Efficacy of Side Air Bags in Reducing Driver Deaths in Driver-Side Collisions

Elisa R. Braver1,2 and Sergey Y. Kyrychenko1

1 Insurance Institute for Highway Safety, Arlington, VA.
2 Current address: National Study Center for Trauma and Emergency Medical Services, University of Maryland School of Medicine, Baltimore, MD.

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Side air bags, a relatively new technology designed to protect the head and/or torso in side-impact collisions, are becoming increasingly common in automobiles. Their efficacy in preventing US driver deaths among cars struck on the near (driver’s) side was examined using data from the Fatality Analysis Reporting System and the General Estimates System. Risk ratios for driver death per nearside collision during 1999–2001 were computed for head/torso and torso-only side air bags in cars from model years 1997–2002, relative to cars without side air bags. Confounding was addressed by adjusting nearside risk ratios for front- and rear-impact mortality, which is unaffected by side air bags. Risk ratios were 0.55 (95% confidence interval: 0.43, 0.71) for head/torso air bags and 0.89 (95% confidence interval: 0.79, 1.01) for torso-only air bags. Risk was reduced when cars with head/torso air bags were struck by cars/minivans (significant) or pickup trucks/sport utility vehicles (nonsignificant). Risk was reduced in two-vehicle collisions and among male drivers and drivers aged 16–64 years. Protective effects associated with torso-only air bags were observed in single-vehicle crashes and among male and 16- to 64-year-old drivers. Head/torso side air bags appear to be very effective in reducing nearside driver deaths, whereas torso-only air bags appear less protective.

Accidents, traffic; air bags; automobiles; mortality; safety; vehicles

Abbreviations: CI, confidence interval; FARS, Fatality Analysis Reporting System; GES, General Estimates System; RR, risk ratio; SUV, sport utility vehicle; VIN, Vehicle Identification Number.

Side-impact collisions pose higher risks to occupants of passenger vehicles than do collisions involving impacts to vehicles’ fronts or rears, because the sides of passenger vehicles have a limited ability to crumple and absorb energy in collisions (1). Each year, 3.18 million US passenger vehicles are involved in police-reported crashes in which they are struck on the side; these crashes result in approximately 9,400 deaths—about 30 percent of all passenger vehicle occupant deaths (2, 3).

The occupants at highest risk of serious injury, usually injury to the chest and head, in side-impact collisions are those seated on the side struck (4–7). An estimated 40–75 percent of passenger vehicle occupant deaths in side-impact crashes result from head injuries (8). Passenger vehicle occupants struck in the side by another vehicle are more likely to sustain serious injuries when the striking vehicle is a pickup truck or sport utility vehicle (SUV) than when it is a car (4, 5). Pickups and SUVs cause more fatalities because of their higher average weight and because their higher front-end geometry increases the risk of direct head strikes and other injuries among occupants of struck vehicles (9, 10).

To reduce the risks to occupants of vehicles struck on the side, side air bags designed to protect the torso (chest and abdomen) were introduced by Volvo (Volvo Car Corporation, Gothenburg, Sweden) in model year 1995 (11). Torso-protection side air bags, mounted in doors or seats, are designed to attenuate and distribute forces on the chest and abdomen from the intruding vehicle side (12). Side air bags designed to protect the head were introduced by BMW (BMW AG, Munich, Germany) in model year 1998, and more than 90 percent of makes and models offering head-protection side air bags also include torso protection (12). Head-protection side air bags are designed to keep an occu-
pant’s head from striking interior vehicle structures or being struck by external objects intruding into the vehicle (13).

Crash tests have suggested that both head-protection side air bags and torso-only side air bags should be beneficial to vehicle occupants, yet crash test ratings are not always improved by the addition of either torso-only or combined head/torso-protection side air bags (5, 6, 8, 14–16). Whether side air bags are beneficial in real-world crashes has not been established by prior research. One German study reported that injured automobile occupants with torso-only side air bags had lower proportions of moderate to severe injuries to the thorax and head; however, the report did not indicate whether injury incidence was reduced (17). Another study reported that side air bags failed to reduce injury risk in near-side crashes, but it classified all vehicle models offering optional side air bags as having side air bags, made no distinction between side air bags with head protection and those without head protection, and derived injury severity data from a source that often misclassifies minor injuries as serious injuries (18).

