Effect of Model Year and Vehicle Type on Rollover Crashes and Associated Injuries to Children

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ABSTRACT

In child-involved crashes, there was a greater risk of rollover in pickups and SUVs than in passenger cars and minivans. Risk of injury to the corresponding child occupants in rollovers was significantly higher than for those in non-rollover crashes. There has been little change in overall rollover rates for passenger cars, pickup trucks, and minivans in the most recent model years (since 2002); however, there has been evidence of a declining rollover rate in SUVs during this same period. Even with this decline in SUV rollover risk, similarly aged passenger cars and minivans still exhibited a rollover risk approximately half that of their SUV counterparts.

Over the past fifteen years, the composition of the U.S. passenger vehicle fleet, and in particular the types of vehicles used by families, has undergone significant changes. According to Environmental Protection Agency data, the combined market share of SUVs and pickup trucks has been at least 40% of all light duty vehicles every year since 2002. This proportion is approaching the steadily decreasing share of passenger cars, now down to 46% by the end of this same period in 2005 [EPA, 2006]. These changes in the vehicle

fleet have helped to push the problem of rollover into the forefront, as SUVs and pickup trucks tend to be more top-heavy than passenger cars and minivans, making them more susceptible to rollover in single-vehicle crashes [NHTSA, 2006]. Despite making up only 3-4% of observed crashes in the National Automotive Sampling System (NASS), rollover crashes accounted for nearly one-third of all occupant fatalities to their vehicle occupants [NHTSA, 2003; Rivera, 2003].

With more than a quarter of a million children injured in crashes during 2004 [NHTSA, 2005], research focusing exclusively on child-based crash populations is of particular interest. Fatality Analysis Reporting System (FARS) and NASS Crashworthiness Data System (NASS-CDS) data from 1993-1998 found 10% of children involved in crashes in the United States were in rollovers. When restricted to SUVs, there were more child occupants involved in rollovers (60%) than in non-rollover crashes [Rivera, 2003]. Daly studied child occupants in newer model year (1998 and later) SUVs and passenger cars that were involved in all types of crashes and found an equivalent (unadjusted) risk of injury for children in the two vehicle types. Despite SUVs being on average more than 1,300 pounds heavier, this advantage was offset by several factors, including a rollover risk nearly two and a half times higher compared to that of passenger cars [Daly, 2006].

In response to these overall concerns about rollover and the corresponding injury risk, design changes such as electronic stability control (ESC) and curtain airbags have been introduced in an ever increasing proportion of newer vehicle makes and models. Also, with recent research showing SUVs to be the vehicle type most susceptible to rollover [NHTSA, 2000 & 2003; Kweon, 2003; Rivera, 2003; Daly, 2006], many newer SUV models have been manufactured with a unibody construction. These SUVs tend to have a lower center of gravity height and research suggests that they are less likely to rollover compared to their body-on-frame counterparts [Wenzel, 2005].

Though these advances are relatively recent in scope, it is important to determine whether or not they have had any effect on rollover and corresponding injury rates, both across all vehicles and within vehicle type. Therefore, the main objectives of this analysis were to examine the effect of model year on the relative risk of rollover within vehicle types in crashes involving child occupants, and to explore the corresponding injury risk in these rollover crashes. We hypothesized that the proportion of crashes involving a rollover and their associated risk of injury has decreased in more recent model years due to the aforementioned design changes.

METHODS

STUDY POPULATION AND DATA COLLECTION - The Partners for Child Passenger Safety program consists of a large scale, child-specific crash surveillance system: insurance claims from State Farm™ (Bloomington, IL) function as the source of subjects, with telephone survey and on-site crash investigations serving as the primary sources of data. A description of the study methods has been published previously. [Winston, 2000; Durbin, 2001]

Data were collected from March 1, 2000 to December 31, 2005. Vehicles qualifying for inclusion were State Farm-insured, model year 1990 or newer, and involved in a crash with at least one child occupant ≤15 years of age. Qualifying crashes were limited to those that occurred in sixteen states and the District of Columbia, representing three large regions of the United States (East: NY, NJ [through 11/01], PA, DE, MD, VA, WV, NC, DC; Midwest: OH, MI, IN, IL; West: CA, NV, AZ, TX [starting 6/03]). After policyholders consented to participate in the study, limited data were transferred electronically to researchers at The Children's Hospital of Philadelphia and the University of Pennsylvania. Data in this initial transfer included contact information for the insured, ages and genders of all child occupants, and a coded variable describing the level of medical treatment received by all child occupants (no treatment, physician's office or emergency department only, admission to the hospital, or death).

