Injuries in Rollovers by Crash Severity

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ABSTRACT

Earlier studies by the authors have examined factors that contribute to rollover crash severity. These factors include: (1) belt use, (2) the number of quarter-turns aggregated according to number of vehicle inversions, and (3) the damage severity from planar impacts with fixed and non-fixed objects that occur before or during the rollover. Further research indicated that rollovers with severe damage from planar impacts should be analyzed separately from other rollovers since the injury rates for these crashes is 2 to 3 times greater than equivalent rollover crashes with less severe damage.

This paper separates rollovers into two categories, based on the presence or absence of severe damage from a planar crash. The research then examines the distribution of MAIS 3+ injuries and harm by body region and contact for belted adult occupants in each rollover category. The rollover categories are further examined using the number of vehicle inversions to quantify rollover crash severity.

Based on the analysis, the magnitude of the opportunities for injury and harm reduction through safety enhancements such as air curtains and safety belts designed for rollover protection is examined.

INTRODUCTION

The NASS CDS (National Automotive Sampling System/ Crashworthiness Data System) is a sample of tow away crashes that occur on US roads each year. The sample is stratified by the severity of the crash. The sample rate for minor crashes is much lower than for severe crashes. In order to expand the stratified sample to the entire population it represents, an inflation factor is assigned to each case in the NASS CDS sample. When the data are processed using the actual number of cases investigated, the data is referred to as "unweighted". When the data are processed using the inflation factors, the results should represent the total population of vehicles and the data are referred to as "weighted".

Earlier analysis by the authors showed clearly that rollovers with 4+ quarter-turns carried a higher injury rate than rollovers with fewer quarter-turns. Prior to 1995, NASS did not code the number of quarter-turns beyond four. Beginning in 1995, the NASS coding was expanded to enumerate the number of quarter-turns up to 16. Rollover extent of damage was also measured and categorized in three severity levels – minor, moderate, and severe. Unlike the extent of damage classified via the Collision Deformation Classification, a reserved phrase and variable name in NASS CDS, this study examines total delta-V and estimated delta-V, as given for the most severe event. For planar crashes, for which a delta-V can be calculated by measurements taken at the crash scene, the numeric or total delta-V is considered. In cases where the algorithm parameters are exceeded, a qualitative or quantitative delta-V is reported as the estimated delta-V. Delta-V is a measure of crash energy transfer and deemed to form part of a composite crash severity indicator. For rollover crash events, however, the reported delta-V is a qualitative indicator of crash severity not energy transfer. It should be noted that, the algorithm fails in extreme or complex planar engagements and rollover crashes. The enumeration of up to 16 quarter-turns in NASS has provided a much more detailed characterization of the rollover. However, it has complicated the analysis because it has created smaller cells with varying amounts of data. As an artifact of sample size and cell size issues, some lower numbers of quarter turns carry higher injury rates than subsequent numbers of quarter-turns. Previous analysis has demonstrated the merit of aggregating quarter turn cells producing increasing injury risk. Owing to the complex nature of rollover crashes, it is desirable to identify the factors other than quarter-turns that contribute to injury risk.

In an earlier study, crash factors that increased the risk of MAIS 3+ injuries in rollovers were examined

[Digges 2006]. The study found that the number of times the vehicle roof faces the ground (number of vehicle inversions) was a statistically significant factor that predicted increased injury risk for single vehicle rollovers. The analysis also examined the extent of damage to the vehicle as an added severity metric for rollovers that are preceded by or interrupted by impacts with fixed and non-fixed objects. Vehicle damage was measured and categorized in three severity levels: minor, moderate, and severe. Rollovers were also coded into four classes : (1) rollover as a single event, (2) rollover as the 1st event of multiple harmful events, (3) rollover preceded by impact with a non-fixed object, and (4) rollover preceded by impact with a fixed object. It was found that the number of vehicle inversions was a good severity metric for rollovers with fixed and non-fixed object impacts so long as cases with severe damage from the object impacts were excluded. The inclusion of the rollovers with minor and moderate damage from fixed object impacts with pure rollovers permits the application of the number of vehicle inversions as a severity metric to about 80% of the rollovers with belted front seat occupants and MAIS 3+ injuries. The remaining 20% are rollovers with severe damage with fixed or non-fixed objects and the planar impact may have contributed to the injury severity. In an earlier study, new NASS codes were used to examine crash factors that increased the risk of MAIS 3+ injuries [Digges 2003]. That study used NASS CDS 1995-2001 data. The variables added in 1995 permitted a more robust examination of how planar damage and number of quarter-turns may influence the risk of injury. These rollovers may require countermeasures to protect against both the planar impact and the rollover.

