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INJURIES, RESTRAINTS AND VEHICLE FACTORS IN ROLLOVER CAR CRASHES

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Abstract—Rollover crashes involving 997 automobile occupants of the front outboard seating positions were reviewed. Injury levels, using the Abbreviated Injury Scale, were studied for their association with ejection, restraint use, roof crush, car weight, and the absence or presence of the B-pillar.

The results indicate that the more serious injuries and fatalities are sustained by those ejected from the car, with ejection occurring most often through the side glass area. Restraints are related to less severe injuries to the non-ejected occupant as well as to a reduced rate of ejection. Roof crush is found to be a factor that interacts with restraint use and with the vehicle factors.

INTRODUCTION

This article describes the results of an analysis of injuries in rollover car crashes. The injuries are described in terms of their severities with special consideration given to injuries of the head, neck, and spine. The effects of ejection, restraint use, roof crush, vehicle weight, and vehicle B-pillars on injury are considered.

The rollover is one of the most severe types of crash. The occupant is exposed to a greater chance of ejection, and ejection has been shown to be more life-threatening than containment [Huelke, Marsh and Sherman, 1973; Huelke, Marsh, DiMento and Sherman, 1972; Huelke and Gikas, 1966; Schwimmer and Wolf, 1962; Hight, Siegeland and Nahum, 1968].

The variety of rapidly changing force vectors that may be applied to car occupants during the rollover sequence presents a unique hazard, with many injuries occurring when the car is upside down [Moffatt, 1975]. Because of this tumbling motion, serious injuries to the head, neck, and spine are frequently sustained by non-ejected occupants.

The rollover is the one type of crash where roof crush is a common feature. Roof crush has been associated with more serious injury, and a Motor Vehicle Safety Standard has been proposed by the federal government [Federal Register 36 (236), 1971].

Restraint use has a significant effect upon injury. Ejection is nearly eliminated through the use of belts, and the severity of injuries to occupants within the rolling car is reduced.

The type of vehicle has an effect upon occupant injury. In most crash situations, larger, heavier cars have been shown to be safer than smaller cars [Mela, 1975; O'Day and Kaplan, 1975; Highway Loss Data Institute, 1976].

MATERIALS AND METHODS

The Highway Safety Research Institute (HSRI) of The University of Michigan is the repository for more than 200 accident data files, ranging from police-reported data to detailed accident reports prepared by Level III in-depth investigation teams [Green, 1975]. The Collision Performance and Injury Reports (CPIR) coded by the in-depth field teams and computerized by HSRI were used for this study. In this file there are numerous details about crash events, the types of crashes, vehicle damage assessments, and specific, detailed injury descriptions and injury severity ratings.

More than 7000 CPIR reports are now in computer storage. Most of these reports are on the newer model cars. The CPIR reports were prepared by research teams from 39 different in-depth clinical investigation projects in the United States and Canada. These research activities were supported by the National Highway Traffic Safety Administration (NHTSA), the Motor Vehicle Manufacturers Association (MVMA), and the Canadian Ministry of Transport.

It must be emphasized that the CPIR file is not a random sample of crashes. While each team selected individual cases according to its own criteria, in general, the CPIR file contains fairly severe crashes (e.g. 7% fatality rate) in newer model cars (1968 to current). As a result, statements of statistical significance may not refer to the total population of U.S. crashes. This is a serious limitation that should be kept in mind. However, the CPIR file is the only data base available that includes extensive, accurate crash and injury details on a large number of accidents.

For this study a computer search was conducted of passenger car rollover crashes. A total of 997 drivers or far right-front passengers between the ages of 13 and 90 were studied. Data analysis showed no difference in driver and passenger injury levels; thus they have been combined in this study. The Chi-Square statistic was used to test for statistical significance. A significance level of less than 0.05 was selected.

In previous articles we showed that a typical rollover crash involves a single car of smaller size, traveling at excessive speed, on a curve in the road, in a rural area, with limited visibility (dawn, dusk, or night) [Huelke, *et al.*, 1972, 1973]. In the present study, all rollovers were included even if another crash type preceded the rollover event. For injury ratings the 1976 revision of the Abbreviated Injury Scale (AIS-76) was used throughout this study (Table 1). Whenever necessary, the original reports were reviewed to clarify vehicle, occupant or injury details.

Table 1. Abbreviated injury scale†

AIS code	
0	No Injury
1	Minor
2	Moderate
3	Severe (not life-threatening)
4	Serious (life-threatening, survival probable)
5	Critical (Survival uncertain)
Killed	Died within 24 hr

†The Abbreviated Injury Scale (AIS-76) is available from: Elaine Petrucelli, P.O. Box 222, Morton Grove, IL 60053, U.S.A.

EJECTION

The most striking finding of the study is the statistical association between ejection and increased severity of injuries. This is graphically illustrated in Fig. 1, which illustrates the data in Table 2. Note, in Table 2, that one in five (21%) of the out-board-front-seat occupants was ejected. The ejectees have relatively few injuries that have a combined overall effect on the individual of minor, moderate, or severe (OAIS 1, 2, or 3) but nearly half (47%) of the serious and critical (OAIS 4 and 5) injuries, and 59% of the fatal injuries.

Only 4% of the restrained occupants were partially or completely ejected, compared to 25% of the unrestrained occupants. When the factor of belting is removed by eliminating all cases of restrained occupants from the analysis (Table 3), the data still show an association between ejection and a greater frequency of more severe injuries. In Table 3, 46% of the ejectees were killed, compared to only 10% of the non-ejected occupants. Ejectees also incurred three times as high a percentage of serious and critical (OAIS 4 and 5) injuries, compared to non-ejectees. Complementing this, contained occupants had a higher incidence of minor and moderate injuries (49% and 17%), compared to ejectees (15 and 12%). Some contained occupants (10%) in rollover crashes did not have any injuries, but all ejectees were injured.