The purpose of the present study was to evaluate the real-world performance of vehicles equipped with side air bags to determine whether they reduce mortality among US drivers in vehicles struck on the left (driver’s) side. Side air bags are becoming increasingly common: In 2003, more than one third of all new vehicles sold in the United States had side air bags, most of which were designed primarily for torso protection (19). Side air bags are being considered as one countermeasure to the problem of geometric incompatibility between passenger cars and SUVs/pickup trucks. Determining whether side air bags work as intended is important for future decisions concerning vehicle design.

MATERIALS AND METHODS

Mortality during 1999–2001 was studied among drivers of passenger cars for model years 1997–2002. Pickup trucks were excluded, because they were rarely equipped with side air bags during these model years (5). Minivans and SUVs with side air bags could not be studied, because the numbers of crashes involving these vehicles in government crash databases were too low.

The measure studied was risk of death per side-impact collision among passenger car drivers involved in police-reported crashes during 1999–2001. The Fatality Analysis Reporting System (FARS), a census of fatal collisions on US public roads in which a death occurs within 30 days of the crash, was the source for data on driver deaths (20). The General Estimates System (GES), a national sample of US police-reported crashes, was the source for data on drivers involved in police-reported crashes (21). For generation of national estimates, the 55,000 annual crashes (raw counts) included in GES are weighted according to their probability of selection for the stratified national sample.

A vehicle-features database maintained by the Highway Loss Data Institute (Arlington, Virginia) was used to compile a list of 1997–2002 model year vehicles with standard or optional side air bags. The list indicates vehicle make and model, model year, the standard or optional status of side air bags, and whether the side air bag systems are designed to protect the head, the torso, or both. Manufacturers assign each vehicle a 17-digit vehicle identification number (VIN), the last five digits of which are unique to the vehicle. To preserve driver privacy, FARS provides only the first 12 digits, and GES provides only the first 11. These partial VINS usually indicate whether the vehicles are equipped with side air bags (standard or optional), but some vehicles’ VIN codes do not indicate the presence of optional side air bags. After such vehicles had been identified in the FARS and GES databases, the National Highway Traffic Safety Administration sent their full 17-digit VINS to the manufacturers, who supplied the agency with information about side air bag presence and type of side air bag. This information was then transmitted to us by the National Highway Traffic Safety Administration.

The comparison group of vehicles consisted of model year 1997–2002 cars without side air bags that were involved in police-reported crashes. These included vehicles for which side air bags had been an option that was not chosen by buyers and vehicles for which side air bags were unavailable.

Statistical analysis

Risk ratios and 95 percent confidence intervals were calculated for nearside death (from FARS) among passenger car drivers involved in police-reported crashes (from GES) by side air bag status. Separate risk ratios were calculated for side air bags that included head protection and side air bags designed to protect mainly the torso. These ratios were stratified according to crash, vehicle, and driver characteristics. Analyses were carried out using Microsoft Excel, SUDAAN, and SAS software (22–24).

Risk ratios were computed as follows. 1) Expected number of nearside deaths in cars with side air bags = (number of nearside deaths with no side air bags × number of drivers involved in nearside collisions with no side air bags) × number of drivers involved in nearside crashes of cars with side air bags. 2) Crude risk ratio for nearside deaths in cars with side air bags = observed number of nearside deaths in cars with side air bags ÷ expected number of nearside deaths.

Because cars with side air bags are more costly, their drivers are probably of higher socioeconomic status, which has an inverse relation with motor vehicle-related fatality risk (25, 26). Thus, drivers with side air bags may differ systematically from the general population of drivers in having a lower likelihood of fatal outcomes in collisions in which they are involved, irrespective of the presence of side air bags. Speed of travel, especially in single-vehicle crashes, seat-belt use, percentage of travel on different types of roads (including urban, rural, and suburban roads), and occupant compartment safety design are some potentially confounding factors that may be influenced by socioeconomic status. We examined the mortality experience of drivers in vehicles with and without side air bags in front- and rear-impact collisions (collisions in which side air bags should have no effect). To address a wide range of confounding factors, we then adjusted risk ratios for nearside collisions for the combined front- and rear-impact mortality experience among vehicles with side air bags relative to...
those without side air bags by dividing the crude risk ratios for nearside collisions by the crude risk ratios for front/rear collisions. Both crude and adjusted risk ratios are reported so that the effects of adjustment can be discerned. Formulae for calculation of adjusted risk ratios and their 95 percent confidence intervals are shown in the Appendix.

