Concussion, Diffuse Axonal Injury, and AIS4+ Head Injury in Motor Vehicle Crashes

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Purpose: This is a descriptive study of the annual incidence of brain injuries in motor vehicle crashes by type, seat belt use, and crash severity (delta V) using national accident data. The risk for concussion, diffuse axonal injury (DAI), and severe head injury was determined.

Methods: 1994–2011 NASS-CDS was analyzed to estimate the number of brain injuries annually in nonejected adults involved in motor vehicle crashes. Crashes were grouped by front, side, rear, and rollover, and the effect of belt use was investigated. Light vehicles were included with model year 1994+. Head injuries were identified as concussion, DAI, severe head injury (Abbreviated Injury Scale [AIS] 4+), and skull fracture. The annual incidence, risk, and rate for different types of head injury were estimated with standard errors.

Results: Motor vehicle crashes involved 33,191 ± 7,815 occupants with concussion, 5,665 ± 996 with AIS 4+ head injuries, 986 ± 446 with DAI, and 3,300 ± 531 with skull fracture annually. The risk was 1.64 ± 0.39% for concussion, 0.28 ± 0.05% for severe head injury (AIS 4+), 0.05 ± 0.02% for DAI, and 0.17 ± 0.05% for skull fracture in tow-away crashes. The risk for severe head injury (AIS 4+) was highest in rollovers (0.74 ± 0.16%) and lowest in rear impacts (0.17 ± 0.05%). Head injury risk depended on seat belt use, crash type, and crash severity (delta V). Seat belt use lowered the risk for AIS 4+ head injury by 74.8% and skull fracture by 73.2%.

Conclusions: Concussions occur in about one out of 61 occupants in tow-away crashes. The risk was highest in rollover crashes (4.73 ± 1.09%) and it was reduced 69.2% by seat belt use. Severe brain injuries occurred less often and the risk was also reduced by seat belt use.

Keywords: head injury, concussion, DAI, seat belts, restraint effectiveness, motor vehicle crashes

Introduction

A number of studies have been published using NASS-CDS data to look at head injuries. Pintar et al. (2000) found that brain injuries and skull fractures were prevented by the use of seat belts and that airbags had their greatest effect in 16–45 kph delta V crashes. Mallory (2010) found that bleeding in the brain increased with age for 50- to 70+-year-old occupants compared to younger occupants. Talmor et al. (2006) found that head injury risks increased with crash severity in terms of delta V. Parenteau and Viano (2014) found higher risks for serious head injury than spine injury, irrespective of crash type. The relative risk for severe head to spine injury was 27.2 in side impacts, 14.1 in frontal impacts, 8.9 in rollovers, and 3.7 in rear impacts. For unbelted occupants, the relative risk was 18.5 in side impacts, 14.0 in rollovers, 12.9 in rear impacts, and 10.9 in frontal impacts.

Yoganandan et al. (2011) found an increase in head injury risk of 4% per unit increase in crash severity in side impacts. Griffin et al. (2012) found that side airbags reduced the risk for serious head injury by 30%. This extended the earlier work by McCartt and Kyrychenko (2007), who found that side airbags substantially reduced the risk of car and SUV driver death in driver-side collisions. In passenger cars, the risk for death in driver-side collisions was reduced by 37% for head-protecting airbags and 26% for torso-only side airbags. Other studies have improved the understanding of side airbag effectiveness (D’Elia et al. 2013; Sunnevang et al. 2009). Mattos et al. (2013) found that 21% of seriously injured occupants had head injuries and that the risk for head injury was not related to the extent of roof crush greater than 15 cm in rollovers. Cox et al. (2004) studied the effectiveness of seat belts in preventing maxillofacial trauma. Duma and Jernigan (2003) studied the effects of airbags on orbital fractures in frontal crashes. Huber et al. (2005) studied the influence of airbags on the incidence of facial injuries.

There are a number of studies on the effectiveness of lap–shoulder belts in preventing serious and fatal injury. Levine and Campbell (1971) studied 1966–1968 data and found that seat belts reduced the risk of serious injury by 43% in high-speed frontal crashes and by 37% in all frontals.
They found lower risks of serious injury in side impacts (right side 22% and left side 26%) and rear crashes (57%) with seat belt use. In 1984, the NHTSA estimated the effectiveness of seat belt was 45% in reducing fatality risks (Kahane 1984). Later, Kahane (2000) used the double pair analysis method and 1986–1999 Fatality Analysis Reporting System. He found a 45% reduction in fatality risk with seat belt use in passenger cars and 60% reduction in light trucks. The effectiveness of seat belts in preventing various head injuries has not been reported.