The earlier study found that the number of vehicle inversions was a statistically significant factor that predicted increased injury risk for belted occupants in single vehicle rollovers and in rollovers with impacts with fixed and non-fixed objects where only minor and moderate damage occurs.

DATA QUERIES

The data set described in this paper was queried from NASS CDS, a database of NASS, years 1995 through 2005. Definitions were prepared below for: occupant selection, quarter turn (rollover) codification, crash configuration, restraint usage, ejection status, injured body region groupings, injury severity, and occupant counts versus injury counts.

Occupant Selection

As described in previous works, occupancy rates of the various vehicle platforms dictated the selection of drivers and right front passengers. It was found that the higher occupancy rates of vans and SUV's tended to bias the results when all rear seat occupants were included [Digges 2003]. Earlier work has shown that belted and unbelted occupants should not be combined when attempting to characterize rollover crash severity [Digges 2003]. In the present study, only belted occupants were considered. Occupants less than 12 years old were excluded from the study because of complications that could be introduced by the presence of a variety of supplemental restraint systems not accounted for by the OEM.

Quarter Turn Codification

In addition to the classification of quantifiable quarter turns, rollover crashes may be defined as end-over-end rollover crashes or rollover with unknown details. The end-over-end rollover crash owing to its severe nature and varying crash dynamics requires an individual severity metric and is not examined in detail. Although reported in the Table 3 for completeness, the rollover of unknown detail was excluded from the analysis since the number of quarter turns was not quantified and it could not be established whether the rollover was lateral or longitudinal.

Crash Configuration

Two types of data queries were run for the analysis. First, all applicable front seat occupants involved in single vehicle rollovers were disaggregated. In this run, all damage levels were included but impacts with fixed and non-fixed objects were excluded. Second, all remaining rollover types were disaggregated and the cases with severe planar damage were excluded. The data runs provided the distribution of crashes and injured occupants by MAIS, Fatality, and Injured Body Regions. The results are presented in the sections to follow.

Restraint Usage and Ejection Status

As reported in Digges [2003], restraint usage and ejection status were applied in this paper. In summary, restraint usage was disaggregated by restrained, unrestrained, and ineffectively restrained occupants with respect to the rollover crash exigencies. The ejection analysis was an underlying element of this research and considered in the data interpretation presented in the Discussion.

Definition of MAIS 3+F and Harm

MAIS 3+ refers to occupants who sustain injuries with classification of serious (MAIS 3), severe (MAIS 4), critical (MAIS 5), or maximum (MAIS 6). In NASS CDS, a treatment variable is coded indicating the occupant disposition pursuant to the crash. One of the possible dispositions is fatality and must be consulted in conjunction with the MAIS score to ascertain occupant outcome.

The MAIS 3+F populations were determined by separating the fatally injured from the survivors. All the fatalities were that added to the survivor data at the MAIS 6 level. The Harm was then calculated using the procedures reported by Malliaris [1982]. The Harm weighting factors were based on the costs in Appendix E of DOT HS 809 203. Both MAIS 1 and 2 injuries were excluded from the MAIS 3+ Harm calculation. AIS 3+ Harm is calculated by applying the Harm weighting factors to the most severe AIS 3+ injury for each body region that sustains a serious injury.

