

ORIGINAL ARTICLE

Injuries and death of children in rollover motor vehicle crashes in the United States

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Context: There is an increased awareness of the problem of rollover crashes, but few data on children involved in rollover crashes in the United States.

Objective: To determine: (1) the rates of rollover crashes involving children and the incidence of fatal injury; (2) the characteristics of crashes involving children; (3) the risk factors for children being in a rollover compared with a non-rollover crash; and (4) whether the risk of death is greater for children involved in crashes in sport utility vehicles (SUVs) or passenger cars.

Design: Retrospective cohort study.

Data: 1993 through 1998 crashes involving children younger than 16 years included in the Crashworthiness Data System or reported to the Fatality Analysis Reporting System.

Results: During the study period, 100.4 children per 100 000 person-years were involved in a rollover crash, accounting for 10% of all children involved in crashes. The incidence of fatal injuries in rollover crashes was 3.4 per 100 000 person-years. Sixty percent of children involved in rollovers were riding in SUVs. Among vehicles carrying children and involved in a crash, the adjusted relative risk of the crash being a rollover was 11.1 (95% confidence interval (CI) 9.3 to 13.3) for SUVs compared with passenger cars. The adjusted relative risk of death was 1.8 (95% CI 1.1 to 2.8) in a rollover crash and the relative risk of injury was 2.1 (95% CI 1.1 to 3.8) compared with non-rollover crashes. However, the relative risk of death for children in SUVs which crashed was 0.4 (95% CI 0.1 to 2.5) compared with passenger cars which crashed.

Conclusions: Crashes involving children in SUVs were more likely to be rollover crashes than those involving passenger cars, and rollover crashes were associated with an increased risk of death and injury. However, the overall risk of death for children in a crash was not higher for children who crashed in an SUV compared to children who crashed in a passenger vehicle. Whether children are safer overall in SUVs compared with other cars cannot be answered with the data used.

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The recent media attention to rollovers involving certain sport utility vehicles (SUVs) in the United States has increased the awareness of the problem of rollover crashes. In the United States in 1999, 10 142 people were killed as occupants in automobile and light truck rollovers, including 8345 killed in single vehicle rollovers; 55% of light vehicle occupant fatalities in single vehicle crashes involved rollover.¹ The proportion of fatal crashes which involved a rollover differed by vehicle type: 46% of passenger car occupant fatalities in single vehicle crashes involved rollover, compared with 63% for pick-up trucks, 60% for vans, and 78% for SUVs.

Based on 1995–99 data, the National Highway Traffic Safety Administration (NHTSA) estimated that 241 000 light vehicles rolled over each year (on average) in crashes reported to the police, and that 57 000 occupants in rollover crashes received injuries.^{2,3} An estimated 16% of light vehicles in police reported single vehicle crashes rolled over. The estimated risk of rollover in a crash differed by vehicle type: 13% of cars and 14% of vans in police reported single vehicle crashes rolled over, compared with 24% of pick-up trucks and 32% of SUVs.

To our knowledge, there have been no studies of rollovers involving children, and no studies examining the factors which affect the risk of injury or death for children in rollover crashes. We undertook a study to answer the following questions: (1) what were the rates of children involved in rollover crashes in the United States and what was the incidence of fatal injury; (2) what were the characteristics of rollover crashes involving children; (3) given a crash involving a child, what factors were associated with the likelihood that the crash would be a rollover; and, (4) what was the overall risk, for a

child, of dying if they crashed in a SUV compared with a passenger car?

METHODS

This was a retrospective cohort study of children younger than 16 years involved in crashes in the United States during 1993 through 1998.

Data sources

Data regarding crashes and non-fatal injuries were obtained from the NHTSA Crashworthiness Data System (CDS).² The CDS collects detailed information on an annual sample of approximately 5000 police reported tow away crashes involving passenger vehicles each year in the United States. The CDS uses a three stage sampling scheme to make the data representative of all police reported tow away crashes in the United States. In the first stage, the United States was divided into 1195 primary sampling units (PSUs) composed of large cities, counties, or a contiguous group of counties. These were grouped into 12 categories by region and degree of urbanization and two PSUs were selected from each category with probability proportional to population. In the second stage, police agencies were selected from these 24 PSUs based on the number and type of crash reports they process annually.

