

Sport Utility Vehicle (SUV) Rollover Collisions: An Analysis of NASS – CDS Injury Data for 1998 through 2004

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ABSTRACT

Rollover collisions are very complex and the subject of significant interest. Roll-over collisions involving Sport Utility Vehicles (SUV) are of particular interest due to their high center of gravity (increased propensity for rollover) and recent surge in popularity. The following research examines SUV rollover collisions documented in the National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) for the years 1998 through 2004. The NASS/CDS was initially screened for SUV rollover collisions, then screened to eliminate soft top vehicles, such as the Jeep Wrangler and Suzuki Samurai. The injury data was further limited to driving age teens and adults (age 16 and older) in the front outboard seating positions. The data was evaluated with respect to injury severity using the Abbreviated Injury Scale (AIS), roof crush, seatbelt usage, seated position in the vehicle and with respect to roll direction (far-side/near-side), ejection status and crash severity measured by number of quarter turns of the vehicle. The data shows that ejection is the best single predictor of serious or fatal injury and that seatbelts are highly effective in preventing ejection. Further, seatbelted occupants have significantly less severe injuries than their non-seatbelted non-ejected counterparts, regardless of roll direction and number of rolls. As a general trend, non-ejected seatbelted occupants had a lower fraction of MAIS 3 and above injuries than their non-seatbelted non-ejected counterparts for various categories of roof crush depth; however, not all categories reached a $p < 0.05$ level of significance.

INTRODUCTION

Rollover collisions are complex as compared to their planar counterparts because they involve six degrees of freedom, as opposed to three. Yet, the number of staged rollover crashes are relatively sparse and therefore substantial information must be derived from historical crash data. Concerning injury, several variables have been considered in the past generally evaluating data from the National Automotive Sampling System (NASS) Crashworthiness Data System (CDS), and the Fatal Accident Reporting System (FARS). It has been shown, for example, that the injury incidence and severity is substantially higher for ejected occupants, as opposed to non-ejected occupants. Paranteau, et. al. (2000) concluded that “for unbelted drivers, the rate to be seriously injured was 10 times higher when completely ejected than non-ejected. Furthermore, for non-ejected drivers, the rate of seriously injured [occupants] seemed higher when they were unbelted than belted”. Esterlitz et. al. (1989) found “single vehicle rollover crashes have the highest increase risk of death due to ejection: about eightfold for the driver and sevenfold for the right front passenger”. Paranteau, et. al. (2001) divided the passengers into nearside and farside; where nearside was the seat adjacent to the roll direction. Based on the data presented, the ejection rate for unbelted passengers was approximately 25.4% (farside) and 23.1% (nearside). For belted drivers, the ejection rate was 1.8% (farside) and 2.1% (nearside). The seatbelt usage rate was reported at approximately 71%. Considering only fatal crashes, Determann, et. al. (2002) reported a

seatbelt usage of 73%, with a 4% ejection rate of belted occupants and a 53% ejection rate of unbelted occupants. Diggs, et. al. (1998) examined the rate of serious or fatal injuries for passenger cars and light trucks. They found that for seatbelted occupants in automobiles, fatal or serious injury occurred in 2.84% of belted occupants and 9.55% for unbelted occupants, a ratio of 3.36 for unbelted to belted occupant's serious/fatal injury rate. Similarly for light trucks, the serious/fatal injury rate for belted occupants was 1.8% and for unbelted occupants 11.01%, an unbelted to belted serious/fatal injury ratio of 6.12. Freidman, et. al. (1998) reported that "although nearly half of the occupants were wearing safety belts, unrestrained occupants received more than four times as many serious to fatal injuries". Godrick (2002) examined injury data specifically for Sport Utility Vehicles (SUV's). His data indicates that the injury rate for unbelted occupants is approximately four times that of belted occupants, assuming a 67% seatbelt usage rate.