A stratified cluster sample was designed in order to select vehicles (the unit of sampling) for the conduct of a telephone survey with the driver. In the first stage of sampling, vehicles were stratified on the basis of whether they were towed from the scene or not, and a probability sample of both towed and non-towed vehicles was selected at random, with a higher probability of selection for towed vehicles. In the second stage of sampling, vehicles were stratified on the basis of the level of medical treatment received by child occupant(s). A probability sample from each tow status / medical treatment stratum was selected at random with a higher probability of selection for vehicles in which a child occupant died, was admitted to the hospital, or evaluated in a physician's office or emergency department. In this way, the majority of injured children would be selected while maintaining the representativeness of the overall population. If a vehicle was sampled, the "cluster" of all child occupants in that vehicle was included in the survey.

Drivers of sampled vehicles were contacted by phone and screened via an abbreviated survey to verify the presence of at least one child occupant with an injury. All vehicles with at least one child who screened positive for injury and a 10% random sample of vehicles in which all child occupants screened negative for injury

were selected for a full interview; a 2.5% sample of crashes where no medical treatment was received were also selected. The full interview involved a 30-minute telephone survey with the driver of the vehicle and parent(s) of the involved children. Only adult drivers and parents were interviewed. If the driver was not available for any reason, another adult occupant in the vehicle or another adult member of the driver's household was used as a proxy respondent (necessary in approximately 7% of cases). The median length of time between the date of the crash and completion of the interview was seven days.

VARIABLE DEFINITIONS – Vehicle type of the insured vehicle was obtained from the vehicle identification number (VIN) using VINDICATOR (Insurance Institute for Highway Safety – Highway Loss Data Institute, 2006), and were classified as either passenger cars, pickup trucks, SUVs, or minivans. Size classification information (for SUV only, described below in Table 1) was also verified though the use of VINDICATOR. Vehicles were restricted to model year 1998 and later to provide a reasonably comparable sample in terms of technological and crash worthiness factors. Only crashes meeting these criteria were included in the analysis.

Table 1: SUV Classification Table

Classification	Definition
Small	Vehicle Curb Weight ≤ 3,500 lbs. (1,587 kg)
Midsize	Vehicle Curb Weight 3,501-4,500 lbs. (1,588-2,041 kg)
Large	Vehicle Curb Weight > 4,500 lbs. (2,041 kg)
NOTE: When different models of the same vehicle series span size groups, all are categorized in the same classification regardless of their weight. Vehicles may also be placed in a different size class than their weight would indicate to better group the vehicle with its market class competitors.	

Both rollover status and whether the crash was single or multi-vehicle were determined from respective questions in the telephone survey. Among the 214 crashes for which paired information on rollover status was available from both the telephone survey and crash investigations, agreement was 99.5% between the driver report and the crash investigations (kappa=0.98, $p<0.001$). Among the 313 crashes for which paired information on the type of crash (single vs. multi-vehicle) was available from both the telephone survey and crash investigations, agreement was 97.8% between the driver report and the crash investigator (kappa=0.93, $p<0.001$).

Survey questions regarding injuries to children were designed to provide responses that were classified by body region and severity based on the Abbreviated Injury Scale (AIS) score. [AAAM, 1998] The ability of parents to accurately distinguish AIS 2 or greater injuries from those less severe has been previously validated for all body regions of injury [Durbin, 1999]. For the purposes of this study,

injuries were defined as those with AIS scores of 2 or greater such as the following: concussions and more serious brain injuries, facial bone fractures, spinal cord injuries, internal organ injuries, and extremity fractures.

Separate verbal consent was obtained from eligible participants for the transfer of claim information from State Farm to CHOP/Penn, for the conduct of the telephone survey, and for the conduct of the crash investigation. The study protocol was reviewed and approved by the Institutional Review Boards of both The Children's Hospital of Philadelphia and The University of Pennsylvania School of Medicine.

