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TWO-VEHICLE SIDE IMPACT CRASHES: THE RELATIONSHIP OF VEHICLE AND CRASH CHARACTERISTICS TO INJURY SEVERITY

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Abstract—Injury type and severity among front outboard occupants of passenger vehicles struck in the side by another passenger vehicle and recorded in the United States National Accident Sampling System Crashworthiness Data System were examined in relation to the location of impact, the angle of impact, occupant gender and age, seat belt use, the weight and body style of the side-impacted vehicle, and the weight and body style of the striking vehicle. Elderly occupants were three times as likely as younger occupants in similar crashes to be seriously injured. Serious injuries were also more likely for occupants seated on the struck side and occupants of lightweight passenger vehicles. After accounting for vehicle weight differences, struck-side occupants of cars were still much more likely to be seriously injured than struck-side occupants of light trucks. However, among occupants seated on the side of the vehicle opposite the impact, the likelihood of serious injury was higher for those seated in light trucks. © 1997 Elsevier Science Ltd

INTRODUCTION

Although collisions between motor vehicles are most commonly either head-on or rear-end crashes, side-impact crashes account for a considerable portion of the overall collision picture. According to the National Highway Traffic Safety Administration (NHTSA), approximately 34% of passenger cars and 32% of light trucks in police-reported crashes in the United States are initially impacted on the side (NHTSA, 1995). Also, approximately 30% of passenger-vehicle occupant deaths in the United States occur in vehicles where the principal impact is to the side (IIHS, 1995). Although single-vehicle side impacts with roadside objects are common, most side-impact crashes occur at roadway intersections and involve the front of one vehicle impacting the side of another. Of the estimated 3,653,000 cars and light trucks impacted in the side in the United States in 1994, 3,155,000 were struck by other vehicles (NHTSA, 1995).

Injuries tend to be more severe in cars in side impacts compared with cars in front and rear impacts,

largely because of the limited side-crush space. In a study of patients admitted to trauma centers in the State of Maryland, Dischinger et al. (1993) reported that drivers involved in near-side impacts had mortality rates twice as high as drivers involved in frontal crashes. They also found that drivers in near-side impacts were more likely to incur multiple abdominal or chest injuries than drivers in frontal crashes.

Serious injuries (Abbreviated Injury Scale (AIS) ≥ 3) in side-impacted cars most frequently occur to the chest, head and abdomen. A study of vehicle crashes in Australia has revealed that typically the chest and abdomen are contacted by the door panel, whereas the head tends to contact exterior objects, the side window, and the B-pillar (Fildes et al., 1994). Håland et al. (1993), in a study of car-to-car side collisions in Sweden, found that males on the near side receive twice as many chest injuries as females. They hypothesized that this is due to the higher average weight of males, which leads to greater compression of the chest by the impacting door.

Side impacts involving the occupant compartment are more likely to produce serious injuries than impacts confined to the side areas ahead of or to the rear of the occupant compartment. In a study of side-impact crashes in Germany, Otte et al. (1984)

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reported that less than 14% of seat-belt wearing occupants were injured when the impact area was away from the passenger compartment, and none of these injuries were serious. Huelke and Compton (1992) studied a statistical sample of crashes throughout the United States and found that less than 1% of drivers involved in near-side impacts away from the passenger compartment were seriously injured, whereas serious injuries were incurred by 8% of those in impacts including the passenger compartment.

Doors are generally wider in two-door cars than four-door models, and there is less stiff structure to prevent intrusion into the occupant compartment. In side-impact crash tests of two-door and four-door versions of the same model, NHTSA found that the Thoracic Trauma Index (TTI) of the driver dummy was 14% higher in the two-door cars (NHTSA, 1990). However, there is as yet no evidence that occupants of two-door cars in real-world side impacts are at greater risk than occupants of four-door cars.

Two studies, one in the United States and one in Canada, have suggested that front-seat occupants of light trucks are less likely to be seriously injured in side impacts than front-seat occupants of passenger cars (Partyka, 1991; Eguakun and Wilson, 1995). Those light-truck occupants who are seriously injured are more likely to have been ejected from the vehicle. However, neither of these studies investigated whether the additional protection offered by a light truck is due to vehicle size or vehicle design.

