The Effectiveness of Child Restraint Systems for Children Aged 3 Years or Younger During Motor Vehicle Collisions: 1996 to 2005

Thomas M. Rice, PhD, MPH, and Craig L. Anderson, DHSc, PhD

Objectives. We estimated the effectiveness of child restraints in preventing death during motor vehicle collisions among children 3 years or younger.

Methods. We conducted a matched cohort study using Fatality Analysis Reporting System data from 1996 to 2005. We estimated death risk ratios using conditional Poisson regression, bootstrapping, multiple imputation, and a sensitivity analysis of misclassification bias. We examined possible effect modification by selected factors.

Results. The estimated death risk ratios comparing child safety seats with no restraint were 0.27 (95% confidence interval [CI] = 0.21, 0.34) for infants, 0.24 (95% CI = 0.19, 0.30) for children aged 1 year, 0.40 (95% CI = 0.32, 0.51) for those aged 2 years, and 0.41 (95% CI = 0.33, 0.52) for those aged 3 years. Estimated safety seat effectiveness was greater during rollover collisions, in rural environments, and in light trucks. We estimated seat belts to be as effective as safety seats in preventing death for children aged 2 and 3 years.

Conclusions. Child safety seats are highly effective in reducing the risk of death during severe traffic collisions and generally outperform seat belts. Parents should be encouraged to use child safety seats in favor of seat belts. (*Am J Public Health.* 2009;99:252–257. doi:10.2105/AJPH.2007.131128)

Motor vehicle collisions are the leading cause of unintentional injury and death among children aged 1 year or older in the United States. In 2005, 510 children aged 3 years or younger were killed in traffic crashes.[1] Restraint systems have long been recognized as an important intervention to reduce the likelihood of serious injury during traffic collisions. The use of child safety seats for children aged 3 years or younger has been required, with few exceptions, in all 50 states and the District of columbia since 1985.[2,3] Safety seat use rates are high for these children: among children younger than 1 year, safety seat use increased from 88% in 1994[4] to 93% in 2006,[5] and among children aged 1 to 3 years, use increased from fewer than 50% in 1994[4] to 91% in 2006.[5]

Hertz[6] obtained the most widely used estimates of child restraint effectiveness in preventing fatalities in an analysis of 1988 to 1994 National Highway Traffic Safety Administration Fatality Analysis Reporting System (FARS) data. Hertz used a double-pair comparison method[7] to estimate that child restraints in passenger cars and light trucks reduced fatality risk by 54% and 59%, respectively. Her work updated a similar analysis by Partyka.[8] Neither of these studies provided confidence intervals (CIs) or other measures of uncertainty.

Despite being based on crash data that are now 14 to 20 years old, Hertz's estimates are widely cited in research and prevention programs.[9–11] Since these data were collected, car seat use for toddlers has increased, seating in the rear seat has increased,[12] and forward-facing child safety seats have changed from predominantly t-shield and overhead shield designs[13,14] to almost exclusively 5-point harness designs.[15]

Two studies examined the effects of child safety seats on nonfatal injury risk using accident claim data and interviews of drivers insured by a large US insurance company.[16,17] Arbogast et al.[16] reported that, compared with seat belts, forward-facing car seats reduced serious injury occurrence among children aged 1 to 3 by 78%. Winston et al.[17] found that, among children aged 2 to 5 years, child restraints reduced the risk of serious injury by 71% and the risk of head injury by 76%, compared with seat belts.[17] A major limitation of these studies is possible bias because of incorrect restraint use information provided by parents.

In a more recent analysis of 1975 to 2003 FARS fatality data, Levitt[18] reported that, among children aged 2 to 6 years riding in passenger vehicles, child safety seats were effective but no more effective than seat belts. He calculated fatality risk reductions of 44% to 67% for various restraints.

Other studies have estimated child restraint effects on the risk of injury or death using the Crashworthiness Data System. Elliott et al.[19] compared fatalities in FARS with survivors in the Crashworthiness Data System. They found a 21% lower risk of death for children aged 2 to 6 years restrained in safety seats than for children aged 2 to 6 years using seat belts. These findings are comparable to those of Partyka[8] and Hertz[6] regarding the relative effectiveness of these restraints. Elliot et al. did not compare the effectiveness of safety seats or of seat belts with traveling unrestrained. Zaloshnja et al.[20] reported 82% lower odds of any injury for children aged 2 and 3 years restrained in safety seats than for those in seat belts.

The literature contains great variability in estimates of child restraint system effectiveness, and little is known about how crash, vehicle, and personal characteristics influence the ability of safety seats to prevent death and about whether effectiveness has changed over time. Our objective in this study was to provide updated estimates of the effectiveness of child safety seat use in reducing death risk among children 3 years or younger and to assess the modification of effectiveness by selected characteristics.

