Occurrence of Serious Injury in Real-World Side Impacts of Vehicles with Good Side-Impact Protection Ratings

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Objective: The Insurance Institute for Highway Safety (IIHS) introduced its side impact consumer information test program in 2003. Since that time, side airbags and structural improvements have been implemented across the fleet and the proportion of good ratings has increased to 93% of 2012–2014 model year vehicles. Research has shown that drivers of good-rated vehicles are 70% less likely to die in a left-side crash than drivers of poor-rated vehicles. Despite these improvements, side impact fatalities accounted for about one quarter of passenger vehicle occupant fatalities in 2012. This study is a detailed analysis of real-world cases with serious injury resulting from side crashes of vehicles with good ratings in the IIHS side impact test.

Methods: NASS-CDS and Crash Injury Research and Engineering Network (CIREN) were queried for occupants of good-rated vehicles who sustained an Abbreviated Injury Scale (AIS) ≥ 3 injury in a side-impact crash. The resulting 110 cases were categorized by impact configuration and other factors that contributed to injury. Patterns of impact configuration, restraint performance, and occupant injury were identified and discussed in the context of potential upgrades to the current IIHS side impact test.

Results: Three quarters of the injured occupants were involved in near-side impacts. For these occupants, the most common factors contributing to injury were crash severities greater than the IIHS test, inadequate side-airbag performance, and lack of side-airbag coverage for the injured body region. In the cases where an airbag was present but did not prevent the injury, occupants were often exposed to loading centered farther forward on the vehicle than in the IIHS test. Around 40% of the far-side occupants were injured from contact with the struck-side interior structure, and almost all of these cases were more severe than the IIHS test. The remaining far-side occupants were mostly elderly and sustained injury from the center console, instrument panel, or seat belt. In addition, many far-side occupants were likely out of position due to events preceding the side impact and/or being unbelted.

Conclusion: Individual changes to the IIHS side impact test have the potential to reduce the number of serious injuries in real-world crashes. These include impacting the vehicle farther forward (relevant to 28% of all cases studied), greater test severity (17%), the inclusion of far-side occupants (9%), and more restrictive injury criteria (9%). Combinations of these changes could be more effective.

Keywords: side impact, crashworthiness, crash testing, IIHS, NASS-CDS, CIREN

Introduction

The Insurance Institute for Highway Safety (IIHS) began its consumer evaluation program for side impact crashworthiness in 2003. In the IIHS side impact test, the stationary tested vehicle is struck on the left side by a 1,500 kg moving deformable barrier (MDB) at 50 km/h. One of 4 ratings is assigned based on a combination of structural performance, injury measures recorded on dummies in the driver and left rear passenger seats, and observations of the restraint system and dummy kinematics. Of the 2004–2006 models tested in the program, 27% received the highest rating of good, whereas 41% received the lowest rating of poor. For 2012–2014 models, these proportions had changed to 93 and 1%, respectively (Figure A1, see online supplement). Based on analysis of real-world side impacts, Teoh and Lund (2011) found that when a left-side crash occurred, drivers of good-rated vehicles were 70% less likely to die than drivers of poor-rated vehicles even after taking into account the life-saving benefits of head-protecting side airbags, the fitment of which was encouraged by the IIHS test.

When combined with changes in the fleet, driver behavior, and environmental factors, improved side impact crashworthiness has helped contribute to a decline in side-impact driver fatality in 1- to 3-year-old vehicles from 22 per million registered vehicles in 2005 to 7 per million in 2012 (IIHS 2014).

Despite these improvements, side impacts accounted for 5,570 passenger vehicle occupant fatalities in 2012. The median model year for vehicles with a side impact fatality was 2001, meaning that most were not rated in the IIHS test program. This suggests that side impact fatality rates will continue to fall as the fleet continues to turn over, given the
relationship between good test performance and real-world experience. At the same time, however, 41% of the tested vehicles with 2012 side impact fatalities were rated good (Figure A2, see online supplement). This leaves open the possibility that modifications to the IIHS side impact test program could lead to further real-world crashworthiness improvements and, in the process, offer additional comparative safety ratings. It is this information that distinguishes consumer information test programs from regulatory mandates.