A light truck is considered to be more aggressive than a passenger car as the striking vehicle in a side-impact crash, partly because of its greater weight, but also because its front end is relatively stiffer and higher. An analysis of data from the United States National Crash Severity Study (NCSS) reported that 17% of passenger car drivers struck in the near side by other passenger cars sustained injuries of severity AIS ≥ 3, but over 33% of those struck by light trucks sustained injuries at this level (Terhune et al., 1984).

The present paper addresses the relationship between vehicle and crash characteristics and the severity of injuries received in two-vehicle side-impact crashes. It is motivated by the relative lack of research on the combined influence of vehicle size, vehicle style, crash severity, occupant age, gender and seat-belt use on the likelihood of injury in side-impact crashes. In particular, this paper attempts to determine how differences in vehicle design and weight affect the injury risks of car and light-truck occupants.

METHOD

Subjects are the 4,226 front outboard occupants of model year 1981–93 passenger cars and light trucks

struck (principal impact) on either side by the front of another car or light truck and included in the electronic files of the 1988–92 National Accident Sampling System Crashworthiness Data System (NASS/CDS). The NASS/CDS is a probability sample of police-reported crashes in the United States involving light duty vehicles which were towed from the scene due to damage. Sampling weights, related to the probability that a crash is selected for the sample and appended to the data for each case, can be used to estimate national totals for cases meeting a given set of criteria.

Cars include two- and four-door sedans, hatchbacks and station wagons. Pickup trucks (with separate rear cargo beds) and utility vehicles with gross vehicle weight ratings (GVWR) of no more than 10,000 lbs are collectively referred to as light trucks. Crashes involving convertibles, automobile derivatives (El Camino-type auto-based pickups, large limousines), vans (passenger or cargo versions of minivans, large vans) and cab chassis-based light trucks were excluded. These vehicles differ significantly in design from other cars and light trucks, but were not present in sufficient numbers for a separate analysis.

Data were extracted on curb weight and body style of the subject vehicle, curb weight and body style of the striking vehicle, speed limit of the road on which the striking vehicle was traveling, location and angle of impact, location of occupant relative to the impact (near side or far side), and occupant age, gender, seat-belt use, and injury severity.

Subjects were classified as being seriously injured if the maximum reported AIS was greater than or equal to 3. From 1988 to 1992, the NASS/CDS coded injury severity using the AIS 1985 revision (AAAM, 1988). Beginning in 1993, the NASS/CDS adopted the AIS 1990 revision (AAAM, 1993). Data from 1993 onwards were not included in this analysis because of the differences in the injury-coding system (Garthe, 1996).

All statistical tests were carried out using the SUDAAN computer software (Shah et al., 1995), a package of procedures for analyzing data from complex sampling designs. Chi-square statistics were computed to test for differences in the proportion of seriously injured occupants in side-impacted vehicles for differing locations of deformation and for the occurrence of rollover or occupant ejection. A logistic regression was performed relating the odds of vehicle rollover to differences in vehicle and crash characteristics. These preliminary analyses were to confirm the low injury risk in impacts away from the occupant compartment and the high rollover risk of light trucks which were reported by earlier studies.

Further analyses were then restricted to the 2,993 non-ejected or only partially ejected subjects in impacts which involved at least some portion of the occupant compartment and did not include a rollover. Chi-square statistics and logistic regressions were used to test for the individual and simultaneous effects of differing occupant, vehicle, and crash characteristics on the likelihood of serious injury. Frequency tables were constructed to examine the distribution of injured body regions and suspected sources of injury among seriously injured occupants.

RESULTS

Of the 4,226 subjects, 3,753 were occupants of passenger cars and 473 were occupants of light trucks. Estimates of national totals, based on the sampling weights, are 1,413,042 passenger car occupants and 131,273 light truck occupants. Using these national totals, it is estimated that 2.9% of car occupants and 1.9% of light truck occupants in side-impacted vehicles were seriously injured. Overall then, light truck occupants were less likely than car occupants to be seriously injured.