In total, the amount of roof crush incurred by the vehicle was not associated with occupant ejection. No significant association was found between ejection and amount of roof crush (Table 4), or between injury severity of ejected occupants and amount of roof crush (Table 5).

Although there has been speculation that the amount of roof crush may affect the portal of ejection, it can be seen from the data in Table 6 that the frequency of ejection through specific

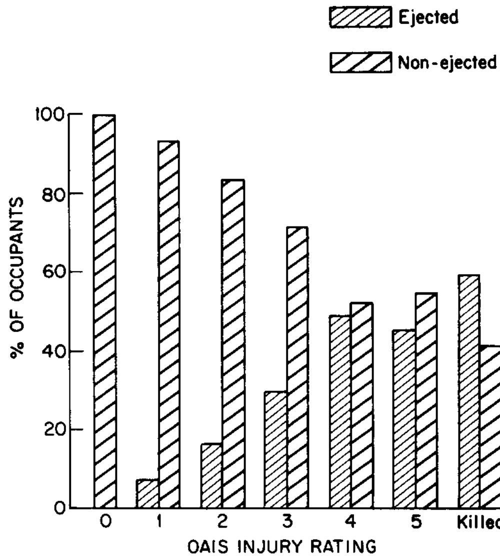

Fig. 1. Overall injury severity vs ejection or containment.

Table 2. OAIS† levels in rollover crashes, by ejection and non-ejection

OAIS level	Ejected occupants		Non-ejected occupants		Total
	N	(%)	N	(%)	N
0	0	(—)	93	(100)	93
1	31	(7.3)	392	(92.7)	423
2	24	(15.8)	128	(84.2)	152
3	32	(29.4)	77	(70.6)	109
4	12	(48.0)	13	(52.0)	25
5	10	(45.5)	12	(54.5)	22
Killed	94	(59.5)	64	(40.5)	158
Total	203	(20.7)	779	(79.3)	982

†Overall Abbreviated Injury Severity rating of the multiple injuries incurred by a crash victim.

Table 3. OAIS levels for unrestrained occupants

OAIS	Ejected occupants		Non-ejected occupants		Total
	N	(%)	N	(%)	N
0	0	(—)	59	(10.4)	59
1	30	(15.5)	277	(48.8)	307
2	24	(12.4)	96	(16.9)	120
3	30	(15.5)	62	(10.9)	92
4	11	(5.7)	10	(1.8)	21
5	10	(5.2)	10	(1.8)	20
Killed	89	(45.9)	54	(9.5)	142
Total	194	(100.0)	568	(100.0)	762

areas of egress is not significantly associated with the amount of roof crush. The data indicate that occupant ejection in rollover crashes occurs more often through the side window areas (47%) or open doors (31%) than through other portals (Table 6).

RESTRAINT USE

Effect of restraints

In addition to almost eliminating ejection, restraint use was advantageous to non-ejected occupants.

Table 4. Levels of post-crash roof crush and ejection of occupants

Roof crush inches	Ejected N	(%)	Non-ejected N	(%)	Total N	(%)
0	24	(14.7)	99	(14.2)	123	(14.3)
1–5	57	(35.0)	282	(40.6)	339	(39.5)
6–10	44	(27.0)	170	(24.5)	214	(24.9)
11–15	22	(13.5)	85	(12.2)	107	(12.5)
16–20	7	(4.3)	29	(4.2)	36	(4.2)
21–25	4	(2.5)	18	(2.6)	22	(2.6)
26+	5	(3.1)	12	(1.7)	17	(2.0)
Total	163		695		858	(100.0)

Table 5. Ejectee OAIS vs roof crush

Roof crush inches	OAIS 0 N	1 N	(%)	2 N	(%)	3 N	(%)	4 N	(%)	5 N	(%)	Killed N	(%)	Total N	(%)
0	—	6	(21.4)	3	(17.6)	3	(11.5)	3	(25.0)	0		9	(12.5)	24	(14.9)
1–5	—	12	(42.9)	7	(41.1)	10	(38.5)	4	(33.3)	1	(16.7)	22	(30.6)	56	(34.8)
6–10	—	5	(17.9)	5	(29.4)	8	(30.8)	2	(16.7)	1	(16.7)	22	(30.6)	43	(26.7)
11–15	—	2	(7.1)	1	(5.9)	5	(19.2)	1	(8.3)	3	(50.0)	10	(13.9)	22	(13.7)
16–20	—	1	(3.6)	0		0		2	(16.7)	0		4	(5.6)	7	(4.3)
21–25	—	2	(7.1)	0		0		0		0		2	(2.8)	4	(2.5)
26+	—	—		1	(5.9)	0		0		1	(16.7)	3	(4.2)	5	(3.1)
Total	0	28		17		26		12		6		72		161	(100.0)

Table 6. Area of occupant ejection vs roof crush

Roof crush inches	Side windows N	(%)	Doors N	(%)	Windshield N	(%)	Tailgate, roof, or open convertible N	(%)	Total N	
0	13	(54.2)	7	(29.2)	3	(12.5)	1	(4.2)	24	
1–5	23	(41.8)	20	(36.4)	9	(16.4)	3	(5.5)	55	
6–10	22	(52.4)	13	(31.0)	6	(14.3)	1	(2.4)	42	
11–15	8	(40.0)	8	(40.0)	2	(10.0)	20	(10.0)	20	
16–20	5	(100)	0	(—)	0	(—)	0	(—)	5	
21–25	2	(100)	0	(—)	0	(—)	0	(—)	2	
26+	1	(20.0)	1	(20.0)	2	(40.0)	1	(20.0)	5	
Unknown	16	(41.0)	11	(28.2)	6	(15.4)	6	(15.4)	39	
Total	90	(46.9)	60	(31.3)	28	(14.6)	14	(7.3)	192	(100%)

Of the non-ejected occupants in rollover crashes, those wearing belts had less severe injuries (Table 7). Of the unrestrained occupants, 10% were killed, compared to 4% of those wearing belt systems. Also, 15% of the unrestrained occupants had an OAIS of 3–5, compared to only 7% of those wearing belts. This indicates a potential reduction for fatalities and severe injuries of about 55% for belted non-ejected occupants in rollovers. Using the Chi-Square statistic, these data are highly statistically significant (Table 8).

