Association Between Different Restraint Use and Rear-Seated Child Passenger Fatalities

A Matched Cohort Study

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Objective: To investigate the association between restraint use and death in rear-seated child passengers and to examine whether the estimated association varies by restraint type and age.

Design: Matched cohort study.

Setting: All reported crashed passenger vehicles with at least 2 rear-seated child passengers of whom at least 1 died from the US Fatality Analysis Reporting System for 1998 to 2006.

Participants: Rear-seated child passengers aged 2 to 6 years.

Interventions: Three models of restraint use: (1) no restraint use, any restraint use; (2) no restraint use, recorded improper restraint use (including improper use of seat belts or child restraints, use of shoulder-only seat belts, and use of an unknown type of restraint), any other restraint use; and (3) no restraint use, improper restraint use, seat belts, and child restraints.

Main Outcome Measure: Death within 30 days of a crash.

Results: Compared with no restraint use, being restrained reduced the risk of death in rear-seated child passengers (relative risk [RR], 0.33; 95% confidence interval [CI], 0.22-0.49). Compared with improper restraint use, any other restraint use reduced the risk of death (RR, 0.46; 95% CI, 0.20-0.63). The RR of death for using child restraints compared with seat belts was 0.91 (95% CI, 0.57-1.14). Child restraints performed slightly better in fatality risk reduction in children aged 2 to 3 years (RR, 0.24; 95% CI, 0.09-0.33) than in children aged 4 to 6 years (RR, 0.32; 95% CI, 0.11-0.44) compared with traveling unrestrained.

Conclusions: This study demonstrates the protective effects of restraints for child passengers and highlights the importance of using restraints correctly.

METHODS

DATA SOURCE

We used the US Fatality Analysis Reporting System (FARS) data sets for 1998 to 2006, which are maintained by the National Highway Traffic Safety Administration (NHTSA). FARS is a census of all motor vehicle traffic crashes in the United States and Puerto Rico that occur on a public roadway and involve at least 1 vehicle occupant or nonmotorist fatality (eg, a pedestrian) within 30 days of the crash. The data sets contain crash, vehicle, and casualty information for these fatal crashes.10 Relevant information on uninjured occupants is also included.

STUDY DESIGN

We used a matched cohort design, which uses all relevant occupants in a motor vehicle when at least 1 has the study outcome. It compares the probability of the study outcome associated with the study exposure for individuals traveling in the same vehicle. It allows the calculation of RRs of the outcome of interest without the need for information on crashes in which all occupants survived.7

DEFINITION OF MATCHED SET

We selected passenger vehicles according to the NHTSA definition,10 that is, passenger cars, vans, and utilities (including pickup trucks and light trucks). Because seating position (ie, front or rear) and front passenger air bags are potential major confounders of injury risk in young child passengers,4 we restricted these analyses to passenger vehicle crashes in which at least 2 child passengers aged 2 to 6 years were rear seated and at least 1 of them died.

STUDY SAMPLE AND OUTCOME

During the study period, there were 705 crashed vehicles and 1517 child passengers for analysis after sequentially excluding matched sets for the following reasons: lack of restraint use information (99 vehicles, 246 children); lack of a known seating position or seated in a nonpassenger position of the vehicle (161 vehicles, 391 children); incomplete injury information (1 vehicle, 3 children); or unknown airbag presence in the vehicle (1 vehicle, 2 children). We further excluded 1 child passenger with missing sex information from a matched vehicle. The outcome variable was death within 30 days of a crash.

STUDY EXPOSURE

The study exposure was restraint use, which was categorized according to 3 classifications. To estimate the association between restraint use and death, we classified restraint exposure into either “no restraint use” or any restraint use” (model 1). Because restraint misuse may affect the study association,2 we further distinguished recorded improper restraint use (including improper use of seat belts or child restraints, use of a shoulder-only seat belt, and use of an unknown type of restraint) from the “any restraint use” category (model 2). To determine the association between type of restraint use and death, we classified restraint exposure into 4 categories: no restraint use, seat belt use, child restraint use, and improper restraint use (model 3).