Of particular interest has been the effect of roof crush to the injury potential. Experimental testing with Hybrid III Anthropometric Test Devices (ATDs) has shown no significant increase in the incidence or severity of head/neck injuries and or load on ATDs, based on increased roof crush for similar rollover crashes with and without roll cages, Orłowski, et al (1985), Bahling, et. al. (1990) and Moffatt, et. al. (2003). Similar conclusions were reached by Paniali, et.al. (1998). Friedman, et.al. (1998) concludes that there is a correlation between increased roof crush and increased injury severity. They state "restraints improve the effective residual headroom by about seven centimeters. That is, a restrained occupant compared with an unrestrained occupant, can withstand as much as seven centimeters of additional roof crush without sustaining serious injury". Godrick (2002) in his study of SUV injury data concludes "when removing the ejected unbelted occupants [from consideration], roof associated contacts show similar trends for both belted and unbelted occupants."

With the increase in popularity of SUV's and their higher propensity to rollover, as opposed to the traditional automobile, specific investigation of SUV rollovers is warranted. The purpose of this

research is to examine SUV rollovers and compare injury outcomes based on severity of the impact, as measured by quarter turns of roll and roof crush, effectiveness of the seatbelt in preventing ejection and injury, and ejection status on injury outcomes. Both exposure and criterion counts are included to give percentage of exposures which result in the criterion being met.

METHODOLOGY AND RESULTS

The National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) for the years 1998 through 2004 was screened for SUV rollover collisions. The data was further screened to eliminate any open vehicles, such as the Jeep Wrangler and Suzuki Samurai; however, all model years of closed SUVs were included. The data was further screened to include only front seat outboard occupants. Only occupants that were 16 years of age or older were considered. The screening resulted in 1,087 vehicle crashes with 1,451 occupants being considered. All information is unweighted, which allows the reader to assess the number of data in each category. It should be noted that some occupant exposures had either missing or unknown data in one or more fields. While all occupant exposures were screened, those with insufficient data for a specific table were not included. Therefore, the total exposures listed in any given table may be less than 1451.

Table 1 gives the breakdown of the collisions by direction of roll.

Rollover collisions		
Leading side	Vehicle count	%
Driver's side	573	52.7
Passenger's side	440	40.4
Unknown	68	6.3
End over end	6	0.6
Total	1,087	

Table 1. Vehicle roll direction.

The collision roll severity is given in quarter turns of the vehicle. Data for this study is presented in Table 2. As can be seen, over half (69.4%) of the rollover collisions, excluding unknown and end-over-end collisions, resulted in one full roll or less. Of those, most were either one half roll with

the final rest on the roof (36.7%) or one full turn, with final rest on the wheels (35.6%). Final rest on the side (¼ or ¾ roll) constituted only 29.1% of the one roll or less collisions. A small percentage (5.9%) of the roll-over collisions, excluding unknown and end over end collisions, resulted in more than two full rolls.

Rollover severity		
¼ turns of roll	Vehicle Count	%
1	102	10.4
2	251	25.5
3	87	8.8
4	243	24.7
5/6	161	16.4
7/8	82	8.3
9 to 12	49	5.0
Over 12	9	0.9
Unknown	97	---
End over end	6	---
Total	1,087	

Table 2. Collision roll severity (*unknown and end-over-end collisions omitted).

The occupants can be categorized by position in the vehicle (driver or passenger) or by position with respect to the roll direction (near and far side, where near side is the seated position adjacent to

Occupant position		
Occupant position	Count	%
Driver's seat	1084	74.7
Passenger's seat	367	25.3
Total	1451	

Table 3. Occupant position in the vehicle.

Occupant position		
Occupant position	Count	%*
Near side	735	54.5
Far side	613	45.5
Unknown	96	---
End over end	7	---
Total	1451	

Table 4. Passenger position with respect to the roll direction. (*unknown and end over end data omitted in calculating the percentage).

the leading side of the roll). The breakdown is given in Tables 3 and 4.