METHODS

We conducted a matched cohort study using data from FARS. Data from vehicles that carried a child aged 3 years or younger and in which 1 or more person died formed matched sets. We analyzed the data with a conditional Poisson regression model and a bootstrap method. We addressed potential problems caused by missing values with multiple imputation. We examined the possible influence of seat belt use misclassification on observed seat belt effectiveness estimates.

Data

FARS is an ongoing census operated by the National Highway Traffic Safety

Administration[21] of fatal traffic collisions that occur on US roadways and result in fatality within 30 days. Data files for 1996 to 2005 were queried for passenger cars, minivans, pickups, and sport-utility vehicles (SUVs) with model years 1990 to 2006 and for which the most harmful event was a single- or multiple-vehicle collision. We identified an initial sample of 295 867 vehicles, and from these, we selected 6303 vehicles in which 2 or more occupants were in the first 2 rows of seating, their ages were known, 1 or more of them was 3 years or younger, and 1 or more of them died. We retained occupants with seating "unknown" seating position within a particular an row in the sample and assigned their seating position within that row with multiple imputation.

We excluded data from Alabama, Indiana, Iowa, Maryland (1996), Massachusetts (1996–2001), Nebraska, Rhode Island (1996–1999), and Virginia because of incomplete occupant ascertainment or incomplete occupant data collection, resulting in the removal of 559 vehicles from the data sample. In addition, we excluded 12 vehicles because a child 3 years or younger was recorded as having been in the driver seat. The resulting sample had data on 5732 vehicles and 19 293 occupants.

Variables

We dichotomized the injury severity variable into fatal injury and all other outcomes (no injury, 4 nonfatal injury codes, and unknown). We used indicator variables for the specific age categories specified in each model. In addition, we used a continuous age variable to create quadratic spline terms for all occupants with nodes at 10, 20, and 40 years.

FARS uses 1 restraint use variable to code for seat belt, child restraint, and helmet use. We combined shoulder belt, lap belt, lap and shoulder belt, and seat belt used improperly into a belt use indicator. We combined child safety seat and child safety seat used improperly into an "as used" child safety seat indicator for children aged 0 to 3 years, because the determination of proper use may be affected by the investigating officer's knowledge of the injury outcome.[22] A very small number of occupants were coded as using a motorcycle helmet, bicycle helmet, or a helmet used improperly, which resulted in missing information on restraint use. We multiplied imputed restraint use for these occupants and for occupants with unknown codes (restraint used–type unknown and unknown).

We created indicators for driver's side, middle, and passenger's side positions in each of the first 2 seating rows. We multiplied imputed values for unknown seating position within a known row. We combined the 2 rollover values, rollover in first harmful event and rollover subsequent to first harmful event, into a rollover indicator. We created an indicator for front or side air bag deployment. We selected calendar year and model year categories to include an approximately equal number of years and vehicles. We did not attempt to capture specific changes in vehicle or restraint characteristics.

Study Design

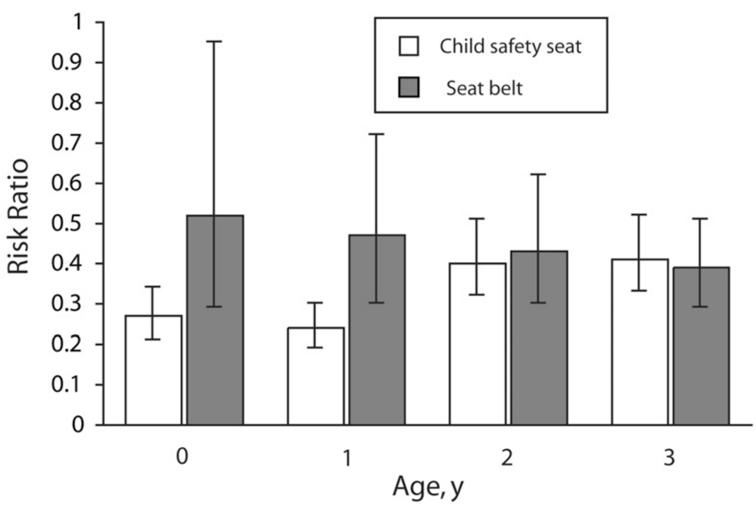
We chose a matched-set cohort design because collision data from FARS and similar data systems possess a characteristic known as "natural matching."[23,24] This quality is present because when a motor vehicle is involved in a collision, the occupants share the same values for most crash and vehicle factors. Conditional analysis methods can estimate risk ratios (RRs) for factors that vary within each matched set (e.g., occupant gender) as well as interactions between these variables and the matched factors (e.g., gender×vehicle type).[23–25]