The advantage of restraint use can also be seen when the association between vehicle roof crush and occupant injury is tested. Using the data from Table 7, the overall injury severity of unrestrained occupants in vehicles with roof crush of 6 in. or more was compared to the injury severity of those in vehicles with less than 6 in. of roof crush. There is a significant statistical associated between greater roof crush and higher injury levels to unstrained, contained occupants (Table 9). However, earlier analyses [Huelke, 1973] are confirmed in Table 9; there is no statistical association between OAIS and roof crush for restrained cooupants.

Restrained fatalities

Eight of the 192 non-ejected, belted occupants in rollover crashes died. Of these eight occupants, only three were involved in "pure" rollover crashes; in all others, the rollover

Table 7. Non-ejected occupant OAIS, belt system usage, and roof crush

	OAIS							
	0		1		2		3	
Roof crush inches	Belts not worn	Belts worn	Belts not worn	Belts worn	Belts not worn	Belts worn	Belts not worn	Belts worn
0	6	6	30	17	12	4	7	1
1–5	26	19	177	43	39	6	14	5
6–10	17	6	55	27	18	10	18	1
11–15	4	1	32	11	11	4	7	—
16–20	4	—	8	2	4	—	3	1
21–25	—	—	7	2	—	—	5	—
26+	—	—	—	—	2	—	4	—
Unknown	4	—	34	7	13	5	8	3
Total	61 (10.4%)	32 (16.7%)	283 (48.2%)	109 (56.8%)	99 (16.9%)	29 (15.1%)	66 (11.2%)	11 (5.7%)

	4		5		Killed		Total	
Roof crush inches	Belts not worn	Belts worn	Belts not worn	Belts worn	Belts not worn	Belts worn‡	Belts not worn	Belts worn
0	1	—	—	—	12	3	68	31
1–5	—	2	2	—	6	1	204	76
6–10	3	—	1§	—	9	2	121	46
11–15	3	—	2	1	8	1	67	18
16–20	1	—	2	—	3	1	25	4
21–25	1	—	—	—	3	—	16	2
26+	1	—	2	—	2	—	11	—
Unknown	1	—	2	—	13	—	75	15
Total	11 (1.9%)	2 (1.0%)	11 (1.9%)	1 (0.5%)	56 9.5%)	8 (4.2%)	587 (100.0%)	192 (100.0%)

†Does not include the six occupants with unknown OAIS who were not belted.
‡See text for case descriptions of those killed wearing belts.
§Back fractures.

Table 8. Chi-square of non-ejected occupant OAIS and restraint usage

	OAIS			
	0–2		3–5 & K	
Belt systems	N	(%)	N	(%)
Worn	170	(88.5)	22	(11.5)
Not worn	443	(94.7)	150	(25.3)

Chi-square = 13.977.
Significance level = 0.0002.

Table 9. Non-ejected occupant OAIS and roof crush, separated by belt usage

Unrestrained					Restrained				
Roof crush inches	OAIS 0–2 N	(%)	3–5 K N	(%)	Roof crush inches	OAIS 0–2 N	(%)	3–5 K N	(%)
0–5	230	(84.6)	42	(15.4)	0–5	95	(88.8)	12	(11.2)
6+	162	(67.5)	78	(32.5)	6+	63	(90.0)	7	(10.0)

Chi-square = 19.737
Significance level = 0.0000

Chi-square = 0.0000
Significance level = 0.9944

followed another type of crash. Of the eight fatalities, seven were not directly related to the rollover event. One individual died when his car rolled down a mountainside.

The following are case descriptions of rollover crashes involving non-ejected, belted occupants who died.

(1) A 1972 Datsun was involved in a severe, head-on collision followed by rollover. The 72-year-old male lap-shoulder belted driver of the Datsun received multiple critical injuries from the steering assembly, hood, and lower instrument panel (DT 72065).

(2) A 1971 Corvette, traveling at an estimated 75 mph in a left curve, went off the road and rolled over. The 26-year-old male lap-belted driver sustained facial injuries and was unconscious. His post-crash body position caused airway obstruction by blood from his non-fatal injuries. There was no roof crush (AA 130).

(3) A 1967 Pontiac went 350 ft down a mountainside. The lap-belted 58-year-old male driver sustained a fatal brain injury during the vehicle's fall and multiple rollovers. The car had 15 in. of roof crush (TR 1294).

(4) A 1971 Maverick went off an expressway and rolled over several times. The lap-belted 30-year-old male driver contacted the left roof side rail near the A-pillar. He died of head injuries. There was no roof crush (OK 147).

(5) A 1972 Chevrolet went off the right side of a curve, down an embankment, and rolled into a utility pole. The lap-belted male driver's fatal head injury was due to roof-pole impact. There was 19 in. of roof crush (CA 72181).

