often for drivers restrained only by an air bag than for drivers restrained only by a belt. This occurrence has been identified in sled tests, real-world crashes, and vehicle compliance tests.

The NASS data and the sled tests suggest the higher probability of brain and facial injuries for occupants restrained by only an air bag is due to increased windshield contacts. However, vehicle compliance tests show lower driver HIC values for air bag only restraints relative to belt only systems. Increases in the number of air bag equipped cars and the subsequent increase in NASS cases will help determine whether the compliance test results accurately reflect the real-world collisions.

It would appear that additional educational programs are needed to inform the public that air bags alone are not sufficient restraints and must be used with seat belts to maximize protection. In addition, design changes in the air bag and knee bolster restraint system could be implemented to reduce windshield contact.

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