Conditioning on the matching allows the estimation of RRs despite the absence of information on crashes in which no occupant died and provides control for potential confounding by the matched factors. Conditioning also controls for potential confounders for which no information is recorded by investigating police officers, such as crash energy and ambulance response time.[26] Matched cohort methods have been used in studies of the effects of seat belts,[7,27] air bags,[28–30] motorcycle helmets,[31–33] occupant seating position,[34–36] and pickup truck cargo area travel.[37]

Statistical Modeling

We used conditional Poisson regression to estimate RRs.[23] Because these models provide incorrect variance estimates,[23,25] we used a bootstrap method to obtain variance estimates.[38] We implemented all statistical procedures with the Stata software package.[39]

We selected models using previous knowledge about the likely causal relations among the factors on which we had data and did not use tests of statistical significance. All models contained terms for restraint use, seating position, air bag deployment, age, and quadratic age spline terms. We included additional product terms to examine possible effect modification. We assessed estimated effect modification with the Wald test of homogeneity.[24]



Restraint	0	1	2	3
Child safety seat	1143	1328	1086	787
Seat belt	41	93	172	320
Unrestrained	270	249	368	432
Unknown[a]	60	46	81	100

[a]Assigned to other values of restraint use by multiple imputation.
*$P<.005$ for child safety seat use; Wald test for homogeneity.
**$P=.68$ for child seat belt use; Wald test for homogeneity.

FIGURE 1—Risk ratios and 95% confidence intervals comparing the effect of child safety seat use and seat belt use with no restraint, by age and restraint use: 1996–2005.

Potential Misclassification Bias

We conducted a sensitivity analysis[40–42] because of the concern that children in seat belts may be more likely than would children in safety seats to be thrown from their seating positions and to suffer fatal injury. Incorrect coding of these children as unbelted may result in the overestimation of seat belt effectiveness. We explored the effects of possible misclassification of seat belt use by examining the bias that would have resulted from a range of hypothesized misclassification rates. We created scenarios and corrected restraint coding by single year of age. Children were randomly selected from the unrestrained or unknown strata and reclassified to the belted strata. We performed the process with 500 Monte Carlo simulations.[43]

Missing Data

A total of 4864 occupants (25%) had 1 or more missing values for 4 occupant-level variables: 12 (0.06%) had a missing value for gender, 187 (1.0%) had missing seating position, 1339 (7.0%) had missing restraint use or type, and 3779 (20.0%) had missing airbag deployment. Multiple imputation[44,45] was used to allow available information from occupants with incomplete information to be utilized and was implemented by chained equations.[46]

Missing data were imputed for the 4 occupant-level variables by using known values for those variables and values for calendar year, urban or rural location, model year, body type, rollover status, fatality, age, and the seating location of other occupants. In addition, the imputation of restraint use utilized the restraint type of other vehicle occupants, and the imputation of airbag deployment utilized initial impact point, principal impact point, vehicle model year, and vehicle type. We retained partial information on seating position (e.g., first row, seat unknown) when available. We identified combinations of values that did not occur in the data, such as left front seating and child restraint use, and used this information to tailor the imputation equations to avoid convergence problems in the imputation model and impossible combinations in the imputed data.

RESULTS

The estimated death RR comparing child safety seat use with no restraint for children 3 years or younger was 0.33 (95% CI=0.29, 0.37). The RR estimate indicates that, assuming no net bias from all sources, children who were restrained in a safety seat were 67% less likely to suffer fatal injury during severe motor vehicle collisions than were children who were traveling unrestrained. The estimated effectiveness of safety seats appears to be greater for very young children. For children aged 0, 1, 2, and 3 years, the estimated RRs for safety seat use were 0.27, 0.24, 0.40, and 0.41, respectively (Figure 1). Seat belt effectiveness, conversely, appears to improve with age. RRs for children with the same ages were, respectively, 0.52, 0.47, 0.43, and 0.39. (Because the safety seat and seat belt estimates are independent, RRs and CIs comparing safety seats with seat belts can be calculated by hand.)