There was nearly three times as many drivers (74.7%) as front seat passengers (25.3%). This is expected since there must be a driver, but the passenger seat can be occupied, empty or occupied with a person under 16 years of age. Concerning the direction of roll of the occupants whose position is known, the distribution was more even, with 54.5% on the near side and 46.5% on the far side.

Seatbelt usage by position is noted in Tables 5 and 6.

Occupant position with respect to the vehicle				
Occupant position	Seatbelted		Non-seatbelted	
	Count	%	Count	%
Driver's seat	765	73.1	282	26.9
Passenger's seat	243	69.0	109	29.7
Total	1008	72.1	391	27.9

Table 5. Seatbelt usage as a function of passenger position in the vehicle.

Occupant position with respect to the roll direction						
Occupant position	Seatbelted		Non-seatbelted		Unknown	
	Count	%	Count	%	Count	%
Near side	530	74.6	180	25.4	25	---
Far side	413	70.2	175	29.8	25	---
Unknown	65	---	36	---	2	---
Total	1008		391		52	

Table 6. Seatbelt usage as a function of passenger position with respect to the roll direction.

As can be seen from Tables 5 and 6, the seat belt usage was approximately 72%, with the driver usage slightly higher and the passenger usage slightly lower. Similarly, the near side seatbelt usage was slightly higher than the far side.

Ejection from the vehicle is divided into three categories: None, partial and full. Partial ejection includes cases where any portion of the body extends out of the vehicle passenger compartment,

such as a head, trunk or an extremity. Ejection from the vehicle, based on the occupant seated position in the vehicle (driver or front seat passenger) and seatbelt usage is presented in Table 7. The seated position and ejected status is known for a total of 1255 exposures.

Ejection of driver and passenger								
Eject.	Seatbelted				Non-seatbelted			
	Drive	Pass	Tot	%	Drive	Pass	Tot	%
None	668	118	786	91.0	128	60	188	48.1
Part.	56	9	65	7.5	26	5	31	7.9
Full	8	5	13	1.5	129	43	172	44.0
Total	732	132	864		283	108	391	

Table 7. Ejection status of occupants as a function of seated position in the vehicle (driver or front seat passenger) and seatbelt usage.

Ejection from the vehicle, based on the position of the occupant with respect to the roll direction and seatbelt usage is presented in Table 8. Note the seated position and ejected status is known for a total of 1287 exposures.

Ejection, farside and nearside								
Eject.	Seatbelted				Non-seatbelted			
	Near	Far	Tot	%	Near	Far	Tot	%
None	490	372	862	92.5	92	79	171	48.2
Part.	30	26	56	6.0	14	15	29	8.2
Full	5	9	14	1.5	74	81	155	42.7
Total	525	407	932	100	180	175	355	

Table 8. Ejection status of occupants as a function of seated position with respect to the direction of roll and seatbelt usage.

As can be seen from Tables 7 and 8, seatbelts are highly effective in preventing ejection. Considering Table 8 data, only 7.5% of seatbelted occupants are either partially or fully ejected, as compared to 51.2% for the non-seatbelted group. The benefit is overwhelming when it comes to full ejection, only 1.5% of seatbelted exposures as opposed to 42.7% of non-seatbelted exposures. There also appears to be a slight benefit concerning partial ejections; 6.0% of those seatbelted were partially ejected as opposed to 8.2% for the non-seatbelted group.

Ejection as a function of roll severity and seatbelt usage is presented in Tables 9 and 10. It appears from Table 9 that full ejection is slightly more prevalent with the far side seating position, despite that there were less far side exposures (45.5% to 54.5% for near side exposures), as reported in Table 4.

