Car Occupant Death According to the Restraint Use of Other Occupants
A Matched Cohort Study

Peter Cummings, MD, MPH
Frederick P. Rivara, MD, MPH

A car occupant could be killed if struck by another occupant who was catapulted forward, backward, or sideways in a crash.1-3 We used a matched cohort study design to estimate the association between the death of a car occupant and the restraint use of another occupant in the same car.

METHODS
Matched Cohort Study Design
Persons entered this cohort study when they crashed in a car. The study outcome was death within 30 days of the crash. We wished to adjust for potential confounding factors, such as crash speed and the ability of the vehicle to protect occupants. It is difficult to measure these variables accurately, and estimates of speed were often missing in the data we used. We therefore restricted our study to pairs of occupants who were in the same car when they crashed; these pairs were therefore matched in regard to all vehicle and crash characteristics, such as vehicle type, speed, crash location, and crash severity. A matched-pair cohort design eliminates confounding by all matched variables.4-8 In addition, risk ratios (RRs) for death may be estimated for all pairs, including those in which both survived, using information only from pairs with at least 1 member who died.4-8

Context A car occupant could be killed if struck by another occupant who was catapulted forward, backward, or sideways in a crash.

Objective To estimate the association between death of a car occupant (the target) and restraint use by other occupants.

Design Matched-pair cohort study comparing the outcomes of 2 target occupants in the same passenger car that crashed.


Subjects Target pairs, at least 1 of whom died: 61834 front-seat pairs, 5278 rear-seat pairs, and 21127 pairs on the left or right side.

Main Outcome Measures Adjusted risk ratio (RR) for death within 30 days of a crash.

Results The risk of death was greater for a restrained front target occupant in front of an unrestrained occupant compared with a restrained front target in front of a restrained occupant (adjusted RR, 1.20; 95% confidence interval [CI], 1.10-1.31). For a restrained rear target occupant behind an unrestrained occupant compared with a restrained rear target occupant behind a restrained occupant, the adjusted RR was 1.22 (95% CI, 1.10-1.36). For a restrained side target occupant sitting next to an unrestrained occupant compared with a restrained side target occupant sitting next to a restrained occupant, the adjusted RR was 1.15 (95% CI, 1.08-1.22). Among unrestrained target occupants, the adjusted RRs were, for front targets, 1.04 (95% CI, 0.97-1.12), rear targets, 1.22 (95% CI, 1.10-1.36), and side targets, 0.85 (95% CI, 0.80-0.92).

Conclusion Persons who wish to reduce their risk of death in a crash should wear their own restraint and should ask others in the same car to use their restraints.

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The study subjects who made up the cohort pairs are referred to as targets in this article to distinguish them from other occupants. The main study exposures for each target occupant were the presence