CONFOUNDERS OF INTEREST

We treated child age group (2-3 years, suitable for forward-facing child restraints, and 4-6 years, suitable for boosters), sex, seating position (left side [yes/no] and right side [yes/no]), and the interaction between seating position and initial impact point as potential confounding variables in all the analyses. Initial impact point was split into the following categories according to the NHTSA definition:2 noncollision, front, right side, left side, rear, and other (underride, overide, and unknown). Because no child was exposed to a deployed rear-seat air bag, the presence of rear-seat air bags was not considered in this analysis. We considered several variables (age group, sex, and seating position) that may modify the effect of restraint use in each of the models.

STATISTICAL ANALYSES

We estimated the association between restraint use and death using conditional Poisson regression. To fit the conditional Poisson model, we used the Cox proportional hazard regression method to estimate the mortality RR, stratifying on the matched vehicle and using the Breslow method to handle ties in follow-up time, which we set equal within each matched set.8 Because the variance estimate for conditional Poisson regression may be too large when data are almost binary,6 we calculated bootstrap CIs at the 95% level based on 1000 replications by assigning an equal probability to each vehicle to be resampled with replacement.11

We used likelihood ratio tests and Akaike Information Criteria to compare nested models (eg, to compare models 1 and 2).12 The interaction terms involving restraint use were added individually to the regression models, and we retained these if P < .05 from a likelihood ratio test. A software program (SAS version 9.1) was used to perform all the data analyses.13

RESULTS

STUDY POPULATION CHARACTERISTICS

Between January 1, 1998, and December 31, 2006, there were 608 matched vehicles with 628 child fatalities traveling with a total of 685 surviving children in which at least 1 child survived; a further 97 vehicles included 204 child fatalities in which all children died. The characteristics of the study population were similar to those of children from excluded matched sets: the proportion of deaths in the study population was 54.8% (832 of 1517) vs 49.1% (316 of 643), the proportion of 2- to 3-year-olds was 40.9% (621 of 1517) vs 38.4% (247 of 643), and the proportion of boys was 48.3% (733 of 1517) vs 51.0% (328 of 643).

In the study population, a greater proportion of children were unrestrained (39.8% [604 of 1517]) than the proportion of those who used seat belts (26.8% [406 of 1517]) or child restraints (26.8% [406 of 1517]) (Table 1). The mean age of the study population was 4.0 years, as was the median age. Just more than half of the children were girls (51.7% [784 of 1517]) and most children were seated in either the left or right rear position (77.9% [1182 of 1517]). Most children who died (90.9% [756 of 832]) were in crashes with disabling deformation of the vehicle. In nondisabling crashes, 45.3% (25 of 55) of seat-belted children died compared with 30.0% (3 of 10) of child restraint users.

Among restrained children, we observed a monotonic decline in child restraint exposure when age increased as opposed to an increase in seat belt exposure (Figure). Approximately 12.1% (36 of 462) of child restraints were used improperly, and 4.0% (17 of 423) of seat belts were used improperly.
RESTRAINT EFFECTS
None of the interaction terms involving restraint use were significant using likelihood ratio tests. Table 2 provides the model comparison results for the 3 models. Compared with no restraint use, any type of restraint use provided a large reduction in the risk of death (RR, 0.33; 95% CI, 0.22-0.49). Improper restraint use affected the association between restraint use and death for rear-seated child passengers aged 2 to 6 years (likelihood ratio test P < .01 for the comparison between models 1 and 2) (Table 2). Compared with improper restraint use, any other restraint use provided a reduction in the risk of death (RR, 0.46; 95% CI, 0.20-0.63).

TYPE OF RESTRAINT
The association between restraint use and death did not vary significantly by type of restraint use (likelihood ratio test P = .62 for the comparison between models 2 and 3); the RR of death for child restraints compared with seat belts was 0.91 (95% CI, 0.57-1.44) (Table 3). The association between restraint use and death did not vary significantly with age (likelihood ratio test P = .66 for testing of the interaction between restraint use and age group in model 3). Child restraints slightly varied in the protective effects by age compared with no restraint use (Table 3).