Figure 1 displays the specific lateral deformation zones coded in NASS/CDS. Codes "F" and "B" refer to impacts which caused direct damage only to areas ahead of or to the rear of the occupant compartment. Table 1 lists the estimated nationwide percentages of occupants incurring serious injuries for the various combinations of occupant location and deformation zone. Only 1% or less of the occupants of vehicles impacted away from the occupant compartment were seriously injured. In crashes involving the occupant compartment, far-side occupants were significantly less likely to be seriously injured than near-
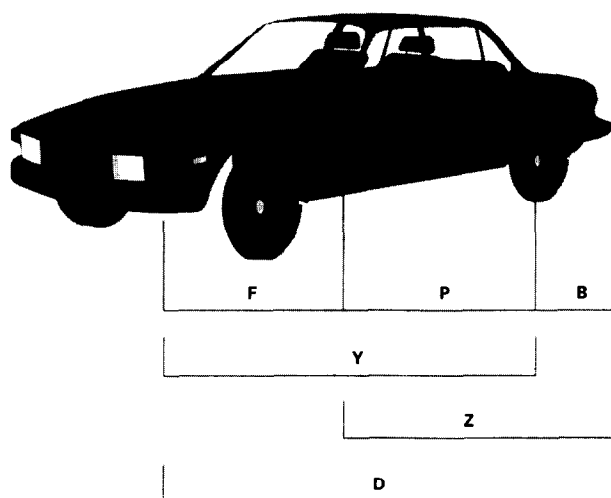
side occupants, except when the impact was distributed.

Table 2 lists the percentages of occupants incurring serious injuries according to whether the vehicle rolled over and/or the occupant was ejected. Rollovers include any vehicle rotation of at least 90°. Ejection refers to complete ejection only. For occupants seated both adjacent to and opposite the struck side, the likelihood of serious injury was greatly augmented by either rollover or ejection. Among non-ejected occupants of vehicles which did not roll, the likelihood of serious injury was only 3% for those on the near side and 2% for those on the far side.

The logistic regression summarized in Table 3 allows one to test for the effects of crash configuration and vehicle body style on the likelihood of rollover. Right-angle crashes were twice as likely to induce a rollover as side impacts at an oblique angle. Light trucks were 14 times as likely as cars to roll when struck in the side. This large disparity in rollover risk between cars and light trucks, along with the greater risk of serious injury in a rollover crash, resulted in the decision to exclude rollovers and full ejections from the remaining analyses.

The risk of serious injury, broken down by both striking and struck vehicle body style, is presented in Table 4. Near-side occupants of cars were more likely to incur serious injuries than near-side occupants of light trucks, though only significantly so when the striking vehicle was a car. There is some indication that far-side occupants of light trucks struck by cars were more likely to incur serious injuries than far-side occupants of cars struck by cars, but the sample sizes were too small to reach statistical significance.

As the speed limit affecting the striking vehicle increased, the likelihood of serious injury in the subject vehicle also increased (Table 5). Serious injuries were incurred by only 1% of those struck by a vehicle traveling on a road posted at less than 25 mph. This increased to over 5%, and 10% on the near side, when the striking vehicle was on a road posted at 55 mph or higher.

As the amount of occupant-compartment intrusion increased, the likelihood of serious injury to the occupants also increased (Table 6). Fewer than 1% of those in vehicles with less than 3 in of intrusion were seriously injured, compared with over 5% of those in vehicles with at least 6 in of intrusion. Among those occupants seated adjacent to the impact and in vehicles with at least 6 in of intrusion, the likelihood of serious injury was 16%.

The proportion of seriously injured occupants among those under age 25 (3.3%) was not noticeably different from the proportion of seriously injured occupants in the 25–64 age group (3.1%). However,

Fig. 1. Deformation zones in NASS/CDS.

Table 1. Percentage* of occupants with AIS ≥ 3 by occupant location and deformation
zone (number of cases in parentheses)

Occupant location	Deformation zone					
	Front (F)	Rear (B)	Center (P)	Front/center (Y = F + P)	Rear/center (Z = B + P)	Distributed (D = F + P + B)
Near side†	1.0 (441)	0.3 (63)	4.8 (180)	6.0 (761)	5.0 (353)	4.9 (258)
Far side‡	1.2 (380)	0.0 (67)	0.5 (147)	2.5 (700)	1.7 (374)	4.5 (257)

*Percentages based on national estimates rather than raw counts.
†$\chi^2 = 35.73$, p-value = 0.0000.
‡$\chi^2 = 12.32$, p-value = 0.0314.

Table 2. Percentage* of occupants with AIS ≥ 3 by occupant location, rollover status and ejection† status (number of cases in parentheses)

Occupant location	No rollover, not ejected	No rollover, ejected	Rollover, not ejected	Rollover, ejected
Near side‡	3.3 (1,934)	52.6 (30)	13.8 (84)	13.1 (4)
Far side§	1.7 (1,807)	31.5 (18)	4.6 (92)	31.5 (5)

*Percentages based on national estimates rather than raw counts.
†Ejection refers to full ejection only.
‡$\chi^2 = 17.25$, p-value = 0.0007.
§$\chi^2 = 9.26$, p-value = 0.0265.