DATA ANALYSIS - The primary purpose of these analyses was twofold: (1) compute the relative risk of rollover for crashes involving child occupants, both overall and by vehicle type and model year, and (2) compute the relative risk of injury for those children in rollover crashes by vehicle type and model year. The above were looked at both for all crashes and then more specifically for single vehicle crashes only. Point estimates of the relative risks with associated 95% confidence intervals (CI) were determined.

Because sampling was based on the likelihood of an injury, subjects least likely to be injured were underrepresented in the study sample in a manner potentially associated with the predictors of interest. To account for the stratification of subjects by medical treatment, clustering of subjects by vehicle, and the disproportional probability of selection, Taylor Series linearization estimates of the logistic regression parameter variance were calculated using SAS-callable SUDAAN®: Software for the Statistical Analysis of Correlated Data, Version 9.0 (Research Triangle Institute, Research Triangle Park, NC, 2006). Results of logistic regression modeling are expressed as unadjusted and adjusted odds ratios with corresponding 95% confidence intervals. Because both rollover and injury are relatively rare events, the odds ratio can be interpreted as a good estimate of relative risk. Adjustments in the modeling of rollover risk included vehicle type, age of the driver, gender of the driver, driver restraint status, and the model year of the vehicle (grouped as 1998-2001 and 2002-2006).

RESULTS

Complete interview data were obtained on 6,421 crashes involving 10,263 children, representing 128,313 crashes with 197,733 child passengers in the study population. Single vehicle crashes made up just over one-sixth of all crashes (18%), and will be looked at separately for analysis purposes. Rollovers occurred in 439 sampled vehicles representing 2,461 vehicles or 1.9% of the crash

population. Vehicle, driver, and child characteristics are described below in Table 2.

Table 2: Driver, vehicle, and child characteristics, ALL crashes

Variables	All Vehicles	Pass. Car	Pickup Truck	SUV	Minivan	p-val
Vehicle Type	**100.0**	**44.4**	**8.5**	**26.6**	**20.6**	---
Drivers <25 yrs	11.0	17.3	8.8	6.8	3.6	<0.001
Male Drivers	28.2	25.1	58.9	27.1	23.7	<0.001
Unrestrained Drivers	3.3	3.5	5.8	3.2	2.1	0.036
Unrestrained Children	2.3	3.0	2.1	1.1	2.4	0.004
Model Year						
1998-2001	71.0	72.6	69.8	65.4	75.4	<0.001
2002-2006	29.0	27.4	30.2	34.6	24.6	
NOTE: p-value is from a χ^2 test of the distributions across vehicle types.						

ALL CRASHES – Table 3a shows the proportion of crashes that were rollovers for vehicles, both overall and by vehicle type, and additionally stratifies by characteristics of the driver (age, gender, and restraint status) and vehicle model year. Higher proportions of rollovers were observed in both SUVs (3.3%) and pickup trucks (2.8%) when compared to either passenger cars (1.2%) or minivans (1.2%). There was an increased overall risk of rollover observed both for younger drivers and those drivers that were unrestrained; though the patterns were not consistent across vehicle types. No overall difference in rollover was found when looking at the gender of the driver, though there appear to be differences within certain vehicle types (particularly pickup trucks). When comparing vehicles from model years 2002-2006 to those from 1998-2001, the overall risk of rollover fell by approximately one-fourth (OR=0.74, 95% CI 0.49-1.12). Though the overall difference was not statistically significant (p=0.11), we did find a significant decline of nearly 40% in rollovers involving SUVs (OR=0.61, 95% CI 0.37-1.00) when looking at the same model year groupings. Even with this drop in SUV rollovers, the observed rollover risk among newer model year passenger cars and minivans remains 50-60% less than that in SUVs.

The risk of rollover by vehicle type is investigated in greater detail in Table 3b. In addition to the vehicle types already discussed, SUVs were further classified (small, midsize, and large) based mainly on curb weight [Highway Loss Data Institute, 2006]. The crude odds ratios compare the unadjusted risks of rollover mentioned above, while the adjusted odds ratios control for the aforementioned driver characteristics (age, gender, and restraint status) and model year of the vehicle. After adjusting for these factors, the rollover risk for those children in both pickup trucks (OR=2.9, 95% CI=1.4-5.9) and SUV (OR=3.2, 95% CI 2.0-5.0) were significantly higher than

for those occupants in passenger cars. Additionally, while rollover rates decreased as SUV size increased, the adjusted risk of rollover was significantly higher even for Large SUVs when compared to passenger cars (OR=2.3, 95% CI=1.2-4.3).