Using FARS, nearside collisions were defined as crashes with initial impacts at the 8 o’clock, 9 o’clock, and 10 o’clock points (the left side of the occupant compartment), and front and rear collisions were defined as crashes with initial impact points at 12 o’clock and 6 o’clock (see figure 1). The clock points 1, 5, 7, and 11 were excluded from the group of front and rear collisions because of the small possibility that side air bags could deploy after impacts in these positions. The GES coding system is different from that of FARS; initial points of impact on the near side were those labeled “left side” in the GES database, and front and rear collisions were those labeled “front” and “back.” As in FARS, impacts to the right and left corners of the vehicle in the front and back were excluded from the definition of front/rear collisions in GES.

**RESULTS**

In estimated police-reported crashes involving drivers struck on the left (driver’s) side during 1999–2001, a total of 35 nearside driver deaths occurred in passenger cars with side air bags designed to protect the head, and 105 deaths occurred in cars with torso-only side air bags (table 1). Approximately 99 percent of cars with head-protection side air bags included in the study also had torso protection. Figure 2 shows rates of passenger-car driver death per 100,000 drivers in crashes occurring during 1999–2001 for impact points on the near (driver’s) side and in the front/rear, according to whether side air bags were optional or standard equipment and according to the type of side air bag. The lowest nearside driver death rates were observed among cars with head-protection side air bags, and the next lowest nearside driver death rates were observed in cars with torso-only side air bags. Cars with no side air bags available had the highest rates of driver death for both nearside and front/rear impact points. For both nearside and front/rear impact points, driver death rates in cars where optional air bags were absent were much lower than in cars that did not have side air bags offered as standard or optional equipment, indicating the presence of factors confounding the relation between side air bags and driver fatality risk.

**Side air bags with head-protection systems**

Risk of driver death in a nearside impact was significantly reduced in passenger cars that had side air bags with head protection (adjusted risk ratio (RR) = 0.55, 95 percent confidence interval (CI): 0.43, 0.71) (table 2). In cars with head-protection air bags, significant reductions in risk were observed among male drivers, drivers aged 16–64 years, and cars with four doors. Reductions in risk among female drivers were similar to those of male drivers; reductions among drivers aged 65 years or more were similar to those of drivers aged 16–64 years. The low numbers of deaths among females and drivers aged 65 years or more led to wide confidence intervals that included 1.0.

Significant protective effects were also observed among the smallest and largest cars equipped with head-protection systems.

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<table>
<thead>
<tr>
<th>Side air bag status</th>
<th>No. of driver deaths</th>
<th>No. of drivers involved in crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Near side</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weighted†</td>
</tr>
<tr>
<td>Side air bags with head protection</td>
<td>35</td>
<td>108</td>
</tr>
<tr>
<td>Torso-only side air bags</td>
<td>105</td>
<td>208</td>
</tr>
<tr>
<td>No side air bags</td>
<td>1,800</td>
<td>3,044</td>
</tr>
</tbody>
</table>

* The near side (driver’s side) is defined as clock positions 8, 9, and 10 in the Fatality Analysis Reporting System and the left side in the General Estimates System. Front/rear impacts are defined as impacts in clock positions 12 and 6 in the Fatality Analysis Reporting System and the front and back in the General Estimates System.

† National estimates were derived by weighting raw counts of drivers in the sample according to the probability of selection of crashes for the stratified national sample.

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side air bags. The adjusted risk ratio showed no reduction in risk for midsize cars, though the crude risk ratio suggested comparable decreases in risk by car size. Among drivers of cars with head-protection side air bags, there was a significant decrease in nearside fatality risk in two-vehicle side-impact crashes and a nonsignificant decrease in risk in single-vehicle nearside crashes. Head-protection side air bags afforded a large degree of protection in two-vehicle crashes in which the other vehicle (the “crash partner”) striking the car on the driver’s side was a passenger car/minivan (adjusted RR = 0.26, 95 percent CI: 0.11, 0.64). Reduced risk of driver death, albeit nonsignificant, was also observed when cars’ crash partners were pickups or SUVs. Risk reductions were observed regardless of whether the crash partners that were passenger vehicles weighed less than 3,800 pounds (<1,724 kg) (significant) or 3,800 pounds or more (≥1,724 kg) (nonsignificant). A large percentage of driver deaths in cars with head-protection side air bags occurred in two-vehicle collisions in which the crash partner was a large commercial vehicle, and these side air bags did not increase protection in such crashes.