It should be noted that MAIS and AIS might be used interchangeably in this study. Although common NASS CDS practice indicates that the maximum abbreviated injury scale score is applied at the occupant level, this concept may be extended to indicate the maximum AIS injury per body region per occupant.

Analysis Variables

The analysis variables were created using existing NASS CDS variables and attributes. These included groupings for the total delta-V, injury source associated with the maximum injury per body region, and consideration of the sequence of the rollover with respect to the crash events.

The delta-V groupings have been used in previous publications and are based upon total delta-V, and where that is unavailable estimated delta-V. The delta-V has been categorized as minor moderate, or severe. The delta-V is related to the most severe event in the crash, with respect to vehicle damage. This is either a calculated or estimated planar delta-V or and an estimated delta-V. In the case of rollover crashes, delta-V is used very loosely and is synonymous with crash severity. This is an accepted meaning of delta-V but in the planar sense, it involves some sense of change in velocity. The estimated planar delta-V is generally associated with the researcher-assessed delta-V based upon experience. This can take on a numeric, as well as a qualitative value.

The sequence of the rollover and its severity was reported in Digges [2006]. This disaggregation considered rollover as a single event crash, otherwise called pure rollover, and multiple event crashes during which the rollover occurred subsequent to the first event, other rollover, per Table 1. The rollover type and severity inclusion was studied, as seen in Table 1. Consideration was also given to whether rollover occurred pursuant to a fixed, nonfixed contact, or mixed fixed and nonfixed contacts.

Table 1: Rollover Type and Severity Inclusion

Rollover Type	**Severity (Extent of Damage)**	**Injury Severity**
Pure Rollover	All	All
Other Rollover	Minor, Moderate	All

The injury source groupings associate occupant contacts to injuries sustained, as shown in Table 2. These groupings are reflective of gross vehicle locations and include: upper vehicle, mid vehicle, safety belt and airbag systems, ground and other vehicle contact, other contacts. The upper vehicle includes roof, headers, windows, frames, and pillars. The mid vehicle consists of side interior, dash board, and steering wheel. The safety belt and airbag systems account for any constituent of the active or passive restraint system exclusive of the knee bolster. Finally, the other grouping considers any contact not listed previously.

The injury source is assessed by comparing physical evidence found within or around the vehicle. Examples of physical evidence may take the form of body fluid residue, tissue transfer, scuffing, denting, or make up traces. The evidence is codified on vehicle diagrams indicating location of transfer. These diagrams are compared with medical records to determine reasonable matching of the evidence with recorded injuries. The injury source is synonymous with injury contact source, as referenced in Table 2, and indicates occupant contact with a vehicle or external component that is associated with an injury sustained by the occupant.

Table 2: Injury Contact Categories

Injury Contact Categories	Description
Upper Vehicle	Window Sills and above, inclusive of frame and glazing
Mid Vehicle	Instrument Panel, Interior Hardware, Steering Assembly
Safety Belt and Airbag System	Active and Passive Restraint System, inclusive of components and hardware
Ground, Vehicle Exterior, Other Vehicle	Any exterior occupant contact, generally associated with some degree of ejection
Other Contact	Any other contact not mentioned in the previous categories.

RESULTS: DATA ANALYSIS

Table 3 shows the distribution of Exposed and MAIS 3+F injuries for relevant belted population in NASS CDS 1995-2005. The relevant population is all outboard front seat occupants age 12 and older. In this table, the authors consider only the relevant belted population involved in rollover without planar impacts and the relevant belted population exposed to rollovers with minor or moderate damage from planar impacts. The raw NASS CDS contains 4,669 belted relevant occupants exposed to rollover and 701 relevant occupants with MAIS 3+ injuries. The weighted numbers are 2,180,113 exposed relevant occupants and 73,340 MAIS 3+F injured occupants.