Table 3c looks at the risk of injury for child occupants in rollover versus non-rollover crashes and then looks at injury risks in rollover crashes by model year. The overall (unadjusted) risk of injury for child occupants in rollover crashes was approximately six times higher than for those children in non-rollover crashes (OR=6.3, 95% CI=4.5-8.8). While this general trend was observed across all vehicle types, some differences in risk of injury by vehicle type were observed (p=0.002). The injury risk discrepancy between rollover and non-rollover crashes was greatest in pickup trucks (OR=27.6); child occupants in pickup trucks were observed to have twice the injury risk in rollover crashes than children in other vehicles. While there were differences in rollover crash injury risks within the individual vehicle types, there was not an overall statistically significant trend observed by model year (p=0.50).

Table 3a: Rollover rates, ALL crashes

Variables	All Vehicles	Pass. Car	Pickup Truck	SUV	Minivan
Overall	**1.9 (439)**	**1.2 (128)**	**2.8 (71)**	**3.3 (191)**	**1.2 (49)**
Driver Age					
<25 years	3.5	3.0	8.5	4.7	0.5
25+ years	1.7	0.9	2.3	3.2	1.3
Driver Gender					
Male	1.6	1.4	1.6	2.9	0.3
Female	2.0	1.2	4.7	3.4	1.5
Driver Restraint					
Unrestrained	4.2	3.6	11.4	2.1	2.4
Restrained	1.8	1.2	2.3	3.3	1.2
Model Year					
1998-2001	2.1	1.4	2.9	3.8	1.3
2002-2006	1.5	0.9	2.6	2.3	1.2
[$] 2002-2006 vs. 1998-2001	0.74 (0.49-1.12)	0.65 (0.25-1.67)	0.88 (0.26-3.00)	**0.61 (0.37-1.00)**	0.91 (0.24-3.42)

[$] Provides the Odds Ratio (OR) and the corresponding 95% confidence interval for rollover risk in model year 2002-2006 vs. model year 1998-2001 crashes.

Table 3b: Odds Ratios of Rollover by Vehicle Type, ALL crashes

Vehicle Type	Crude OR (95% CI)	Adjusted OR (95 % CI) *
Passenger Car	Ref	Ref
Minivan	1.0 (0.5 - 2.0)	1.2 (0.6 - 2.3)
Pickup Truck	**2.3 (1.2 - 4.5)**	**2.9 (1.4 - 5.9)**
SUV	**2.7 (1.7 - 4.3)**	**3.2 (2.0 - 5.0)**
Small	***3.7 (1.9 - 7.4)***	***4.2 (2.1 - 8.2)***
Midsize	***2.8 (1.7 - 4.7)***	***3.3 (2.0 - 5.6)***
Large	*1.8 (0.98 - 3.5)*	***2.3 (1.2 - 4.3)***

NOTE – Results with p<0.05 are bolded.
* Adjusted for model year & the driver's age, gender, and restraint status.

Table 3c: Child Injury Rates by Rollover and Model Year, ALL crashes

Variables	All Vehicles	Pass. Car	Pickup Truck	SUV	Minivan
Overall	1.1 (1,172)	1.6 (592)	0.7 (105)	1.0 (293)	0.5 (182)
Rollovers	**6.0**	**6.5**	**11.3**	**5.1**	**4.3**
M/Y 1998-2001	5.8	6.6	10.8	4.6	5.1
M/Y 2002-2006	6.7	5.8	12.0	6.7	1.9
Non-rollovers	**1.0**	**1.5**	**0.5**	**0.9**	**0.5**
Difference in risk of injury by vehicle type? **YES (p=0.002)** Difference in risk of injury in rollovers by model year? NO (p=0.50)					
** Rollovers vs. Non-rollovers	6.3 (4.5-8.8)	4.4 (2.4-7.9)	27.6 (12.7-60.3)	6.2 (3.5-11.0)	9.5 (4.3-21.0)
** Provides the Odds Ratio (OR) and the corresponding 95% confidence interval for risk of injury to children in rollover vs. non-rollover crashes.					