Complete ejection								
¼ turns	Seatbelted				Non-seatbelted			
	Near	Far	Tot	%	Near	Far	Tot	%
1&2	2	1	3	25.0	4	8	12	7.7
3&4	0	1	1	8.3	24	27	51	32.9
5&6	1	4	5	41.7	25	14	34	21.9
7&8	0	2	2	16.7	12	16	28	18.1
>8	1	0	1	8.3	6	10	16	10.3
Total	4	8	12		74	81	155	
%	33.3	66.7			45.5	54.4		

Table 9. Full ejection of occupants as a function of seated position with respect to the direction of roll and roll severity.

Partial ejection								
¼ turns	Seatbelted				Non-seatbelted			
	Near	Far	Tot	%	Near	Far	Tot	%
1&2	11	4	15	27.7	4	6	10	34.5
3&4	7	8	15	27.2	5	5	10	34.5
5&6	4	4	8	14.8	3	4	7	24.1
7&8	3	1	4	7.4	0	0	0	0
>8	5	7	12	22.2	2	0	2	6.0
Total	30	24	54		14	15	29	

Table 10. Partial ejection of occupants as a function of seated position with respect to the direction of roll and roll severity.

Table 10 shows the distribution of partial ejections. Notably, more partial ejections are reported for seatbelted occupants in near side initial seated positions. It is interesting to note that 22.2% of seatbelted partial ejections occur

Maximum Abbreviated Injury Scale (MAIS)								
MAIS	Seatbelted				Non-seatbelted			
	Near	Far	Tot	%	Near	Far	Tot	%
0	95	77	172	18.2	21	20	41	11.5
1	303	215	518	54.9	54	48	102	28.7
2	72	48	120	12.7	30	26	56	15.8
3	42	46	88	9.3	33	34	67	18.9
4	8	18	26	2.8	18	18	36	10.1
5	4	7	11	1.2	18	18	36	10.1
6	6	2	8	0.8	6	11	17	4.8
Total	530	413	943		180	175	355	

Table 11. MAIS injury level based on position with respect to the roll direction and seatbelt usage.

with roll severity of greater than 2 full rolls (>8 quarter turns), while Table 2 shows that less than 6% of the collisions result in more than two full

rolls. Partial ejections of non-seatbelted occupants appear to be distributed proportionately to the distribution of exposures, with respect to number of quarter rolls, reported in Table 2.

The Maximum Abbreviated Injury Scale (MAIS) level for each occupant was tabulated based on position and seatbelt usage (Table 11).

Table 11 shows a distinct reduction in injury for seatbelted occupants, with nearly three quarters (73.1%) reporting no injury (MAIS-0) or minor injury (MAIS-1), while nearly 60 % (59.8%) of the non-seatbelted occupants had injury levels of MAIS-2 and above.

Roof crush for each occupant exposure as a function of roll direction is given in Table 12.

Roof crush				
Roof crush (cm)	Nearside		Farside	
	Count	%	Count	%
0	322	46.2	266	45.6
1-7	115	16.5	82	14.1
8-14	92	13.2	88	15.1
15-29	124	17.8	107	18.4
30-45	33	4.7	32	5.5
46-60	8	1.1	6	1.0
>60	3	0.4	2	0.3
Total	697		583	

Table 12. Seatbelt usage as a function of passenger position in the vehicle.

Well over half (61.3%) of the exposures had a roof crush of 7 cm or less. Roof crush of 30 cm and above is relatively rare, occurring in approximately 6.4% of the exposures. It is interesting to note that the distribution of roof crush is remarkably similar between near and far side exposures, a result which was not expected.

The most significant occupant injury, using the MAIS, was examined for each occupant, based on the roof crush. Table 13 presents data for seatbelted occupants and Table 14 presents data for non-seatbelted occupants. As expected, seatbelted and non-seatbelted occupant exposures had a similar roof crush distribution.