Table 3. Logistic regression on the odds of vehicle rollover: adjusted odds ratios and 95% confidence limits

Effect	Odds ratio (n = 2,204)
Impact angle	2.38*
Perpendicular vs oblique	(1.26, 4.50)
Deformation zone	1.89
"P" vs ("Y" "Z" "D")	(0.70, 5.04)
Striking vehicle speed limit	0.95
(5 mph increase)	(0.82, 1.10)
Subject vehicle weight	0.96
(100 lb increase)	(0.91, 1.01)
Striking vehicle weight	1.00
(100 lb increase)	(0.98, 1.03)
Subject vehicle type	0.07*
Car vs light truck	(0.04, 0.13)
Striking vehicle type	0.89
Car vs light truck	(0.47, 1.70)

*Statistically significant at the 0.05 level.

6.7% of occupants age 65 and over were seriously injured, 9.6% in near-side impacts and 3.9% in far-side impacts. In far-side impacts, the risk to elderly occupants was twice as high as that of occupants under age 65.

Simultaneous effects of occupant, crash, and vehicle characteristics on the odds of serious injury are summarized in Table 7. After adjusting for all other variables in the logistic regression, males had an increased risk of serious injury in near-side impacts

Table 4. Percentage* of occupants with AIS ≥ 3 by occupant location, striking vehicle body style, and subject vehicle body style (only impacts involving occupant compartment; no rollovers or ejections). Number of cases in parentheses

Occupant location	Striking vehicle	Subject vehicle	
		Car	Light truck
Near side	Car†	5.0 (1,027)	0.7 (97)
	Light truck‡	6.3 (283)	4.8 (35)
Far side	Car§	1.9 (977)	4.1 (103)
	Light truck¶	2.2 (264)	1.7 (30)

*Percentages based on national estimates rather than raw counts.
†$\chi^2 = 7.40$, p-value = 0.0066.
‡$\chi^2 = 0.26$, p-value = 0.6115.
§$\chi^2 = 0.77$, p-value = 0.3790.
¶$\chi^2 = 0.14$, p-value = 0.7115.

Table 5. Percentage* of occupants with AIS ≥ 3 by occupant location and striking vehicle speed limit (only impacts involving occupant compartment; no rollovers or ejections). Number of cases in parentheses

Occupant location	Speed limit (mph)			
	10–20	25–35	40–50	55–65
Near side†	0.8 (8)	2.9 (713)	6.5 (518)	10.0 (193)
Far side‡	1.2 (11)	1.2 (692)	2.7 (484)	5.5 (175)

*Percentages based on national estimates rather than raw counts.
†χ^2 for trend = 19.60, p-value = 0.0002.
‡χ^2 for trend = 8.38, p-value = 0.0394.

and females had an increased risk in far-side impacts, but neither was statistically significant. Elderly occupants (65 years and older) were significantly more likely to receive serious injuries. The odds of an elderly occupant receiving a serious injury were more than three times that of a younger occupant in both

Table 6. Percentage* of occupants with AIS ≥ 3 by occupant location and maximum intrusion (only impacts involving occupant compartment; no rollovers or ejections). Number of cases in parentheses

| Occupant location | Maximum intrusion | | | |
	< 1 in	≥ 1 in but < 3 in	≥ 3 in but < 6 in	≥ 6 in
Near side†	0.2 (322)	0.1 (157)	3.2 (265)	16.0 (685)
Far side‡	0.3 (265)	0.3 (139)	0.6 (257)	5.3 (696)

*Percentages based on national estimates rather than raw counts.
†χ^2 for trend = 76.67, p-value = 0.0000.
‡χ^2 for trend = 45.11, p-value = 0.0000.