COMMENT
This study found that a reduction in the risk of death for rear-seated child passengers is associated with the use of a restraint. This is consistent with 2 earlier studies that also used matched cohort study designs to estimate the association between restraint use and no restraint use. Smith and Cummings4 analyzed FARS data from 1990 to 2001 and estimated a risk reduction for rear-seated child passengers from birth to 12 years of age when no front passenger air bag was present (RR, 0.53; 95% CI, 0.47-0.59). Lardelli-Claret et al14 analyzed road crashes in Spain from 1993 to 2002 for child and adult rear-seated passengers and found an RR of death of 0.56 (95% CI, 0.38-0.82). By comparison, we found a larger reduction in the risk of death when using any type of restraint for rear-seated children aged 2 to 6 years (RR, 0.33; 95% CI, 0.22-0.49).

Improper use of restraints reduced their protective effects in lowering the risk of death in this study. Valent et al15 analyzed National Automotive Sampling System tow-away crash data from 1995 to 1999 for child passengers

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Table 1. Distribution of Characteristics by Restraint Exposure Categories for Rear-Seated Child Passengers Aged 2 to 6 Years in Fatal Crashes During 1998-2006

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No Restraint Use (n = 604)</th>
<th>Improper Restraint Use (n = 101)</th>
<th>Child Restraints (n = 406)</th>
<th>Total (N = 1517)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outcome, No. (%)</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Lived</td>
<td>254 (42.1)</td>
<td>42 (41.6)</td>
<td>193 (47.5)</td>
<td>685 (45.2)</td>
</tr>
<tr>
<td>Died</td>
<td>350 (57.9)</td>
<td>59 (58.4)</td>
<td>213 (52.5)</td>
<td>832 (54.8)</td>
</tr>
<tr>
<td>Age group, No. (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-3 y</td>
<td>213 (35.3)</td>
<td>48 (47.5)</td>
<td>84 (20.7)</td>
<td>321 (40.9)</td>
</tr>
<tr>
<td>4-6 y</td>
<td>391 (64.7)</td>
<td>53 (52.5)</td>
<td>322 (79.3)</td>
<td>986 (59.1)</td>
</tr>
<tr>
<td>Sex, No. (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>300 (49.7)</td>
<td>45 (44.6)</td>
<td>197 (48.5)</td>
<td>733 (48.3)</td>
</tr>
<tr>
<td>Girls</td>
<td>304 (50.3)</td>
<td>56 (55.4)</td>
<td>209 (51.5)</td>
<td>784 (51.7)</td>
</tr>
<tr>
<td>Seating position, No. (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left rear</td>
<td>216 (35.8)</td>
<td>42 (41.6)</td>
<td>167 (41.1)</td>
<td>623 (41.1)</td>
</tr>
<tr>
<td>Center rear</td>
<td>190 (31.4)</td>
<td>24 (23.8)</td>
<td>71 (17.5)</td>
<td>355 (22.1)</td>
</tr>
<tr>
<td>Right rear</td>
<td>198 (32.8)</td>
<td>35 (34.6)</td>
<td>168 (41.4)</td>
<td>559 (36.8)</td>
</tr>
<tr>
<td>Vehicle deformation, No. (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None (or unknown)</td>
<td>16 (2.6)</td>
<td>1 (1.0)</td>
<td>4 (1.0)</td>
<td>21 (1.4)</td>
</tr>
<tr>
<td>Minor and moderate</td>
<td>62 (10.3)</td>
<td>7 (6.9)</td>
<td>51 (12.6)</td>
<td>130 (8.6)</td>
</tr>
<tr>
<td>Disabling</td>
<td>526 (87.1)</td>
<td>93 (92.1)</td>
<td>351 (86.4)</td>
<td>1366 (90.0)</td>
</tr>
</tbody>
</table>