The columns in Table 3 show the number of vehicle inversions. One quarter turn is represented by "0 Inv". Two to five quarter-turns are included in "1 Inv" and so on. The data in the first six columns of each row adds to 100%. The "% of All" column shows the percent of the total population represented by the sum of the six columns. About 33% of MAIS 3+F injuries in this population occur in single vehicle rollovers without planar impact. The remaining 67% are rollovers with planar impact and minor or moderate damage. As stated above, rollovers with planar impact and severe damage are considered a different severity class and have been excluded from this analysis. Approximately 20% of the MAIS 3+ rollover injuries to belted occupants in NASS occur in these severe damage cases.

The "M3+ Risk" row in Table 3 represents the MAIS 3+F injury rates per 100 relevant occupants exposed to the crash environment as defined by the same column. The "M3+ Risk" in the % of All column is the average risk for the population in the row.

Several observations may be made from the data. First, a substantial fraction of the MAIS 3+F injuries (72%) in single vehicle rollovers without planar impact involve crashes with more than one vehicle inversion. These account for about 33% of the MAIS 3+F injuries. In the cases of rollovers with planar impacts, only 43% of the MAIS 3+F injuries occur in crashes with more than one inversion. It should be noted that 1% of the MAIS 3+ injuries are end-over-end, and 6% have unknown numbers of inversions.

Second, the injury risk for 0 inversions is much higher for rollovers with minor and moderate planar damage than it is for pure rollovers. Earlier papers by the authors have noted that this is partially due to the vulnerability of the vehicle to a roof impact with a fixed or non-fixed object when the rollover is interrupted at one quarter-turn. A more precise benefits analysis may help separate out these cases.

Third, the injury rate for one vehicle inversion is generally higher for the crashes with planar impacts, suggesting that the planar crash may contribute to the injury. However, when examining the influence of vehicle inversion on injury rate, the differences are small in comparison.

Finally, the injury risk for end-over-end rollovers with no planar impact is extremely high. These represent a separate class of rollover severity and will not be considered further in the analysis to follow.

Table 4 shows the similar data to Table 3, but with the injuries disaggregated by body region. In Table 4, the two rollover groupings in Table 3 are combined.

The distribution of MAIS 3+ Harm by body region for the population in Table 4 is shown in Table 5. In this table, the cases with unknown number of quarter-turns and end-over-end classification have been excluded. Table 5 also compares the weighted and unweighted data. The number of unweighted cases with MAIS 3+ injuries was 661. These cases expanded to 69,758 when weighting factors were applied. The principal effect of the weighting factors is to increase the number of chest injuries in pure rollovers while decreasing the number of head injuries in rollovers with planar impacts.

Table 6 provides a further disaggregation of the Table 5 weighted data by two classes of rollover severity. Table 7 provides the same categories, but with unweighted data.

The distributions of AIS3+ Harm by injuring contacts in rollover crashes are displayed in Table 8. The NASS codes more than 20 different contacts. These were aggregated into 5 categories- (1) Upper Vehicle, (2) Mid Vehicle, (3) Belt & Air Bag, (4) All Other Interior and (5) Ground, and Other Vehicle. The contents of each category are discussed earlier in the paper. The data in Table 8 is based AIS 3+ injuries to all body regions with known contacts. In cases where occupants had more than one AIS 3+ injury, all the injuring contacts that were associated with all injuries AIS 3 and greater were included. The Harm calculation applied the MAIS weighting factors to the equivalent level of AIS injury. There were 719 raw contacts with AIS 3+ injuries. When weighted, these expanded to 75,341. The principal effect of the weighting factors was to increase the Harm from mid vehicle contacts in pure rollovers at the expense of upper vehicle contact Harm in rollovers with planar impacts.

DISCUSSION

Tables 3 and 4 both show an increasing injury rate for increases in number of vehicle inversions. For planar impact, rollovers with minor and moderate damage, the 0 and 1 vehicle inversions carry a higher injury risk than the single vehicle rollovers. The planar impact may contribute to the injuries in some of these cases. However, the differences are small in comparison with the risk increase when 2 or more vehicle inversions occur. Earlier research found that for the selected populations of rollovers, there was a statistically significant relationship between the number of vehicle inversions and the risk of MAIS 3+ injury [Digges 2006].