**Torso-only side air bags**

For passenger cars, torso-only side air bags were associated with a nearly significant reduction in driver death rates in nearside crashes (adjusted RR = 0.89, 95 percent CI: 0.79, 1.01) (table 2). Greater risk reductions occurred in single-vehicle crashes. Decreased risk, though not statistically significant, appeared to be present among cars of all sizes and among both two-door and four-door cars.

Male drivers and drivers aged 16–64 years had significant reductions in nearside mortality risk. Adjusted risk ratios for female drivers and drivers aged 65 years or more showed no benefits from such air bags; however, the ability to detect decreases in risk was less than optimal for females and drivers aged 65 years or more. Additional analyses stratified by age and gender (not shown in table) suggested that females aged 65 years or more had an increase in nearside mortality associated with torso-only side air bags (adjusted RR = 2.16, 95 percent CI: 1.08, 4.33).

On the basis of adjusted risk ratios, no protective effects of torso-only side air bags were observed in two-vehicle crashes. Neither did adjusted risk ratios indicate benefits when crash partners were cars/minivans or pickups/SUVs in two-vehicle side-impact crashes. In addition, the adjusted risk ratio suggested increased driver fatality risk when crash partners were passenger vehicles that weighed 3,800 pounds or more.

**Head-protection versus torso-only side air bags**

Head-protection side air bags were significantly more effective than torso-only side air bags in reducing nearside driver fatality risk overall and for various categories of vehicles and crash types (table 2). Direct comparisons are valid,
because the same control group (vehicles without side air bags) and the same adjustment methods were used to evaluate the two types of side air bag systems.

**DISCUSSION**

Side air bags designed to protect the head appear to be very effective in reducing mortality in nearside collisions among drivers of passenger cars. Air bags with head protection appeared to provide benefits for both male and female drivers and for both younger and older drivers, though the reductions observed among females and drivers aged 65 years or more were not statistically significant.

Because very few cars in our study (<1 percent) offered head protection without torso protection, it was not possible to identify the separate contributions of head and torso protection in vehicles with head-protection side air bags. However, the estimated risk reduction in nearside collisions for drivers of cars with torso-only side air bag systems was substantially lower, suggesting that the incremental benefit of head protection is considerable.

Large decreases in nearside fatality risk associated with head-protection side air bags were observed when crash partners were cars/minivans or SUVs/pickup trucks. This suggests that such air bags may be addressing some of the problems of incompatibility when passenger cars are struck on the side by vehicles with higher ride heights. These systems were not effective when cars were struck on the side by commercial vehicles with gross vehicle weight ratings in excess of 10,000 pounds (>4,536 kg) (primarily large trucks and buses). The most likely explanation is that head-protection air bags and other restraints cannot overcome extreme
weight mismatches, which often result in massive collapse of the occupant compartment in lighter vehicles.

The benefits of torso-only air bags appear less substantial, with the exception of single-vehicle nearside crashes. Moreover, torso-only air bags provided less uniform protection: Men and drivers younger than 65 years had clear risk reductions, but this was not true for female drivers or older drivers. Some findings hint that torso-only side air bags could be placing female drivers, particularly those aged 65 years or more, at increased risk in nearside crashes; however, more data are needed before such a conclusion can be drawn. There also was an indication that torso-only side air bags were ineffective in two-vehicle crashes.