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a Improper restraint use includes improper use of child restraints (56 [55.4%]), use of an unknown type of restraint (28 [27.7%]), improper use of seat belts (15 [14.9%]), and use of a shoulder-only belt (2 [2.0%]).

b Seat belts include lap-only belts (139 [34.2%]) and lap and shoulder belts (267 [65.8%]).
11 years and younger and found a smaller reduction in the risk of death for improper restraint use (risk ratio, 0.74; 95% CI, 0.11-4.98) than for proper restraint use (risk ratio, 0.26; 95% CI, 0.12-0.59) compared with no restraint use. Sherwood et al\(^6\) also suggested that gross misuse of restraints accounted for 12% of fatalities after examining the most responsible factor for a sample of child passenger fatalities 6 years and younger.

The association between restraint use and death did not vary by type of restraint in this study. Using FARS data from 1975 to 2003, Levitt\(^5\) found no difference in the risk of death for child passengers aged 2 to 6 years using child restraints and seat belts. After controlling for a variety of potential crash- and vehicle-related confounders, Levitt found an identical regression model coefficient for child restraints and seat belts compared with being unrestrained. However, in a recent NHTSA analysis of FARS data from 1988 to 1994 for children aged 1 to 4 years, Hertz\(^2\) used a double-paired study design that adjusted for driver restraint status and child seating position and found that child restraints provided a greater reduction in the risk of death than did seat belts (54% vs 47%) in passenger cars compared with no restraint use (statistical significance not reported). Furthermore, by combining data from the FARS and the National Automotive Sampling System Crashworthiness Data System from 1998 to 2003, Elliott et al\(^6\) found a reduced odds of death for child restraints compared with seat belts after removing serious misuse cases for child passengers aged 2 to 6 years in tow-away crashes (OR, 0.72; 95% CI, 0.54-0.97).

Elliott et al\(^6\) and Levitt\(^5\) adjusted for different sets of variables than those used in this study; both were unable to adjust for some potential confounding factors, such as distance to emergency services, that may have affected the likelihood of death. Similar to the present study, Hertz\(^2\) used a matched design to control for vehicle and crash characteristics that may bias the restraint effectiveness estimation and further controlled for vehicle type by stratification. It is possible that the differences in the adjustment for confounders may partly explain the difference in relative effect estimates for child restraints vs seat belts from the present analysis and earlier analyses.\(^5,6\)

A child restraint is designed to distribute impact forces over a child’s body in a more desirable manner than a seat belt in a crash.\(^17\) Using data sets including nonfatal crashes, child restraints have been reported to provide a reduction in the odds of nonfatal injury compared with seat belts—for example, an OR of 0.41 (95% CI, 0.20-0.86) for children aged 4 to 7 years,\(^18\) an OR of 0.22 (95% CI, 0.11-0.45) for children aged 1 to 3 years,\(^19\) and an OR of 0.18 (95% CI, 0.08-0.42) for children aged 2 to 3 years.\(^20\) Winston et al\(^21\) also reported an elevated RR of injury of 3.5 (95% CI, 2.4-5.2) for children aged 2 to 5 years using seat belts compared with those using child restraints from a representative crash sample. Sherwood et al\(^22\) argued that crashes involving the death of a child passenger using a child restraint were of a so-called unsurvivable crash severity. It is possible that this level of crash severity may be associated with the present study population, with almost all deaths (90.9%) occurring in crashes with disabling deformation of the vehicle.

We did not find evidence that the association between type of restraint use and risk of death varies with age. Although child restraints provided a greater but nonsignificant reduction in the risk of death for children aged 2 to 3 years than for children aged 4 to 6 years compared with no restraint use, our ability to detect whether the association varies with age is limited by the study’s sample size.

Matched designs, such as that used in this study, cannot completely eliminate confounding,\(^23\) and uncontrolled confounders may affect the association between risk of death and type of restraint use in this study. For example, the location and the extent of intrusion have been suggested as possible causal factors related to the risk of death in child passengers.\(^16\) However, this information is not available in FARS. Therefore, we could not control for all potential confounders in the present analysis.