Table 5 indicates that the Head Grouping has the largest fraction of AIS 3+ Harm for both weighted and unweighted data. The weighted data increases the Chest/Abdomen Harm in pure rollovers while decreasing head injuries in rollovers with planar damage. This trend continues in the Table 6 and Table 7 data. Chest/Abdominal injuries in pure rollovers with 2+ vehicle inversions are considerably more numerous in the weighted data than in the unweighted data. An examination of Table 8 shows that mid-vehicle contacts carry much higher Harm for pure rollovers in weighted data compared to unweighted data.

Tables 6 and 7 indicate that the largest opportunity for injury reduction of the belted rollover population under consideration is in multiple impacts with minor and moderate damage and with low numbers of vehicle inversions. This Rollover Grouping accounts for over 50% of the AIS 3+ Harm. The Head Injury Grouping accounts for about half of the body region Harm within this population. Another observation from these tables is that the second largest opportunity for injury reduction is in pure rollovers with 2+ vehicle inversions. The 2+ rollover severity accounts for more than half of the AIS 3+ Harm in pure rollovers. In the 2+ severity grouping, both the Head and Chest Body Regions offer large opportunities for injury reduction.

Table 8 shows the AIS 3+ Harm from injuring contacts by rollover type. Relatively small amounts of Harm are attributed to the Restraints and to 'Other' contacts. Even for belted occupants, about 10% of the Harm is associated with partial or complete ejection. Systems to reduce injuries from the combined upper interior and external contacts could conceivably address a large fraction of the Harm. An almost equally large opportunity exists in trying to reduce injuries from contacts with mid-vehicle surfaces.

CONCLUSIONS

This paper deals only with belted adult front seat occupants exposed to rollover crashes. The grouping of belted occupants in rollovers according to number of vehicle inversions offers the ability to examine opportunities for reducing injuries in crashes of different types and of different severities. This paper excluded rollovers with severe damage from impacts with fixed and non-fixed objects and end-over-end rollovers. These rollovers need special treatment to reflect their high injury risk. The remaining rollovers account for about 80% of the MAIS 3+ injuries and fatalities. The analysis and conclusions in this paper deal with this remaining population of belted occupants rollovers.

Pure rollovers without damage from other crash events account for about 40% of the Harm. Over half of this Harm occurs in rollover crashes with more than 2 vehicle inversions. The injuring contacts for pure rollovers are about equally distributed between upper and mid-vehicle locations. Each accounts for about 45% of the Harm. About 2% of the Harm is attributed to the restraint systems. About 4% is associated with ejection and 4% other contacts. The head and chest body regions are about equal in accounting for 90% of the Harm attributed to this population.

Rollovers with damage from other crash events account for about 60% of the Harm. About 86% of this Harm occurs in rollovers crashes with less than 2 vehicle inversions. Injuries to the head, face, neck, and spine account for about 65% of the Harm in this rollover category. Systems that could address contacts from the combined upper interior and the ground may offer a large opportunity for Harm reduction. Harm reduction from mid-vehicle contacts offers an opportunity of about the same magnitude – about 40% of the Harm attributed to this population.

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REFERENCES

Digges, K., and Eigen, A., "Crash Attributes that Influence the Severity of Rollovers", Paper 231, Proceedings of the ESV Conference, May 2003.

Digges, K., and Eigen, A., "The Injury Risk from Objects Impacted Before and During Rollovers", Paper 231, Proceedings of the IRCOBI Conference, September 2006.

NHTSA, "1995-1997 National Automotive Sampling System/Crashworthiness Data System" NHTSA, DOT HS 809 203, p.152, February 2001

Digges, K., and Eigen, A., "Classification of Rollover According to Crash Severity," 50th Proceedings of the Association for the Advancement of Automotive Medicine", pp. 141-154, October 2006.

Malliaris, A.C., Hitchcock R. and Hedlund, J., search for priorities in crash protection, Proceedings of Society of Automotive Engineers SAE SP-513, p.1–33, (1982).