(6) A 1967 Toyota was involved in an intersectional collision with a 1970 Ford pickup truck. Both vehicles then went off the road and rolled over. The female lap-belted front right passenger of the Toyota had multiple fractures of the skull, brain, ribs, spleen, liver, a rupture of the aorta, lacerations of the lungs, and other injuries. She was dead at the scene. Her injuries were not related to the rollover. There was only 3 in. of roof crush (SW 7147).

(7) A 1968 Chevrolet stationwagon was involved in an oblique head-on collision with a 1971 Plymouth stationwagon that had crossed the median of an expressway. The Chevrolet then rolled over. The male lap-belted driver of the Chevrolet sustained multiple injuries to the head, ribs, and extremities. No injuries were related to the 8 in. of roof crush. The female lap-belted front right passenger had moderate-level injuries (AA 303).

(8) While on an expressway ramp, in a curve, a 1972 Dodge attempted to avoid a slower-moving vehicle. The Dodge struck the other car, spun out of control, struck a chain link fence, and rolled over. The 26-year-old male lap-belted driver was killed by a chain link fence post that penetrated the side window and struck the driver's head. The rollover (10 in. of roof crush) did not play a role in any of his injuries (SC 7421).

HEAD, NECK, AND SPINE INJURIES

Head injuries

Serious-to-fatal head injuries occurred most often to ejected occupants (Table 10). From Table 10, unrestrained ejected occupants had a 32% rate of fatal head injury compared to 3% for the unrestrained non-ejected. Unrestrained ejectees also incurred twice as many serious head injuries (AIS 3–5) as unrestrained non-ejectees (15% vs 7%). Of the belt-restrained non-ejected occupants, only 4% sustained a fatal head injury, and only 3% had the more serious head injuries (AIS 3–5). The comparable rates for unrestrained non-ejected occupants are 3% and 7%. For the non-ejected this is a 24% reduction in severe-to-fatal head injuries through the use of belts.

For those not ejected from the cars, severe-to-fatal head injuries were sustained at all levels of roof crush (Table 11). Of the 22 fatal head injuries sustained by occupants of vehicles with known roof crush, 10 (45%) were in vehicles with less than 6 in. of crush. In addition, cars with less than 6 in. of roof crush account for 34% of the severe-to-critical head injuries. In spite of the occurrence of severe-to-fatal head injuries in cars with lesser amounts of roof crush, there is a statistically significant association between greater roof crush, and a higher frequency of severe-to-fatal head injuries (significance level = 0.0082).

Neck injuries

The frequency and severity of neck injury is associated with ejection from the car (Table

Table 10. Head AIS, belt system usage, and occupant containment†

	Head AIS 0		Head AIS 1		Head AIS 2		Head AIS 3	
Occupant ejection	Belts not worn	Belts worn	Belts not worn	Belts worn	Belts not worn	Belts worn	Belts not worn	Belts worn
Not ejected	244	89	205	70	67	19	24	5
Ejected	38	—	34	1	29	2	14	1
Total	282 (36.9%)	89 44.9%)	239 (31.2%)	71 (35.9%)	96 (12.5%)	21 (10.6%)	38 (5.0%)	6 (3.0%)

	Head AIS 4		Head AIS 5		Killed		Total	
Occupant ejection	Belts not worn	Belts worn	Belts not worn	Belts worn	Belts not worn	Belts worn	Belts not worn	Belts worn
Not ejected	8	1	6	—	17	8	571	192
Ejected	7	—	9	—	63	2	194	6
Total	15 (2.0%)	1 (0.5%)	15 (2.0%)	0 (—%)	80 (10.5%)	10 (5.1%)	765 (100%)	198 (100%)

†This table does not contain the 21 for whom belt usage is "unknown" or the 4 for whom Head AIS is unknown.

Table 11. Head AIS, belt system usage, and roof crush for non-ejected occupants

	Head AIS 0				Head AIS 1				Head AIS 2			
Roof crush inches	Belts not worn N	(%)	Belts worn N	(%)	Belts not worn N	(%)	Belts worn N	(%)	Belts not worn N	(%)	Belts worn N	(%)
0	23	(10.6)	13	(15.3)	26	(14.2)	11	(17.2)	11	(20.0)	4	(25.0)
1–5	94	(43.5)	44	(51.8)	78	(42.6)	26	(40.6)	21	(38.2)	2	(12.5)
6–10	60	(27.8)	19	(22.4)	39	(21.3)	18	(28.1)	9	(16.4)	7	(43.8)
11–15	20	(9.3)	7	(8.2)	26	(14.2)	7	(10.9)	8	(14.5)	3	(18.8)
16–20	10	(4.6)	0	(—)	7	(3.8)	2	(3.1)	3	(5.5)	—	(—)
21–25	6	(2.8)	2	(2.4)	5	(2.7)	0	(—)	2	(3.6)	—	(—)
26+	3	(1.4)	0	(—)	2	(1.1)	0	(—)	1	(1.8)	—	(—)
Total	216		85		183		64		55		16	

	Head AIS 3–5				Killed				Total			
Roof crush inches	Belts not worn N	(%)	Belts worn N	(%)	Belts not worn N	(%)	Belts worn N	(%)	Belts not worn N	(%)	Belts worn N	(%)
0	6	(17.6)	—	(—)	2	(14.3)	3	(17.5)	68	(13.5)	31	(17.5)
1–5	4	(11.8)	3	(75.0)	4	(28.6)	1	(42.9)	201	(40.0)	76	(42.9)
6–10	9	(26.5)	—	(—)	1	(7.1)	2	(26.0)	118	(23.5)	46	(26.0)
11–15	5	(14.7)	—	(—)	4	(28.6)	1	(10.2)	63	(12.5)	18	(10.2)
16–20	2	(5.9)	1	(25.0)	2	(14.3)	1	(2.3)	24	(4.8)	4	(2.3)
21–25	2	(5.9)	—	(—)	1	(7.1)	—	(—)	16	(3.2)	—	
26+	6	(17.6)	—	(—)	—	(—)	—	(—)	12	(2.4)	—	
Total	34		4		14		8		502†		117	

†Does not include one unknown AIS at 6–10 in. of roof crush.