Roof crush									
R.C.(cm)	Seatbelted (All)								
	MAIS								
	0	1	2	3	4	5	6	Tot	%
0	93	227	48	29	4	2	3	406	42.4
1-7	23	89	18	16	4	2	1	153	16.0
8-14	22	82	22	21	2	1	0	150	15.7
15-29	23	92	29	20	11	2	3	180	18.8
30-45	4	26	10	6	2	1	1	50	5.2
46-60	0	7	2	3	0	0	1	13	1.4
>60	0	3	2	0	0	1	0	6	0.6
Total	165	526	131	95	23	9	9	958	

Table 13. MAIS as a function of seatbelt usage and roof crush (including full and partially ejected occupants).

Roof crush									
R.C.(cm)	Non-seatbelted (All)								
	MAIS								
	0	1	2	3	4	5	6	Tot	%
0	20	48	21	30	14	15	8	156	41.5
1-7	9	14	7	11	4	3	2	50	13.3
8-14	5	18	9	6	7	5	2	52	13.8
15-29	8	21	19	17	12	10	3	90	23.9
30-45	2	3	2	3	6	4	2	22	5.9
46-60	1	0	2	2	0	0	0	5	1.3
>60	0	0	0	1	0	0	0	1	0.3
Total	45	104	60	70	43	37	17	376	

Table 14. MAIS as a function of seatbelt usage and roof crush (including full and partially ejected occupants).

Roof crush									
R.C. (cm)	Seatbelted (Not ejected)								
	MAIS								
	0	1	2	3	4	5	6	Tot	%
0	90	218	43	22	4	2	2	381	43.4
1-7	23	87	18	11	3	0	0	142	16.2
8-14	22	76	20	20	1	0	0	139	15.8
15-29	23	87	23	15	6	1	3	158	18.0
30-45	4	25	6	3	1	1	0	40	4.6
46-60	0	7	2	3	0	0	1	13	1.5
>60	0	3	1	0	0	1	0	5	0.6
Total	162	503	113	74	15	5	6	878	

Table 15. MAIS as a function of seatbelt usage and roof crush (excluding full and partially ejected occupants).

Table 15 and Table 16 present significant injury using the MAIS for seatbelted and non-seatbelted occupants based on the roof crush for non-ejected occupants.

Roof crush									
R.C.(cm)	Non-seatbelted (Not ejected)							Tot	%
	MAIS								
	0	1	2	3	4	5	6		
0	16	40	7	12	3	3	0	81	45.5
1-7	7	11	3	3	1	0	0	25	14.0
8-14	3	14	4	2	2	1	0	26	14.6
15-29	5	18	8	3	2	0	0	36	20.2
30-45	0	3	1	2	0	1	1	8	4.9
46-60	0	0	1	1	0	0	0	2	1.1
>60	0	0	0	0	0	0	0	0	0.0
Total	31	86	24	23	8	5	1	178	

Table 16. MAIS as a function of seatbelt usage and roof crush (excluding full and partially ejected occupants).

Table 17 and Table 18 present significant injury using the MAIS for seatbelted and non-seatbelted occupants based on the roof crush for fully ejected occupants

Roof crush									
R.C.(cm)	Seatbelted (Fully ejected)							Tot	%
	MAIS								
	0	1	2	3	4	5	6		
0	0	2	0	2	0	0	1	5	38.5
1-7	0	0	0	2	0	1	0	3	23.1
8-14	0	1	1	0	0	0	0	2	15.4
15-29	0	0	0	1	1	0	0	2	15.4
30-45	0	0	0	0	1	0	0	1	7.7
46-60	0	0	0	0	0	0	0	0	----
>60	0	0	0	0	0	0	0	0	----
Total	0	3	1	5	2	1	1	13	

Table 17. MAIS for fully ejected occupants as a function of seatbelt usage and roof crush .

Table 19 and 20 present significant injury using the MAIS for seatbelted and non-seatbelted occupants based on the roof crush for partially ejected occupants.