To ensure that test results continue to translate into actual crashworthiness improvements, it is imperative that any future test modifications be associated with specific observations made from real-world crashes. Establishing these correlations requires real-world crash data sources with a high level of detail on vehicle performance and occupant outcomes. In addition, analyses should be limited to vehicles that already perform well in the current test program because this represents the baseline state of vehicle design to which any new countermeasures would be applied. Identifying the factors relevant to serious injury in these crashes can help determine whether a new or modified test program could promote meaningful changes. It is possible that any single modification represents only a small portion of the remaining problem and that changing the test would have limited value. Ideally, all studied vehicles also would have good performance in the consumer and regulatory side impact programs maintained by the NHTSA. However, the NHTSA introduced a new oblique pole test in 2010 as part of both of these programs, and there are not yet sufficient numbers of cases to apply this restriction.

A similar process was utilized to evaluate the IIHS 40% moderate overlap frontal test. Queries identified 116 occupants in the NASS-CDS database who sustained serious or fatal injury in frontal crashes of vehicles with good frontal ratings (Brumbelow and Zuby 2009). Detailed analysis of these cases identified the small overlap configuration as a potential area for fleet-wide crashworthiness improvements. A subsequent series of research tests established a set of conditions that reproduced outcomes observed in real-world small overlaps and also demonstrated a range of performance among vehicles with good moderate overlap ratings (Sherwood et al. 2013). The first ratings in the new small overlap evaluation were released in 2012.

### Methods

Real-world crash data were collected from NASS-CDS and the Crash Injury Research and Engineering Network (CIREN). NASS-CDS is a program of crash data collection conducted and maintained by NHTSA. There are 27 teams stationed around the United States that investigate a selection of the police-reported tow-away crashes in their geographic region. The number of total crashes investigated each year ranged from around 3,600 to 5,200 between 2005 and 2012, the years used in this study. CIREN is a data collection program maintained by NHTSA in which designated level 1 trauma centers and engineering laboratories collaborate to determine injury mechanisms in automobile crashes. CIREN teams are composed of physicians, engineers, epidemiologists, and crash investigators. There are approximately 1,400 CIREN cases from 2004–2012 that have been published online after undergoing a process of quality control and screening to remove personal information. Case inclusion criteria were applied to both the NASS-CDS and CIREN data sets. Though NASS-CDS utilizes a weighted sampling process, none of the factors used to assign case weights in the sample design would be expected to bias the resulting cases away from the overall target population of seriously injured occupants in side impact crashes of good-rated vehicles (Zhang and Chen 2013). CIREN is not weighted, and though the inclusion criteria are not identical to those in NASS-CDS, the minor differences would not be expected to be relevant to the target population of the current study (Flannagan and Rupp 2009; Stitzel et al. 2007).

Vehicles selected for the study received good ratings in the IIHS side impact crashworthiness evaluation. IIHS began this test program in 2003, though the designs of some good-rated vehicle models extended back to the 2001 model year. Side crashes for these vehicles were defined as those that were coded with primary general area of deformation values (GAD1) of “L” or “R” by the NASS-CDS or CIREN investigators, except when there was a subsequent rollover. All such cases were included when any occupant sustained an injury with a severity of 3 or greater on the Abbreviated Injury Scale (AIS; AAAM 1998). Fatally injured occupants were included regardless of the coded maximum AIS.

Detailed reviews were performed of each case meeting the inclusion criteria. Relevant coded variables were included, and crash descriptions, scene photographs, vehicle photographs, and injury diagrams were analyzed. Each occupant was assessed using the characteristics listed in Table 1.

### Assigning Injury Factors

On their own, the crash characteristics above do not explain how each occupant was injured despite being in a vehicle with