This study used NASS-CDS data on field accidents investigated by the NHTSA to estimate the annual incidence of concussion, diffuse axonal injury (DAI), severe head injury (Abbreviated Injury Scale [AIS] 4+) and skull fracture by crash type (front, side, rear, and rollovers), severity (delta V), and seat belt use. This fills a gap in information in the published literature.

Methodology

### NASS-CDS Data

NASS-CDS is a stratified sample of crashes that are prospectively selected for in-depth investigation. Most of the vehicles are towed from the scene because of damage. The data includes information based on crash investigation teams, vehicle registration, medical records, the police report, and interviews. The data were extrapolated to national estimates using weighting factors. In this study, NASS-CDS data for calendar years 1994–2011 were used to study head injuries in nonejected occupants by crash type and belt use. This study included all crashes and occupants aged 13–104 years old. Only light vehicles with model year 1994–2011 were included in the study. The data for calendar years 2009–2011 are representative of model year 2000+ vehicles.

### Crash Types

Crash types were defined as follows:

- **Front:** Vehicles involved in frontal impacts where the greatest damage was to the front (general area of damage in the front, GAD1 = F). Collisions in which a rollover occurred were excluded from the sample (rollover \( \leq 0 \)).
- **Side:** Vehicles involved in side impacts where the greatest damage was to the left or right side (GAD1 = L or R). Collisions in which a rollover occurred were excluded from the sample (rollover \( \leq 0 \)).
- **Rear:** Vehicles involved in rear impacts where the greatest damage was to the rear (GAD1 = B). Collisions in which a rollover occurred were excluded from the sample (rollover \( \leq 0 \)).
- **Rollover:** Vehicles involved in rollover were those with a rollover \( > 0 \).
- **Other:** Vehicles involved in other impacts where the greatest damage was to the top or undercarriage (GAD1 = U or T). Collisions in which a rollover occurred were excluded from the sample (rollover \( \leq 0 \)).
- **Unknown:** Vehicles involved in impacts with unknown damage information.

### Belt Use

Belt use was defined by the NASS-CDS investigator’s variables MANUSE (manual belt use) and ABELTUSE (automatic belt use). Unbelted was defined as MANUSE \( \leq 1 \) and ABELTUSE \( < 1 \) or \( = 2 \). Belted was defined as MANUSE \( = 4 \).

### Injury Severity

Injury severity of the occupant was assessed using the Maximum Abbreviated Injury Scale (MAIS) and the “TREATMNT” variable. MAIS represents the assessment of life-threatening injuries at the time of first medical evaluation and not long-term consequences. It ranges from MAIS 0 to 9, where MAIS 9 is an injury with unknown severity. MAIS 4–6 represents a severe-to-unsurvivable injury. Fatality was also used to determine whether the occupant died of injuries in the accident. The variable “TREATMNT” was used to define fatality, which is TREATMNT \( = 1 \). Because fatalities can occur at any MAIS level, severely injured occupants were defined as those with MAIS 4–6 or fatality. The shorthand notation for this is MAIS 4+F.

Head injuries were classified as concussion, DAI, severe head injury (AIS 4+), and skull fracture:

- **Concussion** was classified as moderate-to-serious injury (AIS 2–3) to the brain (region90 = 1 [head], struspec in \([0, 2, 4, 6, 8, 10]\) and strutype = 6).
- **DAI** was classified as severe-to-critical injury (AIS 4–5) to brain (region90 = 1 [head], struspec in \([0, 2, 4, 6, 8, 10]\) and strutype = 6).
- **AIS 4+ head injury** was classified as severe-to-critical injury (AIS 4–5) to the head (region90 = 1 [head]).
- **Skull fracture** was typically classified as moderate-to-maximum injury (AIS 2+) to skull (region90 = 1 [head], struspec in \([0, 2, 4]\) and strutype = 5 [skeletal]).

NASS-CDS cases involve as many as 15 injuries identified for an occupant that are classified by type, injury severity, and source. In some cases, an occupant can have more than one AIS 4+ head injury. The total number of head injuries was determined as well as the number of occupants with a particular type of head injury.