12). It can be seen in Table 12 that 22% of the ejected occupants had some level of neck injury, while only 15% of those not ejected had a neck injury, a containment improvement of 32%. Ejectees had a 4% rate of more serious (AIS 3–5) neck injuries, while the rate for contained

Table 12. Neck AIS vs occupant containment†

Occupant ejection	Neck AIS 0 N	(%)	1 N	(%)	2 N	(%)	3 N	(%)	4 N	(%)	5 N	(%)	Killed N	(%)	Total N	
Not ejected	664	(84.6)	86	(11.0)	14	(1.8)	7	(0.9)	1	(0.1)	1	(0.1)	12	(1.5)	785	
Ejected	158	(77.8)	17	(8.4)	6	(3.0)	5	(2.5)	—	(—)	3	(1.5)	14	(6.9)	203	
Total	822	(83.2)	103	(10.4)	20	(2.0)	12	(1.2)	1	(0.1)	4	(0.4)	26	(2.6)	988	(100%)

†Does not include three ejected occupants for whom Neck AIS is unknown.

occupants was only 1%. Fatalities resulting from neck injuries occurred in 7% of those ejected, and in less than 2% of the contained occupants, a containment improvement of 71%.

From Table 13, all 9 contained occupants who sustained a fatal neck injury were unrestrained, with 4 dying in cars with no roof crush. Severe neck injuries (AIS 3–5) were found in only 1% of the unrestrained non-ejected occupants, and these neck injuries are scattered throughout the roof crush range. There were no fatal, serious, or critical neck injuries (AIS 4 and 5) to belted, non-ejected occupants, and only one moderate (AIS 2) and one severe (AIS 3) injury.

Back injuries

Most vertebral column injuries below the cervical spine occurred in the lumbar area, although a few individuals suffered thoracic spine injuries. Injuries to the lumbar or thoracic area, the bones or adjacent soft tissue, were reported for only 9% of the non-ejected occupants, but in 17% of the ejectees (Table 14).

In general, AIS 3–5 spine injuries to non-ejected rollover occupants were infrequent, occurring in only 2% of the occupants (Table 15). From Table 15 it can be seen that the 14 more serious spine injuries (AIS 3 and 4) occurred at all levels of roof crush; 5 were at roof crush levels of less than 6 in., and 7 others at a roof crush of 6–15 in. Two were in cars with more than

Table 13. Neck AIS, belt system usage and roof crush for non-ejected occupants

Roof crush inches	Neck AIS 0 Belts not worn N	(%)	0 Belts worn N	(%)	1 Belts not worn N	(%)	1 Belts worn N	(%)	2 Belts not worn N	(%)	2 Belts worn N	(%)
0	56	(13.2)	30	(19.4)	7	(13.7)	1	(5.0)	—	(—)	—	
1–5	177	(41.6)	61	(39.4)	18	(35.3)	13	(65.0)	4	(36.4)	1	(20.0)
6–10	105	(24.7)	42	(27.1)	10	(19.6)	4	(20.0)	2	(18.2)	—	
11–15	48	(11.3)	16	(10.3)	10	(19.6)	2	(10.0)	2	(18.2)	—	
16–20	20	(4.7)	3	(1.9)	1	(2.0)	—		1	(9.1)	—	
21–25	10	(2.4)	3	(1.9)	3	(5.9)	—		1	(9.1)	—	
26+	9	(2.1)	—	(—)	2	(3.9)	—		1	(9.1)	—	
Total	425		155		51		20		11		1	

Roof crush inches	Neck AIS 3–5 Belts not worn N	(%)	3–5 Belts worn N	(%)	Killed Belts not worn N	(%)	Killed Belts worn N	(%)	Total Belts not worn N	(%)	Total Belts worn N	(%)
0	1	(16.7)	2	(100.0)	4	(44.4)	—		68	(13.5)	33	(18.5)
1–5	2	(33.3)	—		—		—		201	(40.0)	75	(42.1)
6–10	1	(16.7)	—		1	(11.1)	—		119	(23.7)	46	(25.8)
11–15	—	(—)	—		2	(22.2)	—		63	(12.5)	18	(10.1)
16–20	1	(16.7)	—		1	(11.1)	—		24	(4.8)	3	(1.7)
21–25	1	(16.7)	—		1	(11.1)	—		16	(3.2)	3	(1.7)
26+	—	(—)	—		—		—		12	(2.4)	—	
Total	6		2		9		—		502		178	

Table 14. Maximum back AIS vs occupant containment

Occupant ejection	Spinal AIS 0 N	0 (%)	1 N	1 (%)	2 N	2 (%)	3 N	3 (%)
Not ejected	713	(90.8)	56	(7.1)	1	(0.1)	13	(1.7)
Ejected	172	(83.5)	22	(10.7)	4	(1.9)	6	(2.9)
Total	885	(89.3)	78	(7.9)	5	(0.5)	19	(1.9)

Occupant ejection	4 N	4 (%)	5 N	5 (%)	Total N	
Not ejected	1	(0.1)	1	(0.1)	785	
Ejected	2	(1.0)	0	(—)	206	
Total	3	(0.3)	1	(0.1)	991	(100%)

Table 15. Maximum back AIS, belt system usage and roof crush for non-ejected occupants†

Roof crush inches	Back AIS 0 Belts not worn	0 Belts worn	1 Belts not worn	1 Belts worn	2 Belts not worn	2 Belts worn
0	63	30	4	1	1	—
1–5	178	71	18	5	—	—
6–10	107	42	8	4	—	—
11–15	58	14	4	3	—	—
16–20	22	4	1	—	—	—
21–25	15	2	—	—	—	—
26+	12	—	—	—	—	—
Total	455	163	35	13	1	—

Roof crush inches	3–5 Belts not worn	3–5 Belts worn	Killed Belts not worn	Killed Belts worn	Total Belts not worn	Total Belts worn
0	—	—	—	—	68	31
1–5	5	—	—	—	201	76
6–10	4	—	—	—	119	46
11–15	2	1	—	—	64	18
16–20	1	—	—	—	24	4
21–25	1	—	—	—	16	2
26+	—	—	—	—	12	—
Total	13	1	—	—	504	177

†Because of the very few injuries, percentages are not given.