Safety seat effectiveness does not appear to have varied meaningfully over time (Table 1). The RR (for all ages) for years 2004 and 2005 was 0.29 compared with 0.34 for 1996 to 1998 (P=.57). Seat belt effectiveness was

TABLE 1—Potential Modifiers of Child Restraint Effectiveness During Motor Vehicle Collisions: United States, 1996–2005

	Safety Seat Use			Seat Belt Use		
Potential Effect Modifier	Age, y	RR[a] (95% CI)	P[b]	Age, y	RR (95% CI)	P
Calendar year						
1996–1998	0–3	0.34 (0.29, 0.41)		0–3	0.41 (0.30, 0.56)	
1999–2001	0–3	0.34 (0.28, 0.40)		0–3	0.32 (0.23, 0.44)	
2002–2003	0–3	0.33 (0.28, 0.38)		0–3	0.51 (0.37, 0.71)	
2004–2005	0–3	0.29 (0.25, 0.35)	.57	0–3	0.43 (0.30, 0.62)	.23
Car model year						
1990–1992	0–3	0.34 (0.29, 0.41)		0–3	0.51 (0.37, 0.70)	
1993–1996	0–3	0.32 (0.28, 0.37)		0–3	0.34 (0.26, 0.44)	
1997–2000	0–3	0.32 (0.27, 0.37)		0–3	0.43 (0.30, 0.61)	
2001–2006	0–3	0.33 (0.27, 0.41)	.93	0–3	0.36 (0.21, 0.63)	.27
Motor vehicle type						
Car	0–1	0.27 (0.23, 0.33)		0–3	0.45 (0.36, 0.56)	
	2–3	0.43 (0.36, 0.52)				
SUV	0–1	0.19 (0.15, 0.24)		0–3	0.31 (0.19, 0.50)	
	2–3	0.32 (0.25, 0.42)				
Minivan	0–1	0.24 (0.18, 0.33)		0–3	0.47 (0.29, 0.76)	
	2–3	0.53 (0.40, 0.69)				
Pickup	0–1	0.22 (0.15, 0.32)		0–3	0.41 (0.24, 0.72)	.45
	2–3	0.37 (0.24, 0.56)	<.005			
Vehicle rolled over						
No	0–1	0.43 (0.36, 0.52)		0–1	0.51 (0.33, 0.79)	
	2–3	0.28 (0.23, 0.33)		2–3	0.46 (0.37, 0.59)	
Yes	0–1	0.22 (0.18, 0.27)		0–1	0.47 (0.27, 0.81)	
	2–3	0.35 (0.28, 0.44)	<.005	2–3	0.26 (0.17, 0.40)	.08
Location						
Urban	0–1	0.30 (0.24, 0.37)		0–1	0.96 (0.54, 1.73)	
	2–3	0.46 (0.37, 0.58)		2–3	0.46 (0.32, 0.64)	
Rural	0–1	0.24 (0.20, 0.28)		0–1	0.35 (0.22, 0.55)	
	2–3	0.39 (0.33, 0.47)	<.005	2–3	0.38 (0.30, 0.49)	.02
Total	0–1	0.26 (0.21, 0.30)		0–1	0.49 (0.35, 0.71)	
	2–3	0.41 (0.35, 0.48)	<.005	2–3	0.40 (0.32, 0.49)	.24

Note. RR = relative risk; CI = confidence interval; SUV = sport utility vehicle.
[a]RRs compared restraint use with no restraint and adjusted for age, gender, air bag deployment, seating position, and all matched collision and vehicle characteristics.
[b]From the Wald test for homogeneity.

more variable over time, but we did not observe a trend. Safety seat effectiveness was nearly unchanged across model years (P=.93). Seat belt effectiveness, on the other hand, may be greater in newer vehicles. The RR (for all ages) for model years 1990 to 1992 was 0.51, compared with 0.34, 0.43, and 0.36 for 1993 to 1996, 1997 to 2000, and 2001 to 2006, respectively (P=.27).

Child safety seats and seat belts appear to be more effective in SUVs and pickups than in cars and minivans (P<.005). We observed this pattern for seat belts and for safety seats among children aged 2 and 3 years and estimated that effectiveness was greatest in SUVs for all children. The observed variation in safety seat RRs across vehicle types is less among children 1 year and younger than among children aged 2 and 3 years.

Rollover status and location (urban vs rural) also appear to be modifiers of child restraint effectiveness. Child safety seat effectiveness was greater during rollovers for children aged 0 and 1 (0.22 vs 0.43; P<.001), whereas seat belt effectiveness was greater during rollovers for children aged 2 and 3 years (0.26 vs 0.46; P=.02). Restraint RRs did not vary meaningfully across levels of land use except in the case of seat belt use among very young children. Seat belts protected children 1 year and younger only in rural environments (RR=0.35 for rural vs 0.96 for urban; P=.01). Rollover status modified the safety seat effectiveness estimates for SUVs and pickups to a greater extent than it did for cars and minivans (Table 2). For example, the rollover and nonrollover RRs were 0.22 and 0.29, respectively, for SUVs and 0.33 and 0.35, respectively, for cars.