| Table 1. Characteristics of interest for included cases |
|-----------------------------|-----------------------------|
| Crash characteristic       | Possible values              |
| Crash partner              | Striking vehicle (e.g., car, LTV, heavy truck) |
|                            | Struck object type: fixed, deformable |
| Impact relative to          | Struck object size: narrow, wide (50 cm boundary) |
| occupant                    | Side: near, far Longitudinal position: rearward of occupant, overlapping occupant, forward of occupant |
|                            | Occurrence of other events/impacts that could have led to occupant being out of position at main impact |
| Damage center relative to   | Maximum crush at occupant location: reported value |
| vehicle                     | Forward of hinge-pillar, hinge-pillar, mid front door, B-pillar, mid rear door, C-pillar, rearward of C-pillar |
| Restraint system            | Occupant belt use: belted, unbelted |
|                            | SAB type at occupant position: none, curtain only, curtain with torso bag, combination head/torso. (Torsor SAB can be with or without abdomen and pelvis coverage.) |
|                            | SAB deployment status: deployed, nondeployed, partially deployed (e.g., curtain deployed but torso SAB did not) |
| Occupant characteristics    | Age, sex, height, weight, body mass index: as reported |
| Occupant injuries           | Body regions with AIS ≥ 3 injury |
|                            | Possible injury sources       |
a good side impact protection rating. For any given impact, the first requirement for occupant protection is a vehicle structure that is able to control deformation in such a way that the occupant survival space remains intact. Given sufficient space, the second requirement is a restraint system that controls occupant loading to minimize the risk of injury. By definition, vehicles with good side impact ratings are able to do this in the test configuration. However, if the real-world crash is more severe than the test, it cannot be assumed that the restraint system should be able to prevent serious injury. Furthermore, some crashes may not be more severe than the test but differ in some other way that may contribute to an occurrence of injury that was not assessed by the test. The most obvious example of this is a far-side impact. Because far-side impacts are not assessed in the IIHS test, there is no expectation that good-rated vehicles will provide a certain level of protection. For this reason, factors relevant to injury were assessed separately for near- and far-side occupants.

Each near-side occupant was assigned to at least one of the following categories:

1. Severity: The severity of the crash exceeded that of the test and directly contributed to the sustained injury. Severity was judged from the perspective of the injured occupant and most often was assessed using measurements and/or photographs that demonstrated greater crush at the location of the injured body region than levels observed in the test.
2. Side airbag (SAB) performance: Injuries attributed to inadequate protection from the SAB. The integrity of the occupant compartment was maintained, but the occupant sustained injury either from loading by the SAB itself or from an impact with an interior component not prevented by the restraints. An additional requirement for this injury factor was that the fitted SAB was intended to provide protection to the specific body region that was injured (see near-side factor 3). However, deployment of this SAB was not a requirement; crashes where the fitted SAB did not deploy would still fall into this category.
3. No SAB coverage: The fitted SAB did not offer protection to the injured body region; for example, torso SABs that do not extend down to the pelvis and rear seat occupants without a torso SAB.
4. Far-side occupant: Injury attributed to loading from an occupant on the other side of the vehicle.
5. Crash dynamics: Characteristics of the impact or injury would make it difficult to reproduce with a test (e.g., underride or override, upper extremity injuries from steering wheel, high likelihood of being out of position due to preceding events).

It was possible for more than one injury factor to be relevant to a specific occupant. For example, an occupant who sustained an AIS ≥ 3 pelvic injury in a crash that was more severe than the test and in which the SAB did not offer pelvic protection would have near-side factors 1 and 3. Another example would be an occupant who sustained an AIS ≥ 3 injury to multiple body regions for different reasons; for example, a near-side abdominal injury from increased severity and a far-side head injury from contact with another occupant.

Injury factors for far-side occupants were assigned based on the injury-producing contacts:

1. Struck-side interior: Injury produced by contact with the door, B-pillar, roof rail, or seat back on the side laterally opposite the occupant’s seating position.
2. Oblique instrument panel/dash: injury due to contact with the instrument panel or dash on the side opposite the occupant’s seating position; for example, driver contacting the right front dash.
3. Adjacent interior: Injury produced by contact with a component at or adjoining the occupant’s seating position such as the console, footwell, seat belt, or steering wheel (for drivers).
4. Other occupant: Injury due to contact with occupant on struck side of vehicle.
5. Unknown: The contacts producing the injury could not be determined.

A specific occupant could have more than one relevant injury factor if they sustained multiple AIS ≥ 3 injuries from different sources.