15 in. of roof crush. Of the lap-belted contained occupants, none had a spine injury greater than minor. Of the lap-shoulder belted occupants, only 4 had a spine injury. Three of these were minor, and one was a fracture of the seventh and tenth thoracic vertebrae (AIS 3).

VEHICLE FACTORS

Three percent of the front-seat outboard occupants were in convertibles. In rollover crashes the problems of occupants in convertibles are compounded when compared to those in other types of passenger cars (Table 16). When both partial and complete ejection are considered in Table 16, ejections from convertibles occur at a rate twice that of other passenger cars (39 vs 20%). This difference is statistically significant. The higher rate of ejection from convertibles is reflected in the injuries received by convertible occupants. Only 3% of convertible occupants in rollovers escaped injury, whereas 10% of the occupants of other passenger cars were not injured. Since convertibles are unique in their occupant containment performance, the occupants of convertibles have been excluded in the consideration of other vehicle factors.

Table 16. Ejection from convertibles and other passenger cars

Occupant ejection	Convertibles N	(%)	Other type cars N	(%)
Not ejected	20	(60.6)	765	(79.9)
Ejected	13	(39.4)	193	(20.1)
Total	33		958	

Vehicle weight

The weight of the vehicle seems to have surprisingly little effect upon occupant injury in rollover crashes.

Of the 964 front-outboard occupants of non-convertible passenger cars, we were able to classify 520 as having been in a "light" car of 3249 pounds or less, and 428 as having been in a "heavy" car of 3250 pounds or more. Vehicle weight data for the remaining 16 occupants were unavailable.

Of occupants in "heavy" cars, 34% had severe-to-critical injuries (AIS 3–5) or were killed, whereas 29% of those in "light" cars had comparable injuries (Table 17). This difference shown in Table 17 is not statistically significant, but it is interesting because other research studies have found large cars to be safer than lighter vehicles in most crash situations [O'Day and Kaplan, 1975; Highway Loss Data Institute Report, 1976; Green, 1975].

When limited to only the contained occupants, the difference in injury level between "heavy" and "light" cars, noted in Table 17, is virtually eliminated (Table 18). Contained occupants in "heavy" cars are seen to have nearly the same rate of severe-to-critical (AIS 3–5) injury or fatality (21%) as those in "light" cars (20%).

Table 17. OAIS of all occupants in light and heavy cars

Car weight	OAIS 0 N	(%)	1 N	(%)	2 N	(%)	3 N	(%)	4 N	(%)	5 N	(%)	Killed N	(%)	Total N
Light	55	(10.7)	235	(45.6)	75	(14.6)	54	(10.5)	13	(2.5)	14	(2.7)	69	(13.4)	515
Heavy	37	(8.7)	172	(40.6)	72	(17.0)	51	(12.0)	10	(2.4)	6	(1.4)	76	(17.9)	424
Total	92	(9.8)	407	(43.3)	147	(15.7)	105	(11.2)	23	(2.4)	20	(2.1)	145	(15.4)	939†

†Nine occupants with an unknown level of injury are excluded.

Table 18. OAIS of contained occupants in light and heavy cars†

Car weight	OAIS 0 N	(%)	1 N	(%)	2 N	(%)	3 N	(%)	4 N	(%)	5 N	(%)	Killed N	(%)	Total N
Light	55	(13.3)	218	(52.9)	56	(13.6)	37	(9.0)	5	(1.2)	7	(1.7)	34	(8.3)	412
Heavy	37	(11.0)	162	(48.1)	66	(19.6)	38	(11.3)	6	(1.8)	3	(0.9)	25	(7.4)	337
Total	92	(12.3)	380	(50.7)	122	(16.3)	75	(10.0)	11	(1.5)	10	(1.3)	59	(7.9)	749

†This table contains only those occupants whose injuries are known.

The lack of a significant association between car weight and injury is particularly surprising because roof crush is not independent of car weight. There is a significantly higher proportion of occupants in "heavy" cars with six or more inches of roof crush than in "light" cars with this much roof crush (Table 19). Also, the association of roof crush with contained occupant OAIS is significant for both "light" and "heavy" cars (Table 20). Therefore, the contained occupants of heavy cars might have been expected to have a significantly higher rate of the more serious injuries than the contained occupants of "light" cars. As we have seen in Table 18, this did not occur.

Upper B-pillars

The B-pillar is the side structure component of the vehicle that provides a place to attach

Table 19. Occupant exposure to roof crush in light and heavy cars†

Roof crush inches	Light cars N	(%)	Heavy cars N	(%)
0–5	287	(62.7)	158	(43.2)
6+	171	(37.3)	208	(56.8)

Chi-square = 30.344
Significance level = 0.0000

†This table includes only those occupants known to have been in "light" or "heavy" cars where the post-crash roof crush level was known.