Abbreviations: CDS, Crashworthiness Data System; CI, confidence interval; FARS, Fatality Analysis Reporting System; NHTSA, National Highway Traffic Safety Administration; PSU, primary sampling unit; SUV, sport utility vehicle

Table 1 Number and annual rate of children 0–15 years in all motor vehicle crashes, United States 1993–98

Age (years) and rollover status	Actual counts in the CDS data	Estimated* number of children in crashes (in thousands)	95% CI (in thousands)*	Rate per 100000 per year
All ages	7003	3685	3077 to 4460	1008.5
Rollover	745	367	306 to 556	100.4
Non-rollover	6258	3318	2771 to 3904	908.1
0–4	2177	1095	884 to 1349	933.0
Rollover	201	54	22 to 116	46.0
Non-rollover	1976	1041	862 to 1233	887.0
5–9	1883	911	720 to 1157	800.0
Rollover	171	46	17 to 110	40.4
Non-rollover	1712	865	703 to 1047	759.4
10–15	2943	1679	1369 to 4927	1251.7
Rollover	373	267	163 to 3303	199.1
Non-rollover	2570	1412	1206 to 1624	1052.6

*National estimates based upon the CDS sampling scheme.

Finally, crashes were selected from each police agency based on the type and severity of crash.

We used CDS records for 1993 through 1998 involving children younger than 16 years who were passengers (non-drivers) in passenger vehicles involved in crashes. Passenger vehicles are defined by NHTSA as cars, pick-up trucks, vans, and SUVs with a gross weight of 10 000 pounds or less.² SUVs are multipurpose vehicles designed to have off-road capabilities and include compact utility vehicles, large utility vehicles, utility station wagons, and utility type unknown. We excluded children who were in the open bed of pick-up trucks.

Injuries were determined by CDS investigators based on interviews with survivors, and medical and autopsy records. Injuries were classified using the abbreviated injury scale⁴; we included injuries with an abbreviated injury scale score of 1 or greater.

Data on the number of fatal crashes were obtained from the Fatality Analysis Reporting System (FARS), which collects information regarding all crashes in the United States on public roads which result in a death within 30 days.¹ While CDS data does allow estimates of the number of deaths, we used the FARS data instead because this includes all deaths occurring within 30 days rather than a sample of deaths. The number of children in the United States was obtained from census data.⁵

Potential confounding variables

We examined several potential confounders of the relationship of rollover status to risk of injury or risk of death. These included age (categorized into 0–4 years, 5–9, 10–15), estimated vehicle speed (categorized into 0–19, 20–39, 40–59, >60 mph), gender, restraint use (proper, improper, or none), seating position, posted speed limit (categorized as <40 mph, 40–50 mph, >50 mph), vehicle type, and vehicle model year. The estimate of deceleration forces experienced by the occupants, a measure called delta-V (change in velocity), was used where applicable. In crashes in which the vehicle rolled over without first striking an object or being struck by another vehicle, the delta-V cannot be calculated. Some vehicles, however, roll over after first being struck by another vehicle or after first striking a fixed object, such as a tree. In this second group, a delta-V can be calculated. Therefore we included in all models an indicator variable for whether or not delta-V could be calculated. In those crashes where it could be calculated, we also adjusted for the actual value of delta-V (in km/hour).

Multiple imputation of missing data

Information was often missing on estimated vehicle speed (68.6%), delta-V where it could be calculated (54.2%), and restraint use (23.4%). Restricting analysis to cases without missing data leads to valid inferences only if data are missing completely at random.⁶ Because these characteristics appeared to be important potential confounders, multiple imputation was employed using an adaptation of the approximate Bayesian bootstrap method.^{7, 8} Multiple imputation is based on the assumption that data are missing at random conditional on the values used to form the imputation groups. Therefore we used multiple imputation to create 10 sets of data which were identical in regard to known information, but could differ, one from another, on the imputed values for the missing information. To impute missing values for a variable, we identified those variables which were most strongly associated with the variable to be imputed, using either logistic regression or ordinal logistic regression in records with complete information. In order to preserve important relationships in the data, all imputation models included the outcome (survival or death) and the sampling weight (quintiles). In addition, model year, speed limit, rollover, age, and vehicle body type were used to impute vehicle speed; model year, vehicle weight, rollover, and injury severity score were used to impute delta-V; and child's age, ejection, model year, and seat position were used to impute restraint use.