Based on the patterns of death rates, using front/rear collisions to adjust nearside risk ratios provides a rational method for controlling some confounding factors associated with side air bags. Figure 2 indicated that the magnitude of the confounding for nearside driver death rates was similar for front/rear death rates. This method addressed both known and unknown factors because it was not confined to specific known confounders. However, it may not have been appropriate for all variables and may have resulted in incorrect upward or downward adjustment of the crude risk ratios. If automobile manufacturers who installed side air bags simultaneously introduced innovations that also improved frontal impact protection in vehicles with side air bags, then adjusting the crude nearside risk ratios for front/rear mortality may have led to underestimates of the true effectiveness of side air bags. When interpreting the findings of this study, both crude and adjusted risk ratios should be considered. The adjusted risk ratios differed greatly from the crude risk ratios for some variables, particularly for torso-only side air bags, for which crude risk ratios suggested decreases of approximately 30 percent in nearside driver

<table>
<thead>
<tr>
<th>Variable</th>
<th>No. of deaths</th>
<th>Risk ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed</td>
<td>Expected</td>
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<tr>
<td>Total no. of cars</td>
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<td>157</td>
</tr>
<tr>
<td>Crash type</td>
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<td></td>
</tr>
<tr>
<td>Single-vehicle</td>
<td>26</td>
<td>38</td>
</tr>
<tr>
<td>Two-vehicle</td>
<td>70</td>
<td>101</td>
</tr>
<tr>
<td>Crash partner vehicle type (two-vehicle crashes)</td>
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<td></td>
</tr>
<tr>
<td>Car/minivan</td>
<td>19</td>
<td>29</td>
</tr>
<tr>
<td>Sport utility vehicle/pickup truck</td>
<td>28</td>
<td>49</td>
</tr>
<tr>
<td>Large truck/bus</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>Other/unknown</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Passenger vehicle crash partner weight</td>
<td></td>
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</tr>
<tr>
<td>&lt;3,800 pounds (&lt;1,724 kg)</td>
<td>28</td>
<td>42</td>
</tr>
<tr>
<td>≥3,800 pounds (≥1,724 kg)</td>
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<td>31</td>
</tr>
<tr>
<td>Car size</td>
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<td></td>
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<tr>
<td>Mini/small</td>
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<td>42</td>
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<tr>
<td>Midsize</td>
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<td>60</td>
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<tr>
<td>Large/very large</td>
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<td>54</td>
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<tr>
<td>No. of doors</td>
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<tr>
<td>2</td>
<td>18</td>
<td>29</td>
</tr>
<tr>
<td>≥4</td>
<td>87</td>
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<tr>
<td>Driver gender</td>
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<tr>
<td>Male</td>
<td>58</td>
<td>90</td>
</tr>
<tr>
<td>Female</td>
<td>47</td>
<td>67</td>
</tr>
<tr>
<td>Driver age (years)</td>
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<td></td>
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<tr>
<td>16–64</td>
<td>59</td>
<td>104</td>
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<tr>
<td>≥65</td>
<td>46</td>
<td>76</td>
</tr>
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</table>

* The near side (driver’s side) was defined as clock points 8, 9, and 10 (see figure 1).
† RR, risk ratio; CI, confidence interval.
‡ Adjusted on the basis of the risk ratio for driver death in initial impacts that were front or rear.
fatality risk. Such differences occurred among midsize cars with head-protection side air bags, and among cars with torso-only side air bags they were present for two-vehicle crashes, crash partner passenger vehicles that weighed 3,800 pounds or more, female drivers (especially older females), and older drivers. For example, the aforementioned increase in risk among older female drivers differed greatly from the corresponding crude risk ratio, which estimated a 15 percent decrease in risk. The differences between crude and adjusted risk ratios reflected varying front/rear mortality experience for these variables. Perhaps the true effect of side air bags on fatality risk for struck-side drivers lies somewhere between the crude and adjusted risk ratios in these cases.

Other potential methods of adjusting for confounding were not reasonable. Using cars within the same cost class without side air bags as a reference group was not possible, because most cars in the high-end cost classes are equipped with side air bags. Using a comparison group composed solely of vehicles without side air bags for which the option of air bags was available was not feasible because of inadequate numbers in this group. Multivariate regression analyses would have been desirable, but such analyses could not be performed because of insufficient numbers, insufficient data on potentially confounding variables in FARS and GES, and the difficulties of combining two very different databases.