After the appropriate injury factors were assigned to each occupant, cases with the same factors were grouped in order to identify patterns of crash characteristics. By cross-referencing the injury factors and characteristics of the crash, potential changes to the crash test program can be identified for addressing a given injury factor. For example, how could a test address the crashes in the “SAB performance” group? If a large proportion of these cases are in pole impacts near the hinge pillar, then a crash test that produces oblique forward movement of the occupant may be required. Once potential modifications to the test program have been identified, the overall relevance of each one to the whole study population was estimated. For example, a forward/oblique crash mode could be common in both the “SAB performance” group of near-side occupants as well as the “oblique instrument panel/dash” group of far-side occupants, suggesting such a test with 2 front-row dummies could be relevant to both groups. Potential changes to the test were not assigned a priori but were identified based on common injury factors and crash characteristics.

Results

There were 82 case occupants from NASS-CDS and 39 from CIREN who met the initial inclusion criteria. There were 109 occupants remaining for analysis after removing 7 cases missing the information necessary for a complete evaluation, 2 that were judged to be small overlap frontal impacts and 3 occupants whose circumstances made it difficult to apply the study’s categorization procedure. These 3 were an unbelted 8-year-old occupant in the right front passenger seat where the side airbag did not deploy (possibly suppressed); the only middle rear-seat occupant in the data set, who was an unbelted adult seated between 2 other unbelted adults; and a driver from a crash that involved severe near- and far-side impacts.
Figure A3 (see online supplement) shows the seating position and impact side for the 109 occupants studied. The impact occurred on the near side for 82 occupants (75%) and on the far side for the other 27 occupants (25%). Overall, 67% of the case occupants were drivers, 27% were right-front passengers, and 6% were second-row passengers. The 109 case occupants were in crashes involving 99 vehicles. There were no major differences in the distributions of crash partners for near- and far-side occupants (Figure A4, see online supplement).

Seventy-six percent of the cases were multiple-vehicle crashes, with light trucks and vans (LTVs) and medium/heavy-duty trucks representing 68% of these. Summary occupant characteristics are shown in Table A1 (see online supplement). Differences between near- and far-side occupants were small and not shown.

### Near-side Occupants

Fifty-five (67%) of the 82 near-side occupants were drivers, 21 (26%) were right-front passengers, and 5 (7%) were second row passengers. The case review process produced a total of 101 injury factors for the 82 near-side occupants. The proportion of occupants with a given injury factor is shown in Figure A5 (see online supplement), along with the mix of crash partners for each injury factor (the percentages sum to 123% because there are more injury factors than occupants). The severity and restraint performance factors each applied to around 40% of near-side occupants ($n = 33$ and 32, respectively), with the lack of side airbag coverage contributing to injury for just more than 20% ($n = 18$).

Overall, 79% of the near-side occupants were involved in crashes with another vehicle. LTVs were the most common crash partner (43% of near-side occupants), with cars the second most common (24%). Taken together, LTVs and medium/heavy-duty trucks were the crash partners for 54% of near-side occupants. Narrow (less than 50 cm diameter) and wide objects represented 17 and 4% of the near-side crash partners, respectively.

Figure 1 shows the injury factors and the longitudinal location on the vehicle where each impact was centered for the 76 near-side occupants seated at the driver or right-front passenger position (for right-front passengers, the impact was actually on the right side of the vehicle). Thirty of the occupants (39%) were in crashes where the impact was centered on the forward half of the front door (including the hinge pillar), compared to 25 occupants (33%) in crashes with the impact centered on the B-pillar. Impacts centered forward of the hinge pillar were the most common for the restraint performance injury factor.

The prevalence of some other crash and occupant characteristics is shown in Figure 2. The 2 most common injury factors had some of the largest characteristic differences. Relative to occupants with a severity injury factor, those with a restraint performance factor were more often female (63 vs. 42%), aged 60 or older (50 vs. 18%), able to survive their injuries (91 vs. 70%), and exposed to less than 40 cm crush at their seating position (93 vs. 18%).

The occurrence of serious injury to different body regions also varied by injury factor (Figure 3). Overall, 59% of near-side occupants sustained at least one serious chest injury, 33% sustained a pelvis/hip injury, and 30% sustained a head injury. Other body regions were more commonly injured than the chest when injury factors included the lack of side airbag coverage (pelvis/hip), unique crash dynamics (head), or contact with another occupant (head).