Analysis

The CDS sample of crashes was a systematic sample of all crashes. We may think of this as a cohort study in which children entered the cohort at the time of the crash and experienced the study outcome, injury or death, moments later. We used Poisson regression to estimate the relative risk of either injury or death among children who were in a rollover crash compared with children in other crashes. Each potential confounder was entered into the regression individually, and kept in the model if it altered the relative risk estimate by more than 10%.^{9, 10} To obtain proper estimates and confidence limits, we used linearization methods that accounted for the sampling strata, weights, and clustering within sampling unit.^{11, 12} Separate, parallel analyses were then carried out on all 10 data sets. Point estimates from each analysis were averaged on the log scale and confidence intervals calculated by methods which accounted for both the variance within each data set and the variance between the data sets.⁷ To allow for modification of the effect of rollover by restraint use, we considered interaction terms between

Table 2 Number of deaths and annual rate of deaths of children 0–15 in motor vehicle crashes, United States 1993–98

Age (years) and rollover status	Deaths of children in crashes*	Rate per 100000 per year	Crude case fatality ratio × 100†	95% CI
All ages	12431	3.4	0.3	0.3 to 0.4
Rollover	3947	1.1	1.1	0.7 to 1.3
Non-rollover	8484	2.3	0.3	0.2 to 0.3
0–4	3695	3.2	0.3	0.3 to 0.4
Rollover	939	0.8	1.7	0.8 to 4.3
Non-rollover	2756	2.4	0.3	0.2 to 0.3
5–9	2670	2.3	0.3	0.2 to 0.4
Rollover	714	0.6	1.6	0.7 to 4.2
Non-rollover	1956	1.7	0.2	0.2 to 0.3
10–15	6066	4.5	0.4	0.1 to 0.4
Rollover	2294	1.7	0.9	0.1 to 1.4
Non-rollover	3772	2.8	0.3	0.2 to 0.3

*Data from the FARS.

†Ratio of the number of deaths to the number of children in crashes × 100. Estimated number of children in crashes from CDS data.

restraint use and rollover. Since these interaction terms were not statistically significant for either death ($p=0.9$) or injury ($p=0.7$), they were omitted from the models.

RESULTS

Incidence of rollover crashes in the United States involving children

During the study period, 100.4 children per 100 000 person-years were involved in a rollover crash (table 1). Children involved in rollover crashes constituted 10.0% (95% confidence interval (CI) 6.9% to 18.1%) of all children involved in crashes in the United States during 1993 through 1998. Involvement was most common among those 10 to 15 years old, among whom 15.9% of crashes were rollovers.

Table 3 Characteristics of children 0–15 years in rollover and non-rollover crashes, United States 1993–98; values are percent (95% CI)

	Rollover (n=367022)	Non-rollover (n=3314221)
Age of occupant (years)		
0–4	14.7 (6.0 to 31.7)	31.4 (26.0 to 37.2)
5–9	12.6 (5.6 to 29.9)	26.1 (21.2 to 31.6)
10–15	72.8 (44.3 to 90.0)	42.6 (35.4 to 49.0)
Gender		
Male	73.8 (51.0 to 88.4)	46.7 (42.3 to 51.2)
Female	26.2 (11.5 to 49.0)	53.3 (48.8 to 57.7)
Restraint used	50.3 (27.7 to 72.8)	79.2 (73.9 to 83.7)
Vehicle body type		
Passenger car	24.5 (6.0 to 62.3)	75.3 (69.6 to 80.3)
SUV	60.3 (21.9 to 89.2)	4.4 (3.1 to 6.1)
Minivan	7.7 (2.4 to 22.0)	11.3 (7.8 to 15.0)
Van	1.9 (1.1 to 3.3)	4.8 (1.8 to 12.3)
Light truck	5.5 (2.5 to 11.5)	4.2 (2.2 to 8.0)
Vehicle manufacturer		
US	80.9 (58.5 to 92.7)	71.7 (67.8 to 75.3)
Japan	15.7 (6.4 to 33.7)	22.9 (19.4 to 26.7)
Germany	1.9 (0.3 to 10.8)	1.6 (0.7 to 3.6)
Scandinavian	0.1 (0.1 to 0.4)	2.3 (1.1 to 4.7)
Other European	0.9 (0.1 to 6.8)	0.1 (0 to 0.2)
Other Asian	0.5 (0.1 to 2.0)	1.4 (0.6 to 3.2)
Estimated vehicle speed (mph)		
0–19	1.7 (0.3 to 9.2)	44.4 (40.1 to 48.9)
20–39	68.5 (20.3 to 94.9)	30.1 (24.4 to 36.6)
40–59	13.0 (3.3 to 39.6)	19.9 (11.5 to 32.1)
60+	16.8 (2.7 to 59.5)	5.5 (2.5 to 11.9)

The annual incidence of fatal injuries to children from rollover crashes during 1993 through 1998 was 3.4 per 100 000 (table 2). Among children fatally injured as motor vehicle occupants, 31.8% were killed in rollovers. As with all rollovers, rollover deaths were most common among the 10 to 15 year age group.