Roof crush									
R.C.(cm)	Non-seatbelted (Fully ejected)							Tot	%
	MAIS								
	0	1	2	3	4	5	6		
0	4	7	11	14	11	11	5	63	37.3
1-7	2	2	4	6	3	3	1	21	12.4
8-14	1	3	4	3	5	4	2	22	13.0
15-29	3	1	11	13	7	9	2	46	27.2
30-45	2	0	1	1	5	3	1	13	7.7
46-60	1	0	1	1	0	0	0	3	1.8
>60	0	0	0	1	0	0	0	1	0.6
Total	13	13	32	39	31	30	11	169	

Table 18. MAIS for fully ejected occupants as a function of seatbelt usage and roof crush.

Roof crush									
R.C.(cm)	Seatbelted (Partial ejection)							Tot	%
	MAIS								
	0	1	2	3	4	5	6		
0	3	6	5	5	0	0	0	19	31.1
1-7	0	2	0	3	1	1	1	8	13.1
8-14	0	5	1	1	1	1	0	9	14.8
15-29	0	3	6	4	3	0	0	16	26.2
30-45	0	1	3	3	0	0	1	8	13.1
46-60	0	0	0	0	0	0	0	0	0.0
>60	0	0	1	0	0	0	0	1	1.6
Total	3	17	16	16	5	2	2	61	

Table 19. MAIS for partially ejected occupants as a function of seatbelt usage and roof crush.

Roof crush									
R.C.(cm)	Non-seatbelted (Partial ejection)							Tot	%
	MAIS								
	0	1	2	3	4	5	6		
0	0	1	3	4	0	1	3	12	41.4
1-7	0	1	0	2	0	0	1	4	13.8
8-14	1	1	1	1	0	0	0	4	13.8
15-29	0	2	0	1	3	1	1	8	27.6
30-45	0	0	0	0	1	0	0	1	3.4
46-60	0	0	0	0	0	0	0	0	0.0
>60	0	0	0	0	0	0	0	0	0.0
Total	1	5	4	8	4	2	5	29	

Table 20. MAIS for partially ejected occupants as a function of seatbelt usage and roof crush.

To determine if seatbelted occupants experience a lower injury level than non-seatbelted non-ejected occupants, the MAIS mean and standard deviation

for all seatbelted occupants and all roof crush levels was calculated for all seatbelted occupants (Table 13) and non-seatbelted/not ejected occupants (Table 16). It was determined that all seatbelted occupants had a mean MAIS of 1.318 (S.D.=1.097) while non-seatbelted/not ejected occupants had a mean of 1.494 (S.D.= 1.258). The statistical analysis (t-test) demonstrates that the seatbelted group had a significantly lower maximum injury level than their non-seatbelted/not ejected counterparts (p=0.041).

To examine significant injuries between seatbelted and non-seatbelted occupants as a function of roof crush, injuries of MAIS 3 and above were considered and presented in Table 21 (all exposures), Table 22 (non-ejected exposures), Table 23 (fully ejected exposures) and Table 24 (partial ejected exposures).

All exposures, including partial and full ejection						
R.C.(cm)	Seatbelted			Non-seatbelted		
	Total	MAIS ≥ 3		Total	MAIS ≥ 3	
		Count	%		Count	%
0	406	38	9.4	156	67	42.9
1-7	153	23	15.0	50	20	40.0
8-14	150	25	16.7	52	20	38.5
15-29	180	36	20.0	90	42	46.7
30-45	50	10	20.0	22	15	68.2
46-60	13	4	30.8	5	2	40.0
>60	6	1	16.7	1	1	100.0

Table 21. Seatbelted and non-seatbelted exposures and most serious injury of AIS 3 and above (MAIS 3 and above) as a function of roof crush..

As can be seen from Table 21, there is an increasing trend for the percentage of MAIS 3 and above injury per exposure with increasing roof crush. In every case, the fraction of MAIS 3 and above injury is less for seatbelted occupants, regardless of roof crush. A statistical analysis (chi-square) was performed for each category of crush level. Seatbelted occupants had significantly less (p<0.05) MAIS 3 and above injuries for all categories of roof crush less than 46 cm. Of note, the data above 46 cm of crush is relatively sparse. While the same trend exists, it did not reach the p<0.05 level of significance.