Table 3. Distributions of Exposed Occupants, Harm, MAIS 3+F and MAIS 3+F Injury Risk for Rollover Populations

Single Vehicle Rollover, No Planar Impact - All Damage Severity							
Population	0 Vehicle Inversion	1 Vehicle Inversion	2 Vehicle Inversion	3+ Vehicle Inversion	END OVER END	Unknown	% of All
MAIS 2+Harm	1%	36%	41%	13%	1%	9%	28%
MAIS 3+ Harm	1%	33%	45%	11%	1%	9%	29%
MAIS 3+F	0.2%	23%	66%	6%	2%	3%	33%
Exposed	8%	72%	14%	1%	0.1%	5%	27%
M3+ Risk	0.11	1.01	11.30	14.35	48.74	3.35	2.71
Rollover with Planar Impact - Minor and Moderate Damage							
Population	0 Vehicle Inversion	1 Vehicle Inversion	2 Vehicle Inversion	3+ Vehicle Inversion	END OVER END	Unknown	% of All
MAIS 2+Harm	14%	50%	22%	7%	1%	6%	72%
MAIS 3+ Harm	14%	48%	24%	7%	1%	6%	71%
MAIS 3+F	8%	48%	32%	5%	2%	6%	67%
Exposed	18%	67%	11%	1%	0.2%	3%	73%
M3+ Risk	1.29	2.02	7.98	14.51	18.38	5.78	2.83
Rollover with No Planar Impact + With Planar Impact - Minor and Moderate Damage							
Population	0 Vehicle Inversion	1 Vehicle Inversion	2 Vehicle Inversion	3+ Vehicle Inversion	END OVER END	Unknown	% of All
MAIS 2+Harm	11%	46%	27%	8%	1%	7%	100%
MAIS 3+ Harm	10%	44%	30%	8%	1%	7%	100%
MAIS 3+F	6%	41%	40%	6%	2%	6%	100%
Exposed	15%	68%	12%	1%	0.2%	3%	100%
M3+ Risk	1.09	1.68	9.19	14.44	23.50	4.72	2.79
Note: Rows may not sum to exactly 100 percent owing to rounding.							

Table 4. Distributions of Harm, MAIS 3+F and MAIS 3+F Injury Risk by Injured Body Region with Rollovers with Severe Damage from Planar Impacts and End-over-end Rollovers Excluded

Head, Face, Neck & Spine Injuries						
Population	0 Vehicle Inversion	1 Vehicle Inversion	2 Vehicle Inversion	3+ Vehicle Inversion	Unknown	Ave Risk
MAIS 2+Harm	8%	50%	23%	12%	6%	
MAIS 3+ Harm	6%	48%	26%	13%	7%	
MAIS 3+F	6%	54%	30%	3%	8%	
Exposed	15%	68%	12%	1%	3%	
M3+ Risk	0.31	0.66	1.78	5.44	1.61	0.83
Chest & Abdomen Injuries						
Population	0 Vehicle Inversion	1 Vehicle Inversion	2 Vehicle Inversion	3+ Vehicle Inversion	Unknown	Ave Risk
MAIS 2+Harm	13%	43%	28%	8%	6%	
MAIS 3+ Harm	13%	40%	30%	9%	7%	
MAIS 3+F	6%	35%	43%	5%	7%	
Exposed	15%	68%	12%	1%	3%	
M3+ Risk	0.41	0.48	3.36	4.79	1.91	0.94
Pelvic, Upper & Lower Extremity Injuries						
Population	0 Vehicle Inversion	1 Vehicle Inversion	2 Vehicle Inversion	3+ Vehicle Inversion	Unknown	Ave Risk
MAIS 2+Harm	20%	50%	18%	7%	4%	
MAIS 3+ Harm	19%	48%	19%	8%	4%	
MAIS 3+F	10%	65%	16%	5%	3%	
Exposed	15%	68%	12%	1%	3%	
M3+ Risk	0.63	0.65	1.01	3.96	0.79	0.74
Note: Rows may not sum to exactly 100 percent owing to rounding.						