Rollover status also modified safety seat effectiveness in urban environments but not in rural environments. Seat belts performed equally well during rollover collisions in both urban and rural environments. The poorest performance of both safety seats and seat belts was in urban nonrollover collisions (RR=0.39 and 0.58, respectively).

Table 3 presents uncorrected RRs and corrected RRs under 8 misclassification scenarios. Under conditions of equal nonfatal and fatal seat belt use misclassification, the corrected estimates differ little from the observed estimates. When the misclassification differed by fatality status, we observed bias. The disparity between the observed and corrected estimates increased with the divergence of misclassification rates. In scenarios in which misclassification was greater for fatally injured children than for nonfatally injured children, the corrected seat belt RRs were higher than the uncorrected RRs. For example, with 25% and 10% misclassification among fatally and nonfatally injured children, respectively, the corrected RR was 0.70, whereas the uncorrected RR was 0.56.

TABLE 2—Potential Modifiers of Child Restraint Effectiveness During Motor Vehicle Collisions Among Occupants Aged 3 or Younger: United States, 1996–2005

Potential Effect Modifier	Safety Seat, RR[a] (95% CI)	Seat Belt, RR[a] (95% CI)
	Vehicle did not roll over	
Vehicle type		
Car	0.35 (0.31, 0.41)	. . .
SUV	0.29 (0.23, 0.38)	. . .
Minivan	0.38 (0.30, 0.49)	. . .
Pickup	0.32 (0.23, 0.45)	. . .
Land use		
Urban	0.39 (0.34, 0.46)	0.58 (0.43, 0.79)
Rural	0.32 (0.28, 0.38)	0.40 (0.31, 0.51)
	Vehicle did roll over	
Vehicle type		
Car	0.33 (0.27, 0.40)	. . .
SUV	0.22 (0.18, 0.28)	. . .
Minivan	0.34 (0.24, 0.48)	. . .
Pickup	0.25[b] (0.15, 0.40)	. . .
Location		
Urban	0.29 (0.21, 0.39)	0.28 (0.11, 0.74)
Rural	0.28[c] (0.24, 0.33)	0.28[d] (0.19, 0.42)

Note. RR = relative risk; CI = confidence interval; SUV = sport utility vehicle. Ellipses indicate that there were insufficient data for RR estimation.
[a]RRs compared restraint use with no restraint and adjusted for age, gender, air bag deployment, seating position, and all matched collision and vehicle characteristics.
[b]P = .03 from Wald test for homogeneity.
[c]P = .02 from Wald test for homogeneity.
[d]P = .02.

DISCUSSION

In this study, we found that child safety seat use among children aged 3 or younger greatly reduces the risk of death during traffic collisions. Overall, unrestrained children were 3 times more likely to die during collisions than were children using a child safety seat. We also found that effectiveness is greater for younger children: death risk reduction is 74% for children aged 1 year and younger and 59% for children aged 2 and 3 years.

Although child safety seat design has improved and the use of rear seating has increased since the earlier estimates, our findings are generally consistent with the 5 studies we identified that estimated the effect of child restraints on fatality.[6,8,18,19,47] Of the 3 studies that examined infants and toddlers separately, 2 reported child safety seats to be more effective for infants.

For children aged 1 year and younger, we found that child safety seats were roughly twice as effective as seat belts; but for children aged 2 and 3 years, seat belts were as effective as child safety seats at preventing death. The latter finding is consistent with that of Levitt, who reported that seat belts were no more effective than were child safety seats for children aged 2 to 6 years.[18] Our estimates of seat belt effectiveness for 2- and 3-year-old children are higher than those of Partyka[8] and Hertz[6] and inconsistent with the better performance of child safety seats over seat belts reported by Elliott et al.[19]

Sensitivity Analyses

Child restraints may prevent fatalities partly by preventing ejection.[48] Ejection is a major risk factor for fatalities in motor vehicle crashes and is especially common in rollover collisions.[48,49] The effects of child restraints on death risk

TABLE 3—Risk Ratios of Child Restraint Use During Motor Vehicle Collisions, Corrected for Seat Belt Use Misclassification: United States, 1996–2005

	Fatally Injured		
Nonfatally injured	No Misclassification	10% Misclassification	25% Misclassification
No misclassification			
Safety seat at age 0–1 y	0.29	0.30	0.31
Safety seat at age 2–3 y	0.47	0.48	0.52
Seat belt at age 0–1 y	0.56	0.63	0.76
Seat belt at age 2–3 y	0.44	0.51	0.65
10% misclassification			
Safety seat at age 0–1 y	0.29	0.29	0.30
Safety seat at age 2–3 y	0.44	0.46	0.49
Seat belt at age 0–1 y	0.52	0.58	0.70
Seat belt at age 2–3 y	0.39	0.45	0.58
25% misclassification			
Safety seat at age 0–1 y	0.28	0.28	0.29
Safety seat at age 2–3 y	0.39	0.40	0.43
Seat belt at age 0–1 y	0.45	0.50	0.60
Seat belt at age 2–3 y	0.31	0.35	0.45