### Far-side Occupants

Eighteen (67%) of the 27 far-side occupants were drivers, 8 (30%) were right-front passengers, and there was one second-row passenger (4%). The injury factors for far-side occupants...
were assigned based on the contact that produced each AIS ≥ 3 injury. Though theoretically possible, the case review process did not identify more than one injury factor for a far-side occupant. The proportion of occupants with a given injury factor is shown in Figure A6 (see online supplement), along with the mix of crash partners. Forty-one percent of far-side occupants were injured from contacts with the struck-side interior (e.g., door, B-pillar, or seat back on opposite side), and 30% were injured by contacting an interior component of the vehicle at or adjacent to their own seating position (e.g., console, footwell, or seat belt). Three occupants (11%) sustained injury from contacting the instrument panel and one (4%) from contact with the near-side occupant. The injury-producing contact could not be determined for 4 occupants (15%); based on exterior crush measures, all were higher severity than the IIHS test with a variety of possible contact locations.

Overall, 70% of the far-side occupants were involved in crashes with another vehicle. LTVs were the most common partner (33%), followed by cars (26%) and medium/heavy-duty trucks (11%). Narrow (less than 50 cm diameter) and wide objects represented 22 and 7% of far-side crash partners, respectively.

The injury factors and longitudinal location on the vehicle where each impact was centered is shown in Figure 4 for the 26 far-side occupants seated in the first row (for drivers, the impact was actually on the right side of the vehicle). Forty-six percent were in crashes where the impact was centered near the far-side B-pillar, compared to 19% centered on the forward half of the far-side door and 35% forward of the far-side hinge pillar. For the 9 occupants in the “adjacent interior” group, contact with the center console produced the injury in 6 cases, the seat belt in 2, and the steering wheel in one.

Some comparisons of other crash and occupant characteristics are shown in Figure 5. The 2 most common injury factors differed from each other in several ways. Relative to occupants with struck-side interior contacts, those with contacts to adjacent interior components were more often female (63 vs. 36%), aged 60 or older (75 vs. 18%), able to survive their injuries (88 vs. 55%), exposed to less than 40 cm crush at the struck-side seating position (88 vs. 27%), belted (100 vs. 55%), and still likely in position at the time of the primary far-side impact (88 vs. 27%).

Figure 6 shows the prevalence of serious injury to different body regions for far-side occupants. Overall, 67% sustained at least one serious chest injury and 41% sustained a head injury. Head injuries were slightly more common than chest injuries for occupants injured by contacting the struck-side interior.

**Discussion**

The consideration of potential future changes to the IIHS side impact test program is informed by the factors producing serious injury in real-world crashes of vehicles that perform well in the current test. Considering the combinations of injury factors and characteristics of the reviewed NASS-CDS and
Increased Test Severity

In the current test configuration, a 1,500 kg MDB strikes the tested vehicle at 50 km/h. The barrier face was designed to represent the height and shape of a midsize SUV (Arbelaez et al. 2002) but the mass is more typical of a small SUV or midsize car (Ward’s Automotive Group 2014). In the current study, the median partner curb weight for near-side occupants struck by another passenger vehicle was 1,756 kg. However, when including those struck by medium/heavy-duty trucks (many of which had unknown curb weights), partner curb weight exceeded the MDB weight for 71% of the near-side occupants in 2-vehicle crashes. This percentage increased to 78% when restricting to occupants for whom a higher crash severity appeared to contribute directly to injury.

Though many of the NASS-CDS and CIREN cases have missing or suspect delta-V values, another means of comparing severity is using the exterior crush values measured at the occupant compartment. For good-rated vehicles, the IIHS test has produced maximum crush ranging from 18 to 43 cm, with a median value of 31 cm. For near-side occupants in the current study, the maximum crush ranged from 0 to 121 cm, with a median value of 33 cm. Limiting to the 40% of near-side occupants with a severity injury factor, maximum crush ranged from 31 to 121 cm, with a 56 cm median.

Increasing test severity with a higher MDB mass and/or impact speed may require simultaneous modifications to the MDB stiffness. Development tests demonstrated that the current MDB design reproduced vehicle-to-vehicle damage patterns on a range of 1992–2000 model vehicles (Arbelaez et al. 2002; Dakin et al. 2003). However, this would not necessarily be the case at higher test severities, especially considering improvements to the side structure of the fleet since that time.