Table 5. Percentage of AIS 3+ Harm by Body Region in All Pure Rollovers and Rollovers with Minor or Moderate Planar Impact Damage by Rollover Type, Weighted and Unweighted Data; End-over-end Rollovers Excluded

Weighted Data			
Body Region	All Pure Roll	Min/Mod Damage	All
Head, Neck, Face, Spine	19%	27%	47%
Thorax, Abdomen	17%	19%	35%
Extremities with Pelvis	4%	14%	18%
Total	40%	60%	100%
Unweighted Data			
Body Region	All Pure Roll	Min/Mod Damage	All
Head, Neck, Face, Spine	19%	36%	55%
Thorax, Abdomen	8%	22%	31%
Extremities with Pelvis	3%	11%	14%
Total	31%	69%	100%
Note: Rows and columns may not sum to exactly 100 percent owing to rounding.			

Table 6. Percentage of AIS 3+ Harm by Body Region in All Pure Rollovers and Rollovers with Minor or Moderate Planar Impact Damage by Rollover Type and Severity, Weighted Data; End-over-end Rollovers Excluded

0 & 1 Inversions - Weighted Data			
Body Region	All Pure Roll	Min/Mod Damage	All
Head, Neck, Face, Spine	10.7%	23.3%	34.9%
Thorax, Abdomen	2.9%	15.3%	18.1%
Extremities with Pelvis	1.7%	12.4%	14.1%
Total	15.2%	51.9%	67.1%
2 & 3+ Inversions - Weighted Data			
Body Region	All Pure Roll	Min/Mod Damage	All
Head, Neck, Face, Spine	8.6%	3.1%	11.7%
Thorax, Abdomen	14.0%	3.3%	17.3%
Extremities with Pelvis	1.8%	2.0%	3.8%
Total	24.4%	8.3%	32.8%
Note: Rows and columns may not sum to exactly 100 percent owing to rounding.			

Table 7. Percentage of AIS 3+ Harm by Body Region in All Pure Rollovers and Rollovers with Minor or Moderate Planar Impact Damage by Rollover Type and Severity, Unweighted Data; End-over-end Rollovers Excluded

0 & 1 Inversions - Unweighted Data			
Body Region	All Pure Roll	Min/Mod Damage	All
Head, Neck, Face, Spine	11.2%	32.7%	43.9%
Thorax, Abdomen	2.5%	18.5%	21.1%
Extremities with Pelvis	1.2%	9.1%	10.3%
Total	14.9%	60.3%	75.3%
2 & 3+ Inversions - Unweighted Data			
Body Region	All Pure Roll	Min/Mod Damage	All
Head, Neck, Face, Spine	7.8%	3.4%	11.2%
Thorax, Abdomen	5.6%	3.9%	9.6%
Extremities with Pelvis	2.2%	1.6%	3.8%
Total	15.6%	8.9%	24.6%
Note: Rows and columns may not sum to exactly 100 percent owing to rounding.			

Table 8. Percentage of AIS 3+ Harm by Injuring Contact in All Pure Rollovers and Rollovers with Minor or Moderate Planar Impact Damage by Rollover Type, Weighted and Unweighted Data; End-over-end Rollovers Excluded

Weighted Data			
Injuring Contact	All Pure Roll	Min/Mod Damage	All
Upper Vehicle	17%	19%	36%
Mid Vehicle	18%	25%	44%
Other	2%	5%	8%
Restraint, Airbag System	1%	4%	5%
Ground, Other Vehicle	2%	6%	9%
Total	40%	60%	100%
Unweighted Data			
Injuring Contact	All Pure Roll	Min/Mod Damage	All
Upper Vehicle	15%	28%	43%
Mid Vehicle	9%	23%	32%
Other	3%	8%	11%
Restraint, Airbag System	1%	3%	4%
Ground, Other Vehicle	3%	7%	10%
Total	32%	68%	100%
Note: Rows and columns may not sum to exactly 100 percent owing to rounding.			