Note. Risk ratios were obtained from 1 imputed data set (nonrestraint variables have imputed values).

during rollover crashes has not been previously reported although at least 1 study found restraints to be more effective in reducing nonfatal injury risk during rollover collisions (among children aged 15 years and younger).[50] We found that safety seats were more effective in preventing death in rollover collisions than in other collisions for children aged 1 year and younger but not for children aged 2 and 3 years.

Misclassification bias should be considered when interpreting these seat belt estimates. Belted children may often be coded as unrestrained or with unknown restraint use because of investigating officers' difficulty in determining seating position and restraint use status. Children thrown from their seating position are more likely to die from their injuries and thus the misclassification of restraint use for these children may bias seat belt RRs downward, making belts appear more effective than they are.

Our bias sensitivity analysis demonstrates that the observed RRs for seat belt use are moderately sensitive to misclassification of seat belt use. Under all scenarios in which the misclassification for fatally injured children exceeded that for nonfatally injured children, the seat belt RRs were biased, particularly for children aged 2 and 3 years. The strength of this type of analysis is that it estimates the magnitude as well as direction of possible bias. For example, under the scenario of 10% and 25% misclassification for nonfatalities and fatalities, the 2 observed estimates, 0.54 and 0.46, would have been biased down from their true values of, respectively, 0.67 and 0.58.

Because air bags are found almost entirely in front seating positions, air bag deployment and seating position effects may be confounded. To examine the possible influence of any confounding variables on our restraint estimates, we used 2 seating position coding schemes. We compared the use of standard indicator variables with a coding scheme used by Olson et al.[30] to estimate rear seating position effects. The use of the second coding scheme altered the seating position coefficients, indicating the presence of confounding by air bags, but affected the restraint use estimates negligibly. It appears that either scheme is adequate for the confounder control purposes of this analysis.

We explored the potential confounding of age and seating position by estimating RRs using a subset of data with drivers removed, an approach used by Smith and Cummings.[36] The removal of drivers resulted in a significant loss of data because children who were unmatched in any set (vehicle) after the removal of the drivers were also removed (because they carry no information in the conditional regression model). The restraint RRs were negligibly different after reducing the data set, indicating that the absence of young children in the driver position does not confound restraint RR estimates.

RRs obtained using a complete-case analysis (safety seat RR=0.31, 0.25, 0.45, and 0.40 for children aged 0, 1, 2, and 3, respectively; see Figure 1 and "Results" section) were similar to but less precise than were those obtained using multiple imputation.

Limitations

This study has several limitations. FARS does not differentiate safety and booster seats. Some children, primarily those aged 3 years, may have been restrained in booster seats. The direction of any bias caused by the inclusion of these children is not known, but we would expect the magnitude of bias to be very low given that the effectiveness of booster seats is similar to that of child safety seats.[51] Also, the coding of restraint use may be influenced by occupant injury severity. Finally, the lack of information in FARS on whether an occupant was thrown from her or his seat required us to use fatality status in our sensitivity analysis, which may have influenced the corrected RRs.

Conclusions

The findings from this study indicate that child restraints greatly reduce the risk of death among children 3 years and younger involved in severe traffic collisions. Child safety seats appear to outperform seat belts in preventing fatalities for children aged 1 year and younger but not for children aged 2 and 3 years. Our bias sensitivity analysis demonstrates that the seat belt RRs for children aged 2 and 3 years are moderately sensitive to bias from misclassification and should be viewed with caution. Child safety seats may not be superior to ordinary seat belts in preventing death among children aged 2 and 3 years, but because numerous studies have found that safety seats are more effective than are seat belts in preventing nonfatal injury among young children, clinicians and public health practitioners should continue to encourage parents to use child safety seats in favor of seat belts and should provide information on the proper selection and use of safety seats. ■

About the Authors

Thomas M. Rice is with the Traffic Safety Center at the School of Public Health, University of California, Berkeley. Craig L. Anderson is with the Department of Emergency Medicine and the Center for Trauma and Injury Prevention Research at the University of California, Irvine.

Requests for reprints should be sent to Thomas Rice, Traffic Safety Center, 2614 Dwight Way #7374, Berkeley, CA 94720–7374 (e-mail: tomrice@berkeley.edu).

This article was accepted May 21, 2008.