The most important limitation of this study is that side air bags, particularly those incorporating head-protection systems, are relatively new, so there have been few crashes and deaths involving cars with side air bags. Investigation of the effects of side air bags according to variables of interest was impeded by low statistical power. Age probably confounded the relation between vehicle size and driver mortality, because a higher proportion of older drivers, who are more vulnerable to fatal injury, drive large cars. In addition, potential differences in efficacy could not be examined among different types of air bags in the same general category, including first-generation side air bags versus those developed after initial experience and curtain versus seat-mounted head-protection air bags (27).

Another limitation stems from missing data in the GES database. This study used only vehicles with valid VINs for GES denominators (drivers involved in crashes). While the FARS database (deaths in numerators) has nearly 100 percent valid VINs, only about 70–75 percent of vehicles in the GES have valid VINs. Some states do not record VINs, so their driver deaths were present in the numerators but not the denominators. This led to underestimation of denominators for death rates; however, this could have biased the results only if both side air bag status and initial impact points influenced the likelihood of vehicles’ having valid VINs, which seems improbable.

Like front air bags, side air bags could pose a risk of injury to some vehicle occupants, particularly children who are too close to the air bags; however, there have been few serious injuries attributed to side air bags thus far (28–30). Automobile manufacturers conduct voluntary tests to ensure that inflating side air bags do not exceed agreed-upon levels of injury measures among test dummies representing small females and children positioned in close proximity to the air bags (31, 32).

Side air bags with both head and torso protection appear to work as intended in terms of decreasing the risk of driver death in nearside collisions, the most dangerous type of impact for motor vehicle occupants. Current findings suggest that such air bags may be an effective method for reducing but not eliminating the adverse effects of incompatibility in ride height between colliding vehicles. In spite of study limitations and inconsistencies, the evidence for major reductions in risk from head-protection side air bags is robust. Torso-only air bags appear to confer lesser benefits on drivers. The numbers of vehicles equipped with side air bags in this study were relatively low, so follow-up of these findings is necessary, as are studies examining the mortality and morbidity of passengers, particularly children, in vehicles with side air bags. Further research is also needed to determine whether side air bags benefit occupants of SUVs, minivans, and pickup trucks.

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APPENDIX

Formulae for Calculation of Adjusted Risk Ratios and 95 Percent Confidence Intervals

Adjustment method

1) Expected number of deaths in front/rear impacts in cars with side air bags = (number of front/rear driver deaths with no side air bags + number of drivers involved in front/rear collisions with no side air bags) × number of drivers involved in front/rear crashes of cars with side air bags.

2) Crude risk ratio for front/rear deaths in cars with side air bags = observed number of front/rear deaths in cars with side air bags ÷ expected number of front/rear deaths.

3) Adjusted risk ratio for nearside deaths in cars with side air bags = crude risk ratio for nearside deaths ÷ crude risk ratio for front/rear deaths.

Adjusted risk ratio and 95 percent confidence interval

1) Adjusted risk ratio for nearside deaths = D × C, where

\[
D = \frac{\text{number of nearside driver deaths with side air bags} \times \text{number of front/rear driver deaths with no side air bags}}{\text{number of nearside driver deaths with no side air bags} \times \text{number of front/rear driver deaths with side air bags}}
\]

and

\[
C = \frac{\text{number of drivers in nearside crashes with no side air bags} \times \text{number of drivers in front/rear crashes with side air bags}}{\text{number of drivers in nearside crashes with side air bags} \times \text{number of drivers in front/rear crashes with no side air bags}}.
\]

2) 95 percent confidence interval for the adjusted risk ratio for nearside deaths:

Lower confidence limit = \(D \times C \times \exp(-1.96(\text{standard error}(\ln C + \ln D)))\).

Upper confidence limit = \(D \times C \times \exp(1.96(\text{standard error}(\ln C + \ln D)))\).

Standard error(\(\ln C\)) is obtained from SUDAAN using the Taylor series linearization method combined with variance estimation formulae specific to the General Estimates System sample design.

\[
\text{Standard error} (\ln D) = \sqrt{\frac{1}{d_1} + \frac{1}{d_2} + \frac{1}{d_3} + \frac{1}{d_4}},
\]

where \(d_1\) = number of nearside driver deaths with side air bags, \(d_2\) = number of nearside driver deaths with no side air bags, \(d_3\) = number of front/rear driver deaths with side air bags, and \(d_4\) = number of front/rear driver deaths with no side air bags.