Table 7. Logistic regression on the odds of AIS ≥ 3 injury: adjusted odds ratios and 95% confidence limits (crashes involving rollovers or ejections excluded)

Effect	Near side (n = 1,334)	Far side (n = 1,260)
Occupant gender	1.60	0.73
Male vs female	(0.75, 3.43)	(0.36, 1.50)
Occupant age	3.59*	3.88*
65 + vs younger	(1.82, 7.06)	(1.52, 9.92)
Belt use	1.48	4.73*
None vs any	(0.72, 3.05)	(1.79, 12.52)
Impact angle	1.58	1.41
Perpendicular vs oblique	(0.74, 3.37)	(0.50, 4.00)
Deformation zone	0.72	0.15
"P" vs ("Y" "Z" "D")	(0.30, 1.78)	(0.02, 1.04)
Striking vehicle speed limit	1.34*	1.40*
(5 mph increase)	(1.22, 1.61)	(1.10, 1.76)
Subject vehicle weight	0.93*	0.87*
(100 lb increase)	(0.89, 0.98)	(0.81, 0.94)
Striking vehicle weight	1.00	1.05
(100 lb increase)	(0.97, 1.04)	(1.00, 1.10)
Subject vehicle type	3.65*	0.29*
Car vs light truck	(1.35, 9.89)	(0.10, 0.89)
Striking vehicle type	0.82	1.25
Car vs light truck	(0.36, 1.87)	(0.42, 3.71)

*Statistically significant at the 0.05 level.

near-side and far-side impacts. Unbelted occupants were significantly more likely to receive serious injuries only in far-side impacts. The odds of an unbelted occupant on the far side receiving a serious injury were more than four times that of a belted occupant.

Although occupants of vehicles struck at right angles had higher odds of serious injury than those struck at oblique angles, the difference was not statistically significant. Also, those occupants in impacts producing damage to more than one zone were more likely to be seriously injured than those in impacts restricted to the passenger compartment, but again the difference was not statistically significant. The one crash characteristic which was a significant predictor of serious injury risk was the speed limit affecting the striking vehicle. For each 5 mph increase

in the speed limit affecting the striking vehicle, the likelihood of serious injury increased 34% for near-side and 40% for far-side occupants.

Occupants of heavier vehicles were less likely to be seriously injured in a side impact than occupants of lightweight vehicles. For every extra 100 lbs in the weight of the subject vehicle, there was a corresponding 7–13% decrease in the odds of serious injury. The effect of the striking vehicle's weight was not statistically significant.

Even after adjusting for the differences in occupant age, belt use and vehicle weight, near-side occupants of cars impacted in the side were three times as likely to be seriously injured as near-side occupants of light trucks. However, far-side occupants of cars impacted in the side were significantly less likely to be seriously injured than far-side occupants of light trucks.

The logistic regression was repeated using only crashes involving two-door and four-door cars (Table 8). Near-side occupants of two-door cars were more likely to be seriously injured than near-side occupants of four-door cars, and far-side occupants of two-door cars were less likely to be seriously injured than far-side occupants of four-door cars. However, neither of these differences was statistically significant.

Table 9 lists the body regions of the most severe injury among all seriously injured occupants. Among both near-side and far-side occupants, the most severe injury occurred most often to the chest. However,

Table 8. Comparison of two-door and four-door cars only: logistic regression on the odds of AIS ≥ 3 injury (adjusted odds ratios and 95% confidence limits; crashes involving rollovers or ejections excluded)

Effect	Near side (n = 848)	Far side (n = 791)
Occupant gender	1.88	0.77
Male vs female	(0.55, 6.39)	(0.28, 2.11)
Occupant age	3.46*	4.52*
65 + vs younger	(1.44, 8.32)	(1.09, 18.74)
Belt use	0.92	5.75*
None vs any	(0.31, 2.70)	(1.95, 16.95)
Impact angle	1.58	1.05
Perpendicular vs oblique	(0.54, 4.60)	(0.32, 3.44)
Deformation zone	0.80	0.02*
"P" vs ("Y" "Z" "D")	(0.24, 2.63)	(0.00, 0.13)
Striking vehicle speed limit	1.47*	1.40*
(5 mph increase)	(1.22, 1.76)	(1.10, 1.84)
Subject vehicle weight	0.95	0.83*
(100 lb increase)	(0.90, 1.01)	(0.73, 0.94)
Striking vehicle weight	1.00	1.15*
(100 lb increase)	(0.95, 1.05)	(1.07, 1.24)
Subject vehicle type	1.47	0.51
2D car vs 4D car	(0.48, 4.51)	(0.20, 1.32)
Striking vehicle type	1.09	0.72
2D car vs 4D car	(0.30, 3.92)	(0.23, 2.22)

*Statistically significant at the 0.05 level.