### Weighted Data

National estimates for the number of occupants and injuries in each category were made using the ratio weight (ratwgt) variable in NASS-CDS. All calculations were based on weighted values. Standard errors (SE) were determined using the SAS procedure “SURVEYFREQ,” accounting for PSU (psustrat) and ratio weight (ratwgt), and are shown as \( \pm \) in the text representing plus and minus one standard error.

### Analyses

- The risk that an occupant experiences head injury was determined by dividing the number of occupants with a
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Table 1. Incidence of head injuries per year, risk, and rate by crash type based on 18 years of weighted NASS-CDS (1994–2011)

| Crash Type | Front | Side | Rear | Rollover | All |
|------------|-------|------|------|----------|-----|
| Occupants  |       |      |      |          |     |
| All        | 917,778 | 404,854 | 136,112 | 158,925 | 2,124,817 |
| MAIS 0+F   | 888,539 | 389,832 | 129,755 | 150,688 | 2,022,762 |
| MAIS unk   | 28,980  | 15,022  | 6,357  | 8,237   | 101,796 |
| MAIS 0     | 495,687 | 220,457 | 72,746 | 59,443 | 1,186,540 |
| MAIS 1–2   | 13,753  | 5,694   | 222    | 4,185   | 26,672 |
| MAIS 3     | 4,842   | 4,715   | 365    | 2,928   | 14,672 |
| MAIS 4+    | 1,530   | 2,121   | 217    | 1,112   | 5,665 |
| With concussion | 14,017 | 6,656   | 1,731   | 7,125   | 33,191 |
| With DAI   | 196     | 381     | 35     | 262     | 986 |
| With skull fracture | 1,128 | 934     | 78     | 687     | 3,300 |
| Risk per MAIS 0+F |       |      |      |          |     |
| MAIS 4+    | 0.54%  | 1.21%  | 0.28% | 1.94%   | 0.73% |
| AIS 4+ head injury | 0.17% | 0.54%  | 0.17% | 0.74%   | 0.28% |
| Concussion | 1.58%  | 1.71%  | 1.33% | 4.73%   | 1.64% |
| DAI        | 0.022% | 0.098% | 0.027%| 0.174%  | 0.0409% |
| Skull fracture | 0.127% | 0.245% | 0.060%| 0.456%  | 0.163% |
| Injuries   |       |      |      |          |     |
| All head injuries | 67,788 | 55,358 | 12,708 | 46,597 | 206,369 |
| AIS Unk    | 1,255  | 421    | 209   | 326     | 2,912 |
| AIS 1      | 45,497 | 39,066 | 9,883 | 34,136 | 145,029 |
| AIS 2      | 14,431 | 7,173  | 1,815 | 7,977 | 35,134 |
| AIS 3      | 4,087  | 4,871  | 446   | 2,281   | 13,367 |
| AIS 4+     | 2,519  | 3,826  | 355   | 1,876   | 9,927 |
| Concussion | 14,017 | 6,656 | 1,731 | 7,125 | 33,191 |
| DAI        | 196    | 381    | 35    | 262     | 986 |
| Skull fracture | 1,128 | 934    | 78    | 687     | 3,300 |
| Rate per MAIS 0+F |       |      |      |          |     |
| AIS 4+ head injury | 0.284% | 0.982% | 0.274% | 1.25% | 0.491% |
| Concussion | 1.58%  | 1.71%  | 1.33% | 4.73%   | 1.64% |
| DAI        | 0.022% | 0.098% | 0.027%| 0.174%  | 0.0409% |
| Skull fracture | 0.154% | 0.367% | 0.060%| 0.62%   | 0.219% |

Concussion (region90 = 1 and (2 < = ais < 4) and strus = 6 and struspec in (0. 2,4,6,8,10)).
DAI (region90 = 1 and (4 < = ais < 6) and strus = 6 and struspec in (2,8)).
Skull fracture (region90 = 1 and (2 < = ais < 7) and strus = 5 and struspec in (0,2,4)).

particular head injury by the number of occupants with known injury status, MAIS 0–6 or F (MAIS 0+F). This gives the risk that an occupant experiences injury, such as concussion, AIS 4+ head injury, DAI, or skull fracture.

- The rate of head injuries was determined by dividing the number of a particular type of head injury by the number of occupants with known injury status, MAIS 0–6 or F (MAIS 0+F).