Misclassification of restraint type may bias the effect estimates for type of restraint use in children (eg, a belt-positioning booster recorded as a seat belt), although seatbelt use misclassification in a matched cohort study\(^23\) did

### Table 2. Model Comparison to Determine the Association Between Type of Restraint Use and Death\(^a\)

<table>
<thead>
<tr>
<th>Restraint Exposure</th>
<th>–2 Log Likelihood</th>
<th>Akaike Information Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1: no restraint use, any</td>
<td>1192.75</td>
<td>1222.75</td>
</tr>
<tr>
<td>Model 2: no restraint use, improper</td>
<td>1185.28</td>
<td>1217.28</td>
</tr>
<tr>
<td>Model 3: no restraint use, improper, any other restraint use</td>
<td>1185.03</td>
<td>1219.03</td>
</tr>
</tbody>
</table>

\(^a\)Each model was adjusted for age group, sex, seating position, and the interaction between initial impact point and seating position.

\(^b\)Improper restraint use includes improper use of seat belts or child restraints, use of shoulder-only belts, or use of an unknown type of restraint.

\(^c\)Seat belts include lap-only belts and lap and shoulder belts.

### Table 3. Comparison of Mortality for Child Restraints and Seat Belts

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Child Restraints vs No Restraint Use</th>
<th>Seat Belts vs No Restraint Use</th>
<th>Child Restraints vs Seat Belts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entire study population</td>
<td>0.27 (0.12-0.36)</td>
<td>0.30 (0.14-0.40)</td>
<td>0.91 (0.57-1.44)</td>
</tr>
<tr>
<td>Children aged 2-3 y(^b)</td>
<td>0.24 (0.09-0.33)</td>
<td>0.30 (0.10-0.41)</td>
<td>0.82 (0.36-1.99)</td>
</tr>
<tr>
<td>Children aged 4-6 y(^b)</td>
<td>0.32 (0.11-0.44)</td>
<td>0.30 (0.14-0.40)</td>
<td>1.07 (0.62-1.39)</td>
</tr>
</tbody>
</table>

\(^a\)Relative risks were adjusted for age group, sex, seating position, and the interaction between initial impact point and seating position.

\(^b\)Relative risks were adjusted for age group, sex, seating position, the interaction between initial impact point and seating position, and the interaction between type of restraint and age group.
not substantially affect the risk estimates for study participants 16 years and older. In addition, we observed a discrepancy between the prevalence of improper use of child restraints (12.1%) in the present study population and previously reported prevalence (72.6%) from a sample population in 6 states in 2002. It is possible that misuse is under-reported in the FARS data set. If systematic misclassification of this type occurs, it would mask the child restraint effectiveness. Seat belt misuse may also have been under-reported because improper use of seat belts by children is commonly found in in-depth crash studies.

Another limitation was that we could not determine whether the mechanism underlying missing data was completely at random. We restricted the analysis to those with complete information and effectively controlled confounding from known risk factors. Because we found no substantial difference regarding age, sex, and death distributions between the present study population and those being excluded due to missing information, it is unlikely that these estimates of the risk of death are biased substantially by missing data.

In conclusion, this study provides support for current recommendations and promotion campaigns about the optimal use of restraints for young child passengers. Given existing evidence that child restraints outperformed seat belts in reducing nonfatal injuries, the lack of evidence indicating that child restraints are better than seat belts in reducing fatalities raises the need for further study of the performance of child restraint systems in fatal crashes.

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Author Contributions: Mr Du had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Du and Hayen. Acquisition of data: Du, Hayen, Bilston, Hatfield, Finch, and Brown. Drafting of the manuscript: Du, Hayen, and Bilston. Critical revision of the manuscript for important intellectual content: Du, Hayen, Bilston, Hatfield, Finch, and Brown. Statistical analysis: Du, Hayen, and Finch. Obtained funding: Bilston and Finch. Administrative, technical, or material support: Bilston. Study supervision: Hayen, Hatfield, and Finch.

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REFERENCES