Table 9. Distribution (percentage*) of body regions with most severe injury among occupants with AIS≥3 (only impacts involving occupant compartment; no rollovers or ejections)

Occupant location	Seat belt status	Head/skull/ Face	Neck	Chest	Pelvic/hip	Other
Near side	Belted (n = 149)	27.9	0.3	54.9	4.7	12.2
	Unbelted (n = 98)	16.3	6.6	59.5	11.8	5.9
Far side	Belted (n = 48)	32.5	17.2	27.4	0.4	22.5
	Unbelted (n = 72)	26.2	10.2	56.6	1.8	5.3

*Percentages based on national estimates rather than raw counts.

seriously injured far-side occupants were more likely than near-side occupants to have received their most severe injury to the head or neck. In particular, 32% of the belted far-side occupants who were seriously injured were most severely injured to the head, and another 17% were most severely injured to the neck.

Over 80% of the time, the source of the most severe injury among near-side occupants was listed as some component of the adjacent side structure, typically the door or the A and B pillars (Tables 10–12). On the far side, however, less than half of the seriously injured occupants were most severely injured by the side structure, and it was usually the structure from the struck side of the vehicle. In comparison to near-side occupants, far-side occupants more often received their most severe injury from the seat structure (including restraint systems) and interior components such as mirrors and sun visors. Twenty-two percent of the belted far-side occupants were most severely injured by mirrors or visors, and another 19% were most severely injured

by the seat structure. None of the belted near-side occupants were most severely injured by mirrors or visors, and only 4% were most severely injured by the seat structure.

DISCUSSION

Elderly persons are particularly at risk of serious injury in side-impact crashes. All else being equal, for impacts adjacent to the occupant, those 65 years of age or older are three times as likely as younger occupants to be seriously injured. When the impact is on the opposite side, occupants age 65 or older are nearly four times as likely as younger occupants to be seriously injured. Elderly drivers are also more likely than younger drivers to make improper turns or run stop signs and red lights, often leading to side-impact crashes (CDMV, 1993). Therefore, any proposed improvements in occupant side-crash protection should have a particular focus on the elderly occupant.

Table 10. Distribution (percentage*) of sources of most severe injury among occupants with AIS≥3 (only impacts involving occupant compartment; no rollovers or ejections)

Occupant location	Seat belt status	Front	Side	Seat	Other occupants	Roof	Floor	Other vehicle	Non-contact	Other
Near side	Belted (n = 134)	0.9	80.5	3.7	0.1	0.8	0.0	4.4	6.4	3.2
	Unbelted (n = 90)	4.6	86.3	0.0	0.0	0.6	0.4	6.6	0.3	1.2
Far side	Belted (n = 39)	21.9	48.1	19.4	5.1	0.3	1.0	0.0	4.3	0.0
	Unbelted (n = 59)	27.3	24.4	23.0	8.6	11.2	4.9	0.0	0.6	0.0

*Percentages based on national estimates rather than raw counts.

Table 11. Distribution (percentage*) of sources of most severe injury among occupants with AIS≥3: breakdown of front and side sources (only impacts involving occupant compartment; no rollovers or ejections)

Occupant location	Seat belt status	Front			Side			
		Inst. panel/ windshield	Mirror/ visor	Steering assembly	Surface/ armrest	A/B pillar	Window/ other	Other
Near side	Belted	0.0	0.0	0.9	46.3	32.3	1.9	18.6
	Unbelted	3.0	0.0	1.6	74.2	10.4	1.7	9.1
Far side	Belted	0.0	21.9	0.0	26.3	0.0	21.8	30.0
	Unbelted	15.4	2.7	9.3	12.3	8.5	3.6	48.3

*Percentages based on national estimates rather than raw counts.

Table 12. Distribution (percentage*) of sources of most severe injury among occupants with AIS ≥ 3: further breakdown of side sources (only impacts involving occupant compartment; no rollovers or ejections)

| Occupant location | Seat belt status | Side structure adjacent to occupant | | | Side structure opposite occupant | | | |
		Surface/armrest	A/B pillar	Window/other	Surface/armrest	A/B pillar	Window/other	Other
Near side	Belted	46.2	32.0	1.9	0.1	0.3	0.0	19.5
	Unbelted	74.2	10.4	1.7	0.0	0.0	0.0	13.7
Far side	Belted	9.2	0.0	0.0	17.1	0.0	21.8	51.9
	Unbelted	0.0	0.3	0.5	12.3	8.2	3.1	75.6

*Percentages based on national estimates rather than raw counts.