Occupants with unknown injury were removed from the exposure group used to determine rate.

Results

Table 1 shows the annual incidence of motor vehicle injury by crash type based on 18 years of NASS-CDS data from 1994 to 2011. For completeness, the table is provided in the Appendix as Table A1 (see online supplement) with the standard errors included. There were 2,124,817 occupants exposed to tow-away crash per year. The risk for severe-to-fatal injury (MAIS 4+ F) was 0.73 ± 0.14% (the standard errors are provided in the Appendix). There were 13,367 AIS 3 and 9,927 AIS 4+ head injuries. More specific to brain injury, there were 33,191 ± 7,815 occupants with concussion (AIS 2–3), 5,665 ± 996 with AIS 4+ head injury, and 986 ± 446 with DAI. There are 3,300 ± 531 occupants with skull fracture.

The risk was 1.64 ± 0.39% for concussion, 0.28 ± 0.05% for severe head injury (AIS 4+), 0.05 ± 0.02% for DAI, and 0.16 ± 0.03% for skull fracture in tow-away crashes. The risk for severe head injury (AIS 4+) was highest in rollovers (0.74 ± 0.16%) and lowest in rear impacts (0.17 ± 0.05%). Head injury risk depended on seat belt use, crash type, and crash severity (delta f). Seat belt use lowered the risk for AIS 4+ head injury by 74.8% and skull fracture by 73.2%.

The rate of head injury was highest in rollover crashes. The rate for concussion was 4.73 ± 1.09%, the rate for AIS 4+ head injury was 1.25 ± 0.32%, and skull fracture was 0.62 ± 0.14% in rollovers. The largest number of concussions occurred in frontal crashes (14,017 ± 4,538), whereas the largest number of AIS 4+ head injuries was in side impacts (3,826 ± 743). The lowest rates were in rear impacts with 0.274 ± 0.102% for AIS 4+ head injury and 0.069 ± 0.027% for skull fracture. DAI occurred in 35 ± 19 occupants annually in rear crashes compared to 381 ± 137 in side impacts.
Table 2. Head injury risks by belt use and crash type per year based on 18 years of NASS-CDS (1994–2011)

| Occupants | Crash Type | Front | Side | Rear | Rollover | All |
|-----------|------------|-------|------|------|----------|-----|
| Belted    | MAIS 0+4F  | 718,889  | 335,979  | 114,462  | 119,647  | 1,529,424 |
|           | Concussion  | 2,107  | 2,604  | 170  | 1,449  | 6,912  |
|           | AIS 4+ head | 6,532  | 4,668  | 1,220  | 4,098  | 17,664 |
|           | DAI        | 741  | 1,101  | 102  | 493  | 2,690 |
|           | Skull fracture  | 41  | 171  | 22  | 71  | 324  |
| Risk for belted | MAIS 4+4F  | 0.293%  | 0.775%  | 0.149%  | 0.452%  | 0.423% |
|           | Concussion  | 0.909%  | 1.389%  | 0.106%  | 3.425%  | 1.155% |
|           | AIS 4+ head injury  | 0.103%  | 0.328%  | 0.089%  | 0.412%  | 0.176% |
|           | DAI        | 0.006%  | 0.051%  | 0.019%  | 0.059%  | 0.021% |
|           | Skull fracture  | 0.076%  | 0.148%  | 0.045%  | 0.308%  | 0.106% |
| Unbelted  | MAIS 0+4F  | 127,792  | 41,992  | 10,365  | 1,399  | 407,701 |
|           | Concussion  | 2,544  | 1,938  | 183  | 2,948  | 7,230 |
|           | AIS 4+ head injury  | 4,397  | 1,827  | 110  | 566  | 2,848 |
|           | DAI        | 757  | 967  | 478  | 566  | 653  |
|           | Skull fracture  | 152  | 205  | 13  | 21  | 162  |
| Risk for unbelted | MAIS 4+4F  | 1.99%  | 4.61%  | 1.77%  | 5.28%  | 1.77% |
|           | Concussion  | 3.44%  | 4.35%  | 4.61%  | 11.12% | 2.87% |
|           | AIS 4+ head injury  | 0.59%  | 2.30%  | 1.06%  | 2.27%  | 0.70% |
|           | DAI        | 0.119%  | 0.488%  | 0.129%  | 0.718%  | 0.160% |
|           | Skull fracture  | 0.443%  | 1.044%  | 0.201%  | 1.089%  | 0.395% |
| Belt effectiveness | MAIS 4+4F  | 85.3%  | 83.2%  | 91.6%  | 77.1%  | 74.5% |
|           | Concussion  | 73.6%  | 68.1%  | 76.9%  | 69.2%  | 59.8% |
|           | AIS 4+ head injury  | 82.6%  | 85.8%  | 91.6%  | 81.9%  | 74.8% |
|           | DAI        | 95.3%  | 89.6%  | 85.0%  | 91.7%  | 86.8% |
|           | Skull fracture  | 82.8%  | 85.8%  | 77.6%  | 71.7%  | 73.2% |