SINGLE VEHICLE CRASHES – The second set of analyses was limited to the 18% of our population which were single vehicle crashes, which accounted for nearly two-thirds (64%) of all our rollovers. Table 4a shows the previously described rollover information, now limited to single vehicle crashes. Across all vehicles the proportion of crashes that were rollovers was 7.0%, and once again the highest proportions of rollovers were observed in SUVs (13.1%) and pickup trucks (7.7%). The overall risk of rollover was increased for younger, unrestrained, and female drivers; of particular note were some of the rollover risks within the pickup truck group (32.9% for drivers less than 25 years of age, 24.2% for unrestrained drivers and 14.1% for female drivers). The overall risk of rollover in single vehicle crashes has shown a slight non-significant decrease across the model year groups (OR=0.84, 95% CI=0.48-1.48). There is a drop in the relative risk of rollover of nearly 50% for model year 2002 and later SUVs compared to those vehicles from the 1998-2001 model years (OR=0.53, 95% CI 0.25-1.15), which does not quite reach statistical significance. Even with this drop in rollovers, the proportion of SUV crashes that are rollovers in newer vehicles is still approximately 75% higher than that of similarly aged passenger cars and minivans.

More detail on the crude and adjusted risk of rollover by vehicle type for single vehicle crashes is provided in Table 4b. Adjusting for the previously mentioned driver characteristics and vehicle model year, those crashes involving a SUV (OR=2.9, 95% CI 1.6-5.4) were at a significantly higher risk of being in a rollover than those involving a passenger car. The corresponding adjusted risks of rollover were similarly higher for both Small (OR=3.0, 95% CI 1.1-8.0) and Midsize (OR=3.6, 95% CI 1.8-7.5) SUV compared to the reference passenger car group. Large SUVs were at a somewhat elevated risk of rollover than passenger cars, though the adjusted risk did not reach statistical significance (OR=1.3, 95% CI=0.5-3.1).

The risk of injury for child occupants in rollover versus non-rollover crashes and the corresponding risk of injury in rollover crashes by model year are addressed in Table 4c. Similar as for all crashes, the overall crude risk of injury in single vehicle crashes for child occupants in rollovers was nearly eight times higher than for those children in non-rollover crashes (OR=7.6, 95% CI=4.0-14.3). There was a significant trend for differences in risk of injury by vehicle type (p=0.003), both within minivans (OR=22.2) and pickup trucks (OR=49.9) the discrepancy in risk of injury between rollover and non-rollover crashes was much greater. For minivans in particular, this was mainly due to the extremely low injury rate in non-rollover crashes. No overall trend was observed of rollover crash injury rates by model year groups in the single vehicle crash population (p=0.79).

Table 4a: Rollover rates, Single Vehicle crashes ONLY

Variables	All Vehicles	Pass. Car	Pickup Truck	SUV	Minivan
Overall	**7.0 (265)**	**5.4 (91)**	**7.7 (45)**	**13.1 (105)**	**3.4 (24)**
Driver Age					
<25 years	13.0	13.3	32.9	9.7	1.3
25+ years	6.1	3.7	5.3	13.5	3.6
Driver Gender					
Male	3.9	4.5	2.8	7.4	0.8
Female	8.5	5.9	14.1	15.3	4.6
Driver Restraint					
Unrestrained	12.6	16.3	24.2	2.4	4.9
Restrained	6.7	5.0	5.8	13.7	3.4
Model Year					
1998-2001	7.3	5.6	7.1	15.0	3.1
2002-2006	6.2	5.0	9.3	8.6	4.4
[$] 2002-2006 vs. 1998-2001	0.84 (0.48-1.48)	0.87 (0.31-2.46)	1.34 (0.27-6.64)	0.53 (0.25-1.15)	1.44 (0.25-8.16)
[$] Provides the Odds Ratio (OR) and the corresponding 95% confidence interval for rollover risk in model year 2002-2006 vs. model year 1998-2001 crashes.					