Table 20. Chi-square tests: the relation of contained occupant OAIS to roof crush†

	Car weight							
	Light cars OAIS				Heavy cars OAIS			
Roof crush	0–2		3–5 & Killed		0–2		3–5 & Killed	
inches	N	(%)	N	(%)	N	(%)	N	(%)
0–5	200	(85.1)	35	(14.9)	119	(88.8)	15	(11.2)
6+	100	(73.0)	37	(27.0)	116	(73.4)	42	(26.6)

Light: Chi-square = 7.379
Significance level = 0.0066

Heavy: Chi-square = 9.971
Significance level = 0.0016

†This table includes only occupants with data on vehicle weight, roof crush, and injury severity.

the front door striker and the hinges for the rear door. The upper B-pillar extends from the beltline of the car to the roof. In this discussion, the upper B-pillar is referred to as "the B-pillar". We were able to determine, for all but 36 occupants, whether or not their cars had B-pillars. For these occupants in rollover crashes we found that cars with B-pillars had lesser amounts of roof crush and a lower rate of ejection through the side window area.

The level of post-crash roof crush is known for the cars of 88% of the occupants (Table 21). Only 39% of occupants in cars with B-pillars were exposed to roof crush of 6 in or more as compared to 56% of the occupants in cars without B-pillars. This difference is statistically significant (Significance level = 0.0000).

There is no statistically significant difference between the frequencies of ejection of occupants from vehicles with and without B-pillars (Table 22). There is however, a significant difference in the group of occupants ejected through the side window areas (Table 23). Whereas only 7% of the occupants in cars with B-pillars were ejected through the side window areas, 12% of occupants were ejected through the side window areas in cars without B-pillars. This difference from Table 23 is statistically significant (Significance level = 0.0060).

Since B-pillars are associated with lesser amounts of roof crush and are associated with a significantly lower rate of side window ejection, a lower level of injury might be anticipated with B-pillars. The expected association of lower OAIS with presence of B-pillars does appear (Table 24). The association between B-pillars and a lower rate of fatality in Table 24 is

Table 21. Occupant exposure to roof crush in cars with and without B-pillars†

Upper B-pillar		Inches of roof crush: None	1–5	6–10	11–15	16–20	21–25	26+	Total
With	N	79	224	111	51	15	7	8	495
	(%)	(16.0)	(45.3)	(22.4)	(10.3)	(3.0)	(1.4)	(1.6)	(100)
Without	N	36	103	90	48	18	15	9	319
	(%)	(11.3)	(32.3)	(28.2)	(15.0)	(5.6)	(4.7)	(2.8)	(100)

†Convertibles excluded.

Table 22. Occupant ejection from cars with and without B-pillars

Upper B-pillar	No ejection N	(%)	Ejection N	(%)	Total N
With	445	(81.4)	102	(18.6)	547
Without	287	(76.5)	88	(23.5)	375

†Convertibles excluded.
Chi-square = 2.871
Significance level = 0.0748

Table 23. Area of occupant ejection†

Upper B-pillars	Side window N	(%)	Doors N	(%)	Other N	(%)	None N	(%)	Total N	(%)
With	37	(6.8)	33	(6.0)	32	(5.9)	445	(81.4)	547	(100)
Without	46	(12.3)	24	(6.4)	18	(4.8)	287	(76.5)	375	(100)

†Convertibles excluded.

Table 24. All occupant OAIS in cars with and without B-pillars

Upper B-pillars		OAIS 0	1	2	3	4	5	Killed	Total
With	N	52	237	96	63	14	12	73	547
	(%)	(9.5)	(43.3)	(17.6)	(11.5)	(2.6)	(2.2)	(13.3)	
Without	N	32	159	50	38	9	9	75	372
	(%)	(8.6)	(42.7)	(13.4)	(10.2)	(2.4)	(2.4)	(20.2)	

significant (Significance level = 0.007), but the variation in non-fatal injury is not statistically significant.

Much of this effect of B-pillars upon occupant fatality seems to come from the reduction in side window ejection (Table 25). Considering only contained occupants, there is no significant difference between the OAIS of occupants of cars with B-pillars and that of occupants of cars without B-pillars.

Table 25. OAIS of contained occupants in cars with or without B-pillars

Upper B-pillars		OAIS 0	1	2	3	4	5	Killed	Total
With	N	52	218	79	44	8	8	34	443
	(%)	(11.7)	(49.2)	(17.8)	(9.9)	(1.8)	(1.8)	(7.7)	
Without	N	32	149	42	28	3	3	26	283
	(%)	(11.3)	(52.7)	(14.8)	(9.9)	(1.1)	(1.1)	(9.2)	

Another factor to be considered about B-pillars is their intrinsic potential injury producing capacity. Of the 445 contained front-outboard occupants in rollover crashes in cars with B-pillars, 8 individuals received injuries from impacting the B-pillar. One of these 8 occupants was killed and 2 others had severe injuries. The number of occupants contacting the B-pillar may have been underreported because with a significant reduction in ejection through the side window areas in cars with B-pillars, and the tumbling of occupants within a rolling car, more than 8 contacts of B-pillars by contained occupants might be expected.

Vehicle weight, B-pillars and roof crush

The effects of vehicle weight and B-pillars upon occupant injury have been considered separately. These factors are not independent. Significantly more light cars have B-pillars than do heavy cars. To examine the interactions among vehicle weight, B-pillars, roof crush, and AIS, the rate of incidence of severe-to-fatal injury to occupants in each of 8 possible categories has been compared (Table 26).

Table 26. Incidence of severe-to-fatal overall injury to occupants†

	Light cars Roof crush (inches)			Heavy cars Roof crush (inches)	
B-pillars	0–5	6+	B-pillars	0–5	6+
With	13%(25/190)	30%(26/88)	With	19%(11/58)	26%(18/70)
Without	25%(10/40)	22%(9/41)	Without	4%(3/70)	28%(24/85)

†Convertibles excluded: data presented include only those individuals for whom *all* factors were known.