Characteristics of children involved in rollover crashes

Children involved in rollover crashes were more likely to be 10 to 15 years of age and male, compared with children involved in non-rollover crashes (table 3). They were less likely to use seat restraints. Sixty percent of children involved in rollovers were riding in SUVs compared with 4.4% of those in non-rollover crashes. Children in rollovers were less likely to be in vehicles traveling under 20 mph and more likely to be in vehicles traveling between 20 and 39 mph. Among children in rollover crashes, 4.4% were ejected compared with 0.4% in non-rollover crashes.

Risks of rollover compared to non-rollover crashes

Among vehicles carrying children and involved in crashes, the risk of the crash being a rollover was 11.1-fold greater for SUVs and 1.7-fold greater for light trucks compared with crashes involving passenger cars, adjusted for vehicle weight, driver age and gender, vehicle speed, and model year (table 4).

Table 4 Factors associated with being in a rollover crash compared with being in a non-rollover crash, among children who were in any crash, United States 1993–98

	Relative risk*	95% CI
Vehicle		
SUV	11.1	9.3 to 13.3
Light truck	1.7	1.1 to 2.5
Passenger car	1.0	–
Vehicle weight†	0.95	0.9 to 1.0
Model year‡	0.96	0.9 to 0.99
Travel speed§	1.4	1.3 to 1.5
Female passenger	0.6	0.4 to 0.9
Driver age¶	0.97	0.95 to 0.99

*Adjusted for other variables in the model.

†Per 10 kg increment in weight.

‡Per 1 year increment, base year 1960.

§Per 6 mph increment.

¶Per year of age.

Table 5 Factors associated with dying in a crash among children 0–15 years who were in any crash, United States 1993–98

	Relative risk	95% CI
Vehicle		
SUV	0.4	0.1 to 2.5
Light truck	0.4	0.2 to 1.2
Passenger car	1.0	–
Female passenger	1.6	0.8 to 3.2
Restraint use		
Proper restraint use	0.2	0.1 to 0.6
Improper restraint use	0.5	0.2 to 1.5
No restraint use	1.0	–
Vehicle speed*	1.3	1.1 to 1.5
Delta-V calculated†	0.2	0.1 to 0.3
Delta-V amount‡	1.06	1.05 to 1.07

*In 6 mph increments.

†This variable indicates whether delta-V could be calculated in the crash or not (no/yes).

‡This is the actual value for delta-V as a continuous variable in kph.

Heavier vehicles and more modern vehicles were less likely to be in rollovers than non-rollover crashes. The risk of the crash being a rollover increased 1.4-fold for each 6 mph increase in travel speed at the time of the crash.

Among rollover crashes, 65.1% were less than 360 degree turns. Only 2.3% were end-over-end rollovers.

Risk of injury and death

Among children involved in rollovers, 1.1% died (95% CI 0.7% to 1.3%). The crude case fatality proportion for non-rollovers was significantly lower, 0.3% (95% CI 0.2% to 0.3%). Children in each age group had higher case fatality proportions in rollover compared with non-rollover crashes (table 2). Among children in rollovers, 4.2% were injured (95% CI 3.5% to 4.9%), compared with 3.2% (95% CI 2.3% to 4.5%) of children in non-rollover crashes.

After adjusting for delta-V, estimated speed, seat restraint use, type of vehicle and age of the child, being in a rollover crash, compared with all other crashes, was associated with a twofold increase in the risk of death (relative risk 1.8, 95% CI 1.1 to 2.8) and risk of injury (relative risk 2.1, 95% CI 1.1 to 3.8).

Risk of death in SUVs

Because SUVs were associated with an increased risk of being in a rollover crash compared with being in a non-rollover crash, and because being in a rollover crash was associated with an increased risk of death, we sought to determine if the risk of death in a crash was increased or decreased for children in SUVs which crashed compared with passenger cars which crashed. Adjusted for occupant restraint use and gender, vehicle speed and delta-V, the relative risk of death was 0.4 (95% CI 0.1 to 2.5) for occupants of SUVs compared with occupants of passenger cars (table 5). However, the sample of deaths in SUVs was small, and the confidence limits were wide and included 1.