Exposures, excluding partial and full ejection						
R.C.(cm)	Seatbelted			Non-seatbelted		
	Total	MAIS ≥ 3		Total	MAIS ≥ 3	
		Count	%		Count	%
0	381	30	7.9	81	18	22.2
1-7	142	14	9.9	25	4	16.0
8-14	139	21	15.1	26	5	19.2
15-29	158	25	15.8	36	5	13.8
30-45	40	5	12.5	8	4	50.0
46-60	13	4	30.8	2	1	50.0
>60	5	1	20.0	0	0	-----
Total	878	100		178	37	

Table 22. Non-ejected seatbelted and non-seatbelted exposures and most serious injury of AIS 3 and above (MAIS 3 and above) as a function of roof crush.

Table 22 again shows a similar trend of an increasing fraction with MAIS 3 or greater injury as roof crush increases for seatbelted drivers and a less persuasive trend for non-seatbelted drivers. Again, the percentage of MAIS 3 and above injuries was greater for all crush level categories except the 15-29 cm category, for the non-seatbelted drivers. The statistical tests show that the 15-29 cm category and the two categories greater than 46 cm did not reach the p<0.05 level of significance.

Full ejection exposures						
R.C.(cm)	Seatbelted			Non-seatbelted		
	Total	MAIS ≥ 3		Total	MAIS ≥ 3	
		Count	%		Count	%
0	5	3	60.0	63	41	65.1
1-7	3	3	100.0	21	13	61.2
8-14	2	0	0.0	22	14	63.6
15-29	2	2	100.0	46	31	67.4
30-45	1	1	100.0	13	10	76.9
46-60	0	0	----	3	1	33.3
>60	0	0	----	1	1	100.0

Table 23. Fully ejected, seatbelted and non-seatbelted exposures and most serious injury of AIS 3 and above (MAIS 3 and above) as a function of roof crush.

Table 23 suggests that full ejection with a seatbelt has a very high probability of causing a MAIS 3 or above injury. Full ejection without a seatbelt results in an MAIS 3 or greater injury approximately 2/3 of the time.

Partial ejection exposures						
R.C.(cm)	Seatbelted			Non-seatbelted		
	Total	MAIS \geq 3		Total	MAIS \geq 3	
		Count	%		Count	%
0	19	5	26.3	12	8	66.7
1-7	8	6	75.0	4	3	75.0
8-14	9	3	33.3	4	1	25.0
15-29	16	7	43.8	8	4	50.0
30-45	8	4	50.0	1	1	100.0
46-60	0	0	----	0	0	----
>60	1	1	100.0	0	0	----

Table 24. Partially ejected, seatbelted and non-seatbelted exposures and most serious injury of AIS 3 and above (MAIS 3 and above) as a function of roof crush.

Table 24 would seem to suggest that in a partial ejection, there may be some slight advantage to being seatbelted. The data, however is relatively sparse to base conclusions.

Fatal injury data are presented in Table 25.

Fatal injury						
Ejection	Seatbelted			Non-seatbelted		
	Exposures	Fatal	%	Exposures	Fatal	%
None	889	18	2.0	189	5	2.6
Partial	62	12	19.4	31	18	58.1
Full	13	4	30.8	173	62	35.8
Unk	9	1	11.1	0	0	
Totals	973	35	3.6	393	85	21.6

Table 25. Fatal injury for seatbelted and non-seatbelted occupants based on ejection status.

As can be seen in Table 25 the overall non-seatbelted fatality rate is approximately 6 times that of the seatbelted fatality rate (21.6/3.6). There also appears to be a benefit to seatbelt usage in all ejection categories, particularly the partially ejected category.