The most interesting comparison in Table 26 is between cars with 6 in. or more of roof crush and cars with less roof crush. Only one group of cars with minimal roof crush had a severe-to-fatal injury rate greater than 20%, while all groups of cars with the greater roof crush had rates over 20%. Also, there is more variation in the incidence of severe-to-fatal injury, though without a clear pattern, among the cars with lesser roof crush than among the cars with greater roof crush. Among the cars with 6 in. or more of residual roof crush, the rate of severe-to-fatal injury varies only from 22–30%. Among the cars with lesser roof crush, the variation is from 4–25%. This suggests that a greater amount of crush is a positive indication of an injurious rollover and severe roof impact. However, the absence of roof crush is not an indication of a less injurious crash but simply a less severe roof impact.

The figures in Table 26 show that in cars with B-pillars the highest rate of severe-to-fatal injury occurs in light cars with large amounts of crush—24% of the occupants of cars with B-pillars have 33% of the severe-to-fatal injuries. For cars without B-pillars, heavy cars with large amounts of crush are the most severe combination—36% of the occupants of cars without B-pillars have 52% of the severe-to-fatal injuries. Across vehicle weight, the most injurious type of "rolled" light car is one with B-pillars and large amounts of crush—25% of the occupants of light cars have 37% of the severe-to-fatal injuries, while the most injurious heavy car is one without B-pillars and greater roof crush—30% of the occupants of heavy cars have 43% of the severe-to-fatal injuries.

Tables similar to Table 26 have been constructed for head, neck, and spine injuries (Tables 27–29). The data on head injuries for non-ejected occupants are shown in Table 27. Occupants of cars with greater roof crush (6 plus inches) are more often severely injured or killed than are those in vehicles with lesser amounts of roof crush. Heavy cars without B-pillars and more roof crush have the highest rate of severe-to-fatal head injuries. Tables 28 and 29 indicate that very few people have received severe-to-fatal injuries in the neck or back area. Thus, a generalization about specific injuries in cars that are light or heavy, or those with or without B-pillars, cannot readily be made.

Table 27. Incidence of severe-to-fatal (AIS 3–5 and killed) head injury to occupants†

	Light cars Roof crush (inches)			Heavy cars Roof crush (inches)	
B-pillars	0–5	6+	B-pillars	0–5	6+
With	6%(11/191)	11%(10/88)	With	5%(3/56)	11%(8/70)
Without	8%(3/40)	7%(3/42)	Without	3%(2/71)	15%(13/87)

†Convertibles excluded: data presented include only those individuals for whom *all* factors were known.

Table 28. Incidence of severe-to-fatal neck injury to occupants†

	Light cars Roof crush (inches)			Heavy cars Roof crush (inches)	
B-pillars	0–5	6+	B-pillars	0–5	6+
With	2%(4/191)	4%(4/89)	With	2%(1/58)	3%(2/70)
Without	5%(2/40)	2%(1/42)	Without	—(0/72)	1%(1/87)

†Convertibles excluded: data presented include only those individuals for whom *all* factors were know.

Table 29. Incidence of severe-to-fatal back injury to occupants†

	Light cars Roof crush (inches)			Heavy cars Roof crush (inches)	
B-pillars	0–5	6+	B-pillars	0–5	6+
With	2%(3/191)	4%(4/89)	With	3%(2/58)	1%(1/70)
Without	—(0/40)	—(0/42)	Without	—(0.71)	2%(2/87)

†Convertibles excluded: data presented include only those individuals for whom *all* factors were known.

CONCLUSIONS

The data used in this rollover study are biased to the more severe crashes and the more severe injuries and do not represent the total population of U.S. crashes. Even so, the value of containment (non-ejection) and the beneficial effects of belt restraint use in rollover collisions seems well documented.

Ejection

In this study, one of five outboard-front-seat occupants was ejected, with ejectees having 30% of the severe injuries, nearly half of the serious or critical injuries, and 6 out of 10 of the fatalities. The rate of serious and critical injury is more than three times that of the non-ejected and of fatalities is five times that of the non-ejected. Ejected occupants incurred a rate of serious and fatal head injuries eleven times as high as non-ejected unrestrained occupants. Containment reduced the more serious neck injuries by 71%, fatal neck injuries by 78%, and any spine injury by 44%. Ejection occurs most often through side door glass areas, and next most often through the open door.

Restraints

Belts reduced the frequency of more serious and fatal injuries of non-ejected occupants by 55%. Belt restraints reduced the frequency of any neck injury by 25%. Belted occupants did not sustain any serious, critical, or fatal neck injuries, and the vast majority of belted occupants did not have any spine injury. Of the few that did, almost all the injuries were minor. Only 3% of the belted occupants were ejected, compared to 25% of the unrestrained. Furthermore, there is a significant association between increased roof crush and injury levels to non-ejected unrestrained occupants that does not appear for restrained occupants.

Vehicle factors

The rate of ejection from convertibles is twice that from other passenger cars. The data indicate that increased roof crush is not significantly associated with increased frequency of ejection, to specific areas of egress, or to ejectee injury severity. Although there are more occupants in "heavy" than in "light" cars with roof crush of 6 in. or more, there is no difference in the more serious injuries (AIS 3–5) or of fatalities between occupants of the two groups of cars. Cars with B-pillars have a significantly lower percentage of occupants with the more serious injuries. Statistically, more occupants are ejected through side window areas from cars without B-pillars. For all occupants the rate of fatality is higher in cars without B-pillars.

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