Contributors

T.M. Rice conceptualized and designed the study, analyzed the data, and drafted the article. C.L. Anderson contributed to study design, analyzed the data, and revised the article.

Acknowledgments

This research was funded by the AAA Foundation for Traffic Safety (grant AAAFTS-51096). Supplemental support was provided by the California Office of Traffic Safety (grant AL0801).

Human Participant Protection

This study was certified as exempt from institutional review by the University of California, Berkeley, Office for the Protection of Human Subjects.

References

1. Web-Based Injury Statistics Query and Reporting System. WISQARS injury mortality reports, 1999–2005. Atlanta, GA: Centers for Disease Control and Prevention. Available at: http://webappa.cdc.gov/sasweb/ncipc/mortrate10_sy.html. Accessed October 2, 2007.
2. Highway Loss Data Institute, Insurance Institute for Highway Safety. Child restraint laws: July 2007. Available at: http://www.iihs.org/laws/ChildRestraint.aspx. Accessed August 3, 2007.
3. Teret SP, Jones AS, Williams AF, Wells J. Child restraint laws: an analysis of gaps in coverage. *Am J Public Health.* 1986;76:31–34.
4. *Research Note: National Occupant Protection Use Survey—Controlled Intersection Study.* Washington, DC: National Highway Traffic Safety Administration; 1995.
5. Glassbrenner D, Ye TJ. Child Restraint use in 2006: use of correct restraint types. Washington, DC: National Highway Traffic Safety Administration; 2007. Report DOT HS 810798.
6. Hertz E. *Research Note: Revised Estimates of Child Restraint Effectiveness.* Washington, DC: National Highway Traffic Safety Administration; 1996.
7. Evans L. Double pair comparison—a new method to determine how occupant characteristics affect fatality risk in traffic crashes. *Accid Anal Prev.* 1986;18:217–227.
8. Partyka S. *Lives Saved by Child Restraints From 1982 Through 1987.* Washington, DC: National Highway Traffic Safety Administration; 1988.
9. Child passenger safety: fact sheet. Atlanta, GA: Centers for Disease Control and Prevention. Available at: http://www.cdc.gov/ncipc/factsheets/childpas.htm. Accessed February 8, 2008.
10. Traffic safety facts: 2005 data—children. Washington, DC: National Highway Traffic Safety Administration; 2006.
11. 2003 motor vehicle occupant protection facts: children, youth, young adults. Washington, DC: National Highway Traffic Safety Administration; 2006.
12. Glass RJ, Graham JD. Kids at risk: where American children sit in passenger vehicles. *J Safety Res.* 1999;30:17–24.
13. Decina LE, Knoebel KY. Patterns of misuse of child safety seats. Washington, DC: National Highway Traffic Safety Administration; 1996. Report DOT HS 808440.
14. Winston FK, Chen IG, Elliott MR, Arbogast KB, Durbin DR. Recent trends in child restraint practices in the United States. *Pediatrics.* 2004;113(5):e458–e464.
15. 2008 child safety seat ease of use ratings. Washington, DC: National Highway Traffic Safety Administration. Available at: http://www.nhtsa.gov/portal/nhtsa_eou/info.jsp?type=all. Accessed April 21, 2008.
16. Arbogast KB, Durbin DR, Cornejo RA, Kallan MJ, Winston FK. An evaluation of the effectiveness of forward facing child restraint systems. *Accid Anal Prev.* 2004;36:585–589.
17. Winston FK, Durbin DR, Kallan MJ, Moll EK. The danger of premature graduation to seat belts for young children. *Pediatrics.* 2000;105:1179–1183.
18. Levitt SD. *Evidence That Seat Belts Are as Effective as Child Safety Seats in Preventing Death for Children Aged Two and Up.* Cambridge, MA: National Bureau of Economic Research; 2005.
19. Elliott MR, Kallan MJ, Durbin DR, Winston FK. Effectiveness of child safety seats vs seat belts in reducing risk for death in children in passenger vehicle crashes. *Arch Pediatr Adolesc Med.* 2006;160:617–621.
20. Zaloshnja E, Miller T, Hendrie D. Effectiveness of child safety seats vs safety belts for children aged 2 to 3 years. *Arch Pediatr Adolesc Med.* 2007;161:65–68.
21. Tessmer J. *FARS Analytic Reference Guide 1975 to 2002.* Washington, DC: National Highway Traffic Safety Administration.
22. Robertson LS. Bias in estimates of seat belt effectiveness. *Inj Prev.* 2002;8(4):263.