Different Impact Location

Though the current side test gives equal weighting to the dummies in the driver and left rear passenger seats, 93% of near-side case occupants were seated in the front-row. For 61% of these occupants, the center of the impact was forward of the middle of the front door. The proportion was even greater (72%) when considering only those occupants whose injuries were not due to higher crash severity (Figure 1). The MDB alignment in the IIHS test is determined based on the wheelbase of the tested vehicle and for 4-door vehicles usually results in the MDB centerline being within 5 cm of the B-pillar. The forward impact locations observed in the real-world cases may be producing intrusion patterns, occupant kinematics, or airbag deployment times that are not observed in the IIHS test configuration and that result in reduced protection.

Restraint performance or the lack of side airbag coverage was judged to be an injury factor for 60% of occupants with forward impact locations. In some of these cases (around one fifth), the torso and curtain side airbags did not deploy at all. In the others, it was not possible to tell from the injuries whether the airbags deployed on time but offered inadequate coverage or whether they deployed late and failed to offer protection or even compounded the injury. Two cases included side airbag deployment times from the electronic data recorder. Though both deployment times were later than those observed in the IIHS tests (29 ms vs. 8 ms and 14 ms vs. 10 ms; Table A2, see online supplement), the serious pelvic injuries sustained in both cases may have had more to do with the lack of coverage from the airbag. It is notable that though the occupants in the restraint performance and side airbag coverage groups tended to be older, they also were less likely to sustain fatal injuries (Figure 2). Nevertheless, the sizeable proportion of cases without deployment suggests that this impact configuration may not be adequately taken into account by current airbag deployment algorithms.

It is possible that the outcome of some of the crashes included in the current study could have been improved by vehicle structure and restraint system changes already adopted based on the oblique pole tests included in Federal Motor Vehicle Safety Standard (FMVSS) 214 (NHTSA 2007) and NHTSA’s New Car Assessment Program. However, because only 10 of the near-side occupants in the current study were in 2010 or newer model year vehicles, the year the upgraded FMVSS 214 phase-in period began, it is not possible to determine whether the distribution of injury factors and impact locations would be affected. Aekbote et al. (2009) indicated that the IIHS MDB represents a more challenging scenario for occupant protection than the oblique pole impact, but countermeasures adopted based on the unique demands of the latter configuration still could have improved the overall side impact crashworthiness. Because chest injuries were the most common for near-side occupants (Figure 3), it is notable that...
Belcher et al. (2011) found that the 75° pole impact configuration produced almost purely lateral dummy chest deflections. This suggests that any increased risk posed by oblique loading of the chest is not necessarily being addressed with the pole test. Future work is needed to determine whether the oblique pole impact configuration is an adequate representation of the more forward impacts in the real-world cases, most of which were 2-vehicle crashes.

**Modified Injury Criteria or Dummy Size**

The IIHS test could be modified by adjusting injury criteria without any other changes to the configuration. However, as shown in Figure 1, unless the severity of the real-world crash exceeded that of the test, only a limited number of near-side occupants were injured from impacts centered near the B-pillar (20%). This likely reflects the relative success of the test program in promoting crashworthiness improvements that apply to real-world crashes similar to the test (Teoh and Lund 2011). It also implies that modifications to the current injury criteria would have a limited effect unless they were needed to represent the outcomes observed in a different impact configuration. The same applies to changing the size of the dummy used in the IIHS test. Though a 50th percentile male dummy like World SID (theoretical standing height of 175 cm) would more closely match the median occupant height (168 cm; Table A1) than the SID-IIs dummy currently used in the IIHS test (150 cm), it would be unlikely to promote substantially different countermeasures in the absence of other test modifications.