Table 2 gives the risk for head injury by seat belt use and crash type. For completeness, the table is provided in the Appendix as Table A2 (see online supplement) with the standard errors included. The number of belted occupants is given above the rates for head injury and the effectiveness of seat belt use is given at the bottom. Belt use was effective in preventing all types of brain injury, irrespective of the crash type. Seat belt use was most effective in preventing DAI at 86.8% with a 0.160 ± 0.087% risk when unbelted and 0.021 ± 0.006% when restrained. Seat belt use was least effective in preventing concussions, although the reduction in risk was high at 59.8% (2.870 ± 0.613% unbelted vs. 1.155 ± 0.219% belted). The highest effectiveness of seat belt use was preventing DAI in front (95.3%) and rollover (91.7%) crashes and AIS 4+ head injury (91.6%) and DAI (91.6%) in rear impacts.

The overall use of seat belts was 79% (1,529,424 belted and 407,701 unbelted) for the 18 years of NASS-CDS data from 1994 to 2011. The rate of seat belt use risk was higher for each of the 4 crash types listed (82% in rollovers and 92% in rear crashes), because seat belt use was lower in crashes of unknown type.

Figure 1 shows the risk for head injury by crash severity in terms of delta $V$. Four different head injury risks are shown. Concordence can occur in lower speed crashes and the risk increased with crash severity to a risk over 10% in crashes above 55 km/h (34 mph) delta $V$. More severe brain injuries and skull fracture are infrequent until crashes above 40 km/h (25 mph). The overall risk for severe-to-fatal injury (MAIS 4+4F) is also shown. This is the maximum injury severity, irrespective of the body region. The drop in risk for DAI at the higher speeds is based on only a few cases and is not a reliable trend.
Table 3. Injuries per year, rates and risks by crash severity based on 18 years of NASS-CDS (1994–2011)

| Occupants with | AIS 4+ head | Concussion | DAI | Skull fracture |
|----------------|-------------|------------|-----|---------------|
| AIS 4+         | 0.048%      | 0.050%     | 0.015% | 0.048%       |
| Concussion     | 0.048%      | 0.050%     | 0.015% | 0.048%       |
| DAI            | 0.048%      | 0.050%     | 0.015% | 0.048%       |
| Skull fracture | 0.048%      | 0.050%     | 0.015% | 0.048%       |

The prevention of concussion in motor vehicle crashes is less well understood. Figure 1 shows the risk increased to 3% at 40 km/h delta V and steadily climbed in higher severity crashes. The current head injury tolerance of HIC_{15} = 700 and HIC_{36} = 1,000 is the threshold for serious brain injury and skull fracture (Eppinger et al. 2000). NHTSA does not have a tolerance criterion for concussion, which would need to be evaluated over a range of crash severities, including low-severity crashes.

Table 1 shows that the highest risk for severe brain injury (AIS 4+) was in rollovers (0.74 ± 0.16%) and side impacts (0.54 ± 0.11%). Similarly, the highest risk for skull fracture was in rollovers (0.456 ± 0.099%) and side impacts (0.245 ± 0.044%). Over the past years, modern vehicles have included side airbags in the seat and side curtains that deploy from the roof rail in side impacts and rollovers. These technologies have
proven effectiveness in lowering the risks for head injury and fatality.

McCartt and Kyrychenko (2007) conducted the first definitive study on side airbag effectiveness. They found that side airbags substantially reduced the risk of driver death in nearside collisions involving cars and SUVs. In passenger cars, the risk for death in driver-side crashes was reduced by 37% for head-protecting airbags and 26% for torso-only side airbags. The study by McCartt and Kyrychenko (2007) reversed an earlier finding. McGwin et al. (2003) estimated the effectiveness of side airbags in lowering the risk for injury. They found no change with side airbags based on limited data and wide variations in the estimated risks. Sunnevang et al. (2009) extended the previous work by considering the effects of crash severity and occupant age. They found that side airbags provided good protection for non-senior occupants up to 40 km/h delta V crashes.