Table 4b: Odds Ratios of Rollover by Vehicle Type, Single Vehicle crashes ONLY

Vehicle Type	Crude OR (95% CI)	Adjusted OR (95 % CI) *
Passenger Car	Ref	Ref
Minivan	0.6 (0.2 - 1.6)	0.7 (0.3 - 1.8)
Pickup Truck	1.4 (0.6 - 3.4)	1.9 (0.8 - 4.8)
SUV	**2.6 (1.4 - 4.8)**	**2.9 (1.6 - 5.4)**
Small	***2.7 (1.1 - 7.1)***	***3.0 (1.1 - 8.0)***
Midsize	***3.3 (1.6 - 6.6)***	***3.6 (1.8 - 7.5)***
Large	*1.1 (0.5 - 2.6)*	*1.3 (0.5 - 3.1)*
NOTE – Results with p<0.05 are bolded. * Adjusted for model year & the driver's age, gender, and restraint status.		

Table 4c: Child Injury Rates by Rollover and Model Year, Single Vehicle crashes ONLY

Variables	All Vehicles	Pass. Car	Pickup Truck	SUV	Minivan
Overall	1.0 (245)	1.5 (109)	1.1 (36)	1.0 (77)	0.3 (23)
Rollovers	**5.1**	**5.4**	**12.1**	**3.7**	**3.3**
M/Y 1998-2001	4.7	5.6	12.8	2.4	5.1
M/Y 2002-2006	6.5	4.7	11.2	8.7	0.0
Non-rollovers	**0.7**	**1.3**	**0.3**	**0.6**	**0.2**
Difference in risk of injury by vehicle type? **YES (p=0.003)** Difference in risk of injury in rollovers by model year? NO (p=0.79)					
** Rollovers vs. Non-rollovers	7.6 (4.0-14.3)	4.2 (1.7-10.5)	49.9 (15.7-158.6)	6.7 (3.4-13.2)	22.2 (5.8-84.9)
** Provides the Odds Ratio (OR) and the corresponding 95% confidence interval for risk of injury to children in rollover vs. non-rollover crashes.					

DISCUSSION

This research extends that of our previous work which has demonstrated an elevated rollover risk associated with SUVs and pickup trucks compared to passenger cars and minivans by identifying significant declines in rollovers among newer model year SUVs. Across all crashes (39%) and for single-vehicle crashes only (47%) there was a reduction in the risk of rollover for model year 2002 and later SUVs when compared to model years 1998-2001. As has been reported previously [Kallan, 2004], rollover crashes among SUVs were inversely proportional to the vehicle size classification (based mainly on the vehicle curb weight). However, the risk of rollover for Large SUVs was still approximately twice that of both passenger cars and minivans across all crashes.

One factor potentially associated with this drop in newer model year SUV rollover rates is the increased presence of electronic stability control (ESC) systems designed to automatically enhance the lateral stability of vehicles in vulnerable situations [NHTSA, 2004]. While the technology has been in certain vehicles since the late 1990's, it has been until recently a standard feature found only in luxury vehicles. As of model year 2003, less than eight percent of passenger vehicles sold were manufactured with the technology [NHTSA, 2004]. While several analyses have shown some level of effectiveness of ESC systems [NHTSA, 2004; Page, 2006], they have been limited in scope for several reasons. Sample size is a concern given the small proportion of vehicles within the overall fleet that have ESC. Additionally, those vehicles with electronic stability control as an optional feature were excluded from these analyses, which prevented comparisons within specific vehicle makes and models. The presence of an ESC system is not a characteristic that VINDICATOR can currently determine, therefore it was not included in the current analysis. The extent to which ESC explains

the model year effects observed in the current study will be the subject of future research.

In addition to electronic stability control, the increased proportion of sport utility vehicles with unibody construction may also have contributed to rollover mitigation within the SUV group. Also known as crossover SUVs [Wenzel, 2005], they have been designed with a lower average center of gravity height than the traditional truck-based SUV. Recent research suggests that they are less likely to rollover than their body-on-frame counterparts [Wenzel, 2005], though the number of the unibody SUVs within our population is still insufficient at this current time for a separate formal analysis.

Despite the decline in rollovers for newer model year SUVs, they were still twice as likely to rollover (across all crashes and in single vehicle crashes only) than were comparable passenger cars and minivans. This relationship was maintained across each of the three SUV classifications as well. When limited to single vehicle crashes, the approximate doubling of rollover risk in model year 2002 and later vehicles was maintained in the Small and Midsize (but not Large) SUVs. There were the expected sizeable differences in the proportion of crashes that were rollovers when comparing all crashes (1.9%) to those limited to single vehicle crashes (7.0%). Rollover risk was found to be 3-4 times higher in the single vehicle crashes depending on the vehicle type.