Fatalities of seatbelted non-ejected occupants were examined to determine their cause. While the information is generally incomplete, it is significant to note that in 4 cases of a total of 18, positional asphyxiation, compression asphyxiation or suffocation was listed as the cause or a potentially contributing factor to the cause of death.

The body region of serious (AIS 3 or above) injuries was tabulated as a function of seatbelt usage in Table 26.

Area of body with AIS 3 and above injury				
Body region	Seatbelted		Non-seatbelted	
	Count	%	Count	%
Head	42	28.2	81	46.8
Face	2	1.3	3	1.7
Neck	0	0	0	0
Spine	3	2.0	7	4.0
Upper extremity	23	15.4	8	4.6
Thorax	47	31.5	41	23.7
Pelvic/abdomen	17	11.4	16	9.2
Lower extremity	13	8.7	17	9.8
External	2	1.3	0	0
Total	149		173	

Table 26. Body region of serious injury (AIS 3 and above).

As can be seen by Table 26, non-seatbelted occupants have significantly higher AIS 3 and above head injuries, as compared to seatbelted occupants. It should also be noted that there was a fewer incidence of AIS 3 and above injury for seatbelted occupants, despite that approximately 72% of total exposures involved seatbelted occupants.

DISCUSSION

In this study, approximately 72% of the included occupants were restrained with the installed seatbelt. This is consistent with the general trend of seatbelt usage. Paranteau (2001, 2000) reported a seatbelt usage rate of approximately 71% based on NASS/CDS rollover data for the years 1992 through 1998 and 74.4% based on NASS/CDS rollover data for the years 1992 through 1996.

In this study, the fatality rate for non-ejected occupants was 2.0% for those seatbelted and 2.6% for those non-seatbelted. The fatality rate for partially ejected occupants was 19.4% for those seatbelted and 58.1% for those non-seatbelted and for fully ejected occupants, 30.8% for those seatbelted and 35.8% for those non-seatbelted. Ejection status has the largest effect on the fatality rate.

Seatbelts are highly effective in preventing ejection. In this study approximately 7.5% of seatbelted occupants were partially or fully

ejected as compared to 51.2% of the non-seatbelted occupants.

The rate of serious injury appears to increase with roof crush, likely as a result of increased severity, as suggested by Friedman, et.al. (1998). This trend is seen with both seatbelted and non-seatbelted exposures. Serious injuries are clearly more prevalent with non-seatbelted occupants when ejection exposures are included. When only non-ejected exposures are included, as a trend, the seatbelted occupants tend to have less severe injuries; however, not all of the roof crush depth categories reached a statistical level of significance of $p < 0.05$. In particular, the data is limited with roof crush levels over 46 cm and therefore was insufficient for statistical significance.

It should be noted that this study was performed using a wide variety of SUV types and years of manufacture. Current research suggests that increased post rollover headroom and not necessarily decreased roof crush reduces the severity of injury. This study, however, helps to dispell the notion that occupants somehow have reduced their injury potential by being unrestrained, because of the magnitude of the roof crush.

This study presents unweighted data and includes both the number of exposures as well as those exposures which met the noted criteria. Because it is unweighted data, the percentages of all accidents, represented by weighted data, may vary somewhat from that presented. Limited statistical analyses were performed as noted.

CONCLUSION

In this study, approximately 72% of the occupants were seatbelted. Seatbelts were highly effective in minimizing ejection (both partial and full), with only 7.5% ejection rate for seatbelted occupants as compared with 54.4% of non-seatbelted occupants. Ejection is the single best predictor of serious or fatal injuries. For example, non-seatbelted occupants were 6.2 times more likely to receive fatal injuries than their seatbelted counterparts. Seatbelted occupants had less severe injuries than their non-seatbelted counterparts, regardless of roll direction, number of rolls or roof crush, when exposure to ejection is included.

Even when only non-ejected exposures were considered, the injury rate and severity of seatbelted occupants tended to be less than that for the non-seatbelted occupants.

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