DISCUSSION

We found that about one of every 10 children in crashes in the United States during 1993 through 1998 was in a rollover crash. The risk of death to children in rollover compared with non-rollover crashes was increased by 80% and the risk of injury was more than doubled. Sixty percent of children in rollovers were riding in an SUV compared with 4.4% of children in a non-rollover crash. The adjusted risk that the crash would be a rollover was 11.1-fold greater for SUVs than

for passenger cars. However, since rollover crashes are much less common than non-rollover crashes, and since mass of the vehicle is directly related to survival, taking all crashes into consideration, the risk of death was not statistically different for children involved in crashes in SUVs compared to passenger vehicles.

Rollovers accounted for 3.7% of all crashes in the United States, 5.8% of injuries, and 28.3% of occupant fatalities.^{1 2} There are no prior data on risk of injury or death to children in rollovers.

The tendency of SUVs to be involved in rollover crashes has been the subject of recent attention. NHTSA uses the static stability factor, defined as one half the track width of a vehicle divided by the height of its center of gravity, as a measure of rollover risk.³ NHTSA has estimated that the risk of a rollover per single vehicle crash is six times greater for a vehicle with an static stability factor of 1.00 compared with a vehicle with an static stability factor of 1.53 (the range of the observed data) based on a linear regression model. SUVs have a static stability factor generally less than 1.15, while in passenger cars it is generally greater than 1.35. Our study indicates that among children who were in a crash, those in a SUV were about 11-fold more likely to be in a rollover compared with children in a passenger car. However, the overall risk of death for children in SUVs which crashed compared with children in passenger cars which crashed was not increased and may in fact be lower.

The higher risk of rollover for 10 to 15 year old children is unlikely to be related to the age of the driver with whom these children ride. We found no effect in our estimates after controlling for age of the driver. In contrast, NHTSA reported that driver age less than 25 years was a significant predictor of the risk of a crash being a rollover crash compared with being a non-rollover crash.³

There are a number of possible limitations to our data that should be considered in interpreting our results. The number of fatal injuries involving children in SUVs was small and therefore our estimate of the relative risk of death in a SUV that crashed, compared with a passenger car that crashed, was very imprecise. While there may be some misclassification of seat restraint use, CDS data do not rely on police reports. The information on seat restraint use is based primarily on inspection of the belt for evidence of loading forces on the belt in the crash or evidence that the belt was cut by the paramedics indicating that the belt was worn by the occupant, supplemented by medical and autopsy records and confidential interviews with survivors.

In conclusion, among children who were in a crash, the likelihood that the vehicle would rollover was about 11-fold greater if it was a SUV compared with a passenger car. In addition, in a rollover crash, compared with other crashes, the risk of death and injury was greater. However, the overall risk of death for children in a crash was not higher for children who crashed in a SUV compared to children who crashed in a passenger vehicle. Whether children are safer overall in SUVs compared with other cars cannot be answered with the data we used.

IMPLICATIONS FOR PREVENTION

The risk of injury or death for children in motor vehicle crashes was approximately doubled if the vehicle rolled over during the crash. Among vehicles which were involved in crashes, SUVs had an about 11-fold greater risk of rolling over than passenger cars. However, SUVs generally are larger, heavier vehicles than passenger cars and risk of death has been shown previously to be inversely related to the mass of the vehicle in which the occupant is riding.^{13 14} Many motor vehicle crashes are frontal, non-rollover crashes; we found that only about 10% of crashes with child occupants involved rollovers. Thus, the overall risk of death for children involved

Key points

- During 1993 to 1998, rollover crashes accounted for 10% of all crashes involving children in the United States.
- Sixty percent of children involved in rollovers were riding in sports utility vehicles compared to 4% of children involved in non-rollover crashes.
- The risk of death in a rollover crash was 1.8-fold greater and the risk of injury was 2.1-fold greater than for non-rollover crashes.

in a motor vehicle crash was not increased in children riding in SUVs that crashed compared with children riding in other cars. Among SUVs that crashed, the increased risk of death from being involved in a rollover may be outweighed by the lower risk of death due to being in a heavier vehicle in non-rollover crashes.

This study leaves unanswered the question of whether SUVs are in general safer or less safe than other cars because we did not have data to address the risk of crashing in all vehicles traveling on the road.

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