Seat belts are very effective in preventing serious injuries among far-side occupants in side-impact crashes. Belted far-side occupants are much less likely to contact the instrument panel, steering column and roof—major sources of injury for unbelted occupants. However, belts are less useful for occupants on the impacted side of the vehicle. Most serious injuries on the near side are due to contact with the adjacent side structure, which seat belts cannot prevent. Therefore, further steps must be taken to protect the heads and chests of both near- and far-side occupants from contact with intruding objects and the vehicle's side structure. The relatively new federal requirements for side-impact protection which began to be phased in for 1994 models (NHTSA, 1990) and side-impact air bags, first offered in the 1995 Volvo 850 and under development by most other major automakers, may be useful in this regard.

It is difficult to factor out any direct effect of intrusion on injury severity, as both are related to the severity of the crash. Crash severity was represented in these analyses by the speed limit affecting the striking vehicle. Assuming some positive correlation between speed limits and travel speeds, a striking vehicle approaching from a higher-speed roadway should produce a more severe crash. (The deformation-based measure of crash severity, Δv, was not used because more than half of the cases in NASS/CDS are missing the Δv.) Among crashes occurring on both low-speed (10–35 mph) and high-speed (55–65 mph) roads, over 80% of all serious injuries occurred in vehicles which suffered at least 6 in of intrusion. Thus, the magnitude of intrusion does seem to be related to the risk of serious injury.

However, Hobbs and Langdon (1988) report that in their side-impact crash tests there was no direct relationship between the magnitude of intrusion and injury risk as measured by thoracic loading. Rather, they say that it is "important to optimize the relative stiffness of the various parts of the side structure, and it appears to be very important that the inside of the door remains vertical as it intrudes."

This hypothesis could not be checked in the current study because there is no way to determine the orientation of the intruding door from the electronic NASS files.

Near-side front-seat occupants of light trucks have a lower risk of serious injury than near-side front-seat occupants of cars. The most likely explanations for this lower risk are the vehicle weight advantage of light trucks and the difference in vehicle heights. Because light trucks have higher ground clearance than passenger cars, impacting cars are more likely to strike the relatively stiff door sill as opposed to the door panel, thereby producing less intrusion into the occupant compartment. Table 13 summarizes intrusion levels only in those cases where the impacting vehicle was a car and the maximum intrusion occurred on the struck-side door panel. Intrusion levels of at least 6 in were more than twice as likely when the struck vehicle was a car rather than a light truck.

Far-side occupants of light trucks are at greater risk of serious injury than far-side occupants of cars. Terhune et al. (1984) reported that among drivers of vehicles struck in the right side by passenger cars, the rate of AIS ≥ 3 injuries was 15% for passenger car drivers and 20% for light-truck drivers. The increased risk observed among far-side light-truck occupants might be due to higher deceleration forces caused by the striking vehicle contacting the relatively stiff door sill of the light truck, or could indicate that the

Table 13. Distribution (percentage*) of intrusion levels by subject vehicle body type (only impacts by cars producing maximum intrusion to the struck side door panel)

| Subject vehicle | Maximum intrusion | | |
	≥ 1 in but < 3 in	≥ 3 in but < 6 in	≥ 6 in
Car (n = 361)	25.7	31.5	42.9
Light truck (n = 57)	45.8	35.2	19.1

*Percentages based on national estimates rather than raw counts.

interiors of light trucks (mostly pickups in this study) are less protective of occupants than car interiors.

Head and neck injuries are the most severe injuries for far-side occupants more often than for near-side occupants. Near-side occupants receive head and neck injuries as well, but they are usually not as severe as the chest injuries received. For example, a driver in a near-side crash may receive an AIS-3 skull fracture due to contact with the B-pillar, but the maximum coded AIS (AIS-4) is associated with multiple bilateral rib fractures. In 1995, NHTSA strengthened FMVSS 201 to require protection when an occupant's head strikes upper interior vehicle components (49 CFR Part 571.201). This may help reduce the severity of head and neck injuries in side impacts.

The occupant seated on the struck side of the vehicle is at greatest risk of serious injury in a side-impact crash, and thus efforts at side-impact protection have focused on such occupants. There is compelling evidence, however, that far-side occupants are at considerable risk, especially if these persons are elderly or riding in light trucks. Although the numbers in this study are relatively small, the growing popularity of light trucks will result in more occupants at risk of such injuries. Further research to better understand injuries among far-side occupants of light trucks should be conducted.

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