Evaluation of the safety of SUVs for child passengers is particularly important because the majority of existing data on SUVs, including their likelihood to rollover, is focused on crashes of higher severity with often unrestrained young male drivers [NHTSA, 2002]. The characteristics of the drivers in our study population of child-involved crashes are substantially different from those of most existing SUV studies. For example, female drivers had a higher proportion of rollovers in single vehicle SUV and pick-up crashes, as compared to passenger car and minivan crashes (see Table 4a). This was not evident among male drivers. Similarly, restrained drivers had a higher proportion of rollovers in SUV crashes (13.7%) than in the other vehicle types. This reflects the increasing use of SUVs as family vehicles and suggests the need for further research on how specific driving behaviors relate to the risk of a rollover crash in SUVs across a broad range of driver characteristics.

As had been shown previously using the same study population [Daly, 2006], we observed overall injury rates for child occupants in rollover crashes to be significantly higher than for those children in non-rollovers. Across all vehicles, there was little change in the risk of injury in rollovers by model year in either passenger cars or SUVs. Among single vehicle crashes, there is an increased risk of injuries to children in SUV rollover crashes in newer model

year vehicles compared to older vehicles (8.7% vs. 2.4%, p=0.010). In contrast, the risk of injury for children in rollover crashes for minivans have dropped with newer model year vehicles while in pickup trucks the reverse has been true. The overall injury risk for children in rollover crashes was lower in minivan and SUVs when compared to those child occupants in passenger cars and pickup trucks. One possible explanation could be that with a greater likelihood of an SUV to rollover in a crash, the greater risk of rollover may lead to larger proportion of less severe rollovers among SUVs compared to other vehicle types.

LIMITATIONS

This study obtained nearly all of its data via telephone interview with the driver/parent of the child and is, therefore, subject to potential misclassification. As noted previously, ongoing comparisons of driver-reported rollover and type of crash (single vs. multi vehicle) to evidence from crash investigations have demonstrated a high degree of agreement.

Our study sample covers the entire spectrum of crashes with child occupants traveling in 1998 and newer model year passenger vehicles in 16 states and the District of Columbia reported to an insurance company (State Farm ^{TM}). These crashes ranged from those with minor vehicle damage to those with loss of life. It must be noted however, that given this distribution of crashes, we are looking almost exclusively at non-fatal injuries. With rollovers making up a disproportionate amount of the fatalities in the overall crash population given their rate of occurrence, our study sample is not always able to capture the most severe of the rollover crashes. It does, however, complement prior existing studies by focusing attention on non-fatal injuries to children in rollover crashes.

Intrinsically, rollovers are rarely low speed events. This needs to be considered when making direct comparisons of injury frequencies in rollover crashes to those in non-rollovers which cover a larger range of the crash severity spectrum. Within rollover crashes, there are also inherent differences in severity by varying vehicle type. Whether these vehicle type distinctions are present in non-rollover crashes as well presents an opportunity for further study.

There is no information (i.e. type of rollover or its cause) beyond whether or not the insured vehicle rolled over in the crash. Finally, surveillance data of the nature presented in this study cannot detect precise injury mechanisms. Therefore, more detailed information on the nature and severity of the injuries is needed.

CONCLUSIONS

Among child-involved crashes, rollovers were more likely to occur in pickup trucks and SUVs than in passenger cars and minivans. The risk of injury to the corresponding child occupants in rollovers was significantly higher than for those in non-rollover crashes. Across all vehicles, there has been little change in rollover rates in the most recent model years (2002 and later); however there has been evidence of a decline in the proportion of crashes that are rollovers in SUVs during this same period. Even with this decrease in SUV rollovers, similarly aged passenger cars and minivans still exhibited a rollover risk approximately half that of their SUV counterparts. Research and monitoring need to continue on the effects of specific technology such as electronic stability control and structural change (e.g. unibody construction in newer SUVs) and what roles they play in helping to reduce rollover risk in newer model year vehicles.

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