Griffin et al. (2012) found that side airbags protect occupants from head injury but that the protective effect for thoracic injury was limited. D’Elia et al. (2013) found that side airbags were effective in reducing driver injury and death in near-side crashes. There was a 41.1% (25.9%, 53.2%) reduction in the odds of death or injury across all body regions and a 48.0% (28.0%, 62.4%) reduction in the odds of death or injury to the head, neck, face, chest, and abdomen.

Table 2 shows that seat belt use is effective in reducing the risk for all types of head injuries in all types of crashes. Seat belt use lowers the risks for DAI, AIS 4+ head injury, skull fracture, and concussion. The reduction in risk for skull fracture result is contrary to the findings of Pintar et al. (2000). They found that skull fractures were unaffected by the presence of a restraint system in frontal crashes.

Table 2 shows that seat belts are least effective in preventing concussions in rollovers (69.2%) and most effective in preventing DAI in frontal crashes (95.3%). These findings are consistent with those of numerous studies that have shown the effectiveness of lap-shoulder belts in preventing serious and fatal injury, although these studies did not specifically address various types and severities of head injury (Kahane 1984, 2000; Levine and Campbell 1971).

The seat belts in modern vehicles include a number of features that improve occupant restraint in a crash. These include pretensioning the webbing to take slack out of the system and load-limiting the shoulder belt to lower risks of chest injury in older occupants. However, the benefit to older occupants may expose others to serious head injuries in some frontal crashes because of increased excursion (Brumbelow et al. 2007). Modern seat belts also include adjustability of the shoulder belt to improve comfort and fit by changing the height of D-ring anchor. Most restraints now have lap belt anchors attached to the adjustable upper track on the seat, so the anchors move with the seat position. Certainly, further advances in the seat belt are under investigation to improve retention of the occupant in the lap belt and control excursion of the upper body in a range of real-world crashes.

Table 2 also shows that head injury risks in frontal crashes are lower than in side impacts and rollovers. Since the mid-1990s, vehicles have been equipped with airbags. Viano and Parenteau (2010) studied frontal crashes in NASS-CDS by increasing delta V. They found that the airbags deployed in 34–38% of the <16 km/h (<10 mph) and 16–24 km/h (10–15 mph) crashes and the rate of deployment increased to 77–99% for higher severity crashes. Though this study did not specifically segregate the crash data by airbag deployment, the frontal crashes should be assumed to involve vehicles equipped with airbags and that the occupant either was using or was not using the available lap-shoulder belt. Because vehicles with 1994+ model year were included.

Limitations

This was a descriptive study that looked at various types of head injury by crash type, seat belt use, and crash severity. There are a number of limitations to the scope of this work. A number of variables are known to influence head injuries that were not addressed in this analysis. For example, Tagliaferri et al. (2009) found a significant increase in fatality risk with obesity. Funk et al. (2012) found an increase in fatality risk with increasing body mass index (BMI), lack of seat belt use, and older aged occupants. Pal et al. (2014) found that BMI did not influence the risk for head injury, although the height of the occupant was a factor. Bose et al. (2011) analyzed injury data for comparable crashes and reported that the odds for severe injury were 47% higher in lap-shoulder-belted female drivers than belted male drivers. The influence of occupant gender and anthropometry was beyond the scope of this study but these are recognized as influencing factors.

Only 1994+ model year vehicles were included in this study to ensure that frontal airbags were in the fleet. Over time, vehicles have been fit with side airbags and curtains, and the sophistication of the seat belts has increased. Field data have shown that front airbags, side airbags, and side curtains are effective in lowering the risk of head injuries and fatality (Duma and Jernigan 2003; Huber et al. 2005; McCartt and Kyrychenko 2007; McGwin et al. 2003). This study evaluated head injuries in vehicles equipped with safety systems irrespective of airbag deployments in the crash or activation of components in the seat belt system. The effectiveness of these technologies deserves separate evaluation and was beyond the scope of this study.

Supplemental Materials

Supplemental data for this article can be accessed on the publisher’s website.

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