23. Greenland S. Modelling risk ratios from matched cohort data: an estimating equation approach. *Appl Stat.* 1994;43:223–232.
24. Rothman K, Greenland S. *Modern Epidemiology.* 2nd ed. Philadelphia, PA: Lippincott-Raven; 1998.
25. Cummings P, McKnight B, Greenland S. Matched cohort methods for injury research. *Epidemiol Rev.* 2003;25:43–50.
26. Cummings P, McKnight B, Weiss NS. Matched-pair cohort methods in traffic crash research. *Accid Anal Prev.* 2003;35:131–141.
27. Cummings P, Wells JD, Rivara FP. Estimating seat belt effectiveness using matched-pair cohort methods. *Accid Anal Prev.* 2003;35:143–149.
28. Evans L. Airbag effectiveness in preventing fatalities predicted according to type of crash, driver age, and blood alcohol concentration. *Accid Anal Prev.* 1991;23:531–541.
29. Cummings P, McKnight B, Rivara FP, Grossman DC. Association of driver air bags with driver fatality: a matched cohort study. *BMJ.* 2002;324:1119–1122.
30. Olson CM, Cummings P, Rivara FP. Association of first- and second-generation air bags with front occupant death in car crashes: a matched cohort study. *Am J Epidemiol.* 2006;164:161–169.
31. Evans L, Frick MC. Helmet effectiveness in preventing motorcycle driver and passenger fatalities. *Accid Anal Prev.* 1988;20:447–458.
32. Anderson CL, Kraus JF. The changing effect of motorcycle helmet use on mortality: comparisons of drivers and passengers on the same motorcycle. Paper presented at: Meeting of the Association for the Advancement of Automotive Medicine; October 7–9, 1996; Vancouver, British Columbia.
33. Norvell DC, Cummings P. Association of helmet use with death in motorcycle crashes: a matched-pair cohort study. *Am J Epidemiol.* 2002;156:483–487.
34. Evans L, Frick MC. Seating position in cars and fatality risk. *Am J Public Health.* 1988;78:1456–1458.
35. Lardelli-Claret P, Jimenez-Moleon J, Luna-Del-Castillo Jde D, Bueno-Cavanillas A. Individual factors affecting the risk of death for rear-seated passengers in road crashes. *Accid Anal Prev.* 2006;38:563–566.
36. Smith KM, Cummings P. Passenger seating position and the risk of passenger death in traffic crashes: a matched cohort study. *Inj Prev.* 2006;12:83–86.
37. Anderson CL, Agran PF, Winn DG, Greenland S. Fatalities to occupants of cargo areas of pickup trucks. *Accid Anal Prev.* 2000;32:533–540.
38. Efron B, Tibshirani R. *An Introduction to the Bootstrap.* New York, NY: Chapman & Hall; 1993.
39. *Stata* [computer program]. Version 10. College Station, TX: StataCorp, Inc; 2007.
40. Greenland S. Basic methods for sensitivity analysis and external adjustment. In: Rothman K, Greenland S, eds. *Modern Epidemiology.* 2nd ed. Philadelphia, PA: Lippincott-Raven; 1998:343–357.
41. Lash T. Semi-automated sensitivity analysis to assess systematic errors in observational data. *Epidemiology.* 2003;14:451–458.
42. Phillips C. Quantifying and reporting uncertainty from systematic errors. *Epidemiology.* 2003;14:459–466.
43. Gelman A, Rubin DB. Markov chain Monte Carlo methods in biostatistics. *Stat Methods Med Res.* 1996;5:339–355.
44. Rubin D. *Multiple Imputation for Nonresponse in Surveys.* New York, NY: Wiley; 1987.
45. Rubin D, Little R. *Statistical Analysis With Missing Data.* Hoboken, NJ: Wiley-Interscience; 2002.
46. van Buuren S, van Rijckevorsel JLA, Rubin D. Multiple imputation by splines. *Bulletin of the International Statistical Institute, Contributed Papers II.* 1993:503–504.
47. Kahane CJ. *An Evaluation of Child Passenger Safety: The Effectiveness and Benefits of Safety Seats.* Washington, DC: National Highway Traffic Safety Administration; 1986.
48. Evans L. Restraint effectiveness, occupant ejection from cars, and fatality reductions. *Accid Anal Prev.* 1990;22:167–175.
49. Howard A, McKeag AM, Rothman L, Comeau JL, Monk B, German A. Ejections of young children in motor vehicle crashes. *J Trauma.* 2003;55:126–129.
50. Daly L, Kallan MJ, Arbogast KB, Durbin DR. Risk of injury to child passengers in sport utility vehicles. *Pediatrics.* 2006;117:9–14.
51. Durbin DR, Elliott MR, Winston FK. Belt-positioning booster seats and reduction in risk of injury among children in vehicle crashes. *JAMA.* 2003;289:2835–2840.