**Far-side Occupant**

One quarter of the occupants in the current study were seated on the far side of the vehicle from the impact. This proportion is in general agreement with previous research (Digges et al. 2009; Ryb et al. 2007). However, simply including a far-side occupant would not necessarily reflect the most important injury risks for all of these occupants, in the same way that near-side occupants continue to face risks not represented by the current test configuration. In fact, far-side occupants were in more severe crashes, on average, than near-side occupants ($C_{max}$, Figures 7 and 11). In several cases, the intrusion of the struck-side door reached the centerline of the vehicle. In addition, the impact locations for many occupants resulted in oblique (nonlateral) movement inside the vehicle, producing impacts with the instrument panel or steering wheel. This is consistent with findings by Gabler et al. (2005), who found that crashes with an oblique principal direction of force resulted in more seriously injured belted far-side occupants than crashes with a perpendicular principal direction of force. In total, only 4 of the far-side occupants (15%) were in impacts that were centered between the hinge- and C-pillars and that produced less than 40 cm exterior crush, suggesting that including a far-side occupant evaluation in the current test configuration would have limited relevance.

In addition to increased crash severity and nonlateral kinematics, occupant position is another challenge to consider in far-side occupant protection. In the current sample of crashes, far-side occupants more often were unbelted than near-side occupants, and preceding impacts or other events suggested that around half could have been out of position at the time of the primary impact (Figures 7 and 11). This is without considering the fact that even when exposed to the same preimpact events, the shoulder belt geometry could allow increased movement for far-side occupants.

Beyond increased protection for the far-side occupants themselves, including a far-side dummy in the crash test could also encourage countermeasures that improve protection for near-side occupants when far-side occupants are present. There was only one far-side occupant with injuries evident from contacting the other occupant (and 2 more occupants in the “unknown” group who may have had such contact). But there were 7 near-side occupants who sustained injuries from contact with a far-side occupant. In 4 of these cases, the far-side occupant likely was unbelted, which would make it more challenging to prevent this contact. Overall, the data suggest that efforts to prevent occupant-to-occupant contact and make other improvements to far-side occupant protection (e.g., Bostrom and Haland 2003; Thomas et al. 2013) could produce meaningful benefits, but at the same time they indicate the difficulty of assessing far-side protection with a single crash test.

**Comparing Potential Relevance of Test Changes**

One way of comparing the potential relevance of different modifications to the test program is by the proportion of all occupants in the study who fall into certain categories. Such a comparison is made in Table 2. This is necessarily a simplification of the ideal situation in which very specific modifications of the test (e.g., increasing MDB mass by 500 kg) could be evaluated. Instead, the potential of a change such as “increased severity” includes any occupant in the set of real-world cases who was involved in a crash with greater severity than the IIHS test, regardless of how much greater, as long as all of the other crash conditions were similar to the test (i.e., near-side occupants with impacts centered near the B-pillar). These figures also assume that countermeasures promoted by such a test could have provided some benefit to case occupants likely to have been out of position for the primary impact. For a combination of changes to the test, the estimate includes any occupant for whom either or both modifications were applicable to their real-world crash. For example, it is assumed that a test with increased severity and a more forward impact location would promote changes that benefit occupants in crashes sim-
ilar to the new test (forward and more severe), as well as those in more severe crashes centered at the B-pillar and those in lower severity impacts located forward of the hinge pillar. Because the estimates for single test modifications did not include occupants with multiple differences from the test (e.g., the overlapping area in Figure 7), the estimates for combinations of changes are greater than the sum of the individual ones.

Though these relevance estimates are based on several assumptions and limitations, they nevertheless provide a starting point for future side impact crashworthiness research. A test in which a heavier and/or faster MDB impacts the tested vehicle with an alignment closer to the A-pillar is an example of a configuration that might promote countermeasures that provide increased real-world side impact protection in a substantial number of cases. Further work is needed to determine whether these crashes can be adequately represented with current levels of dummy biofidelity (loading and kinematics) and MDB stiffness. In addition, it will be crucial to ensure that any countermeasures that may be encouraged (e.g., stiffer side airbags) do not come at the expense of the crash-involved population not included in the current study due to the fact that they were protected from serious injury. Confirming that good levels of performance are maintained in the existing test will be an important part of this process.

Conclusions

Occupants of good-rated vehicles continue to sustain serious injuries in side impact crashes. Detailed analysis of 109 occupants shows that relatively few were injured in crashes that matched the IIHS test conditions. Most were involved in impacts that were more severe and/or aligned farther forward on the vehicle. One quarter of injured occupants were seated on the far side of the vehicle from the impact, but replicating their injury risks with a test would require addressing the high numbers of unbelted and out-of-position occupants in addition to the severity and alignment differences.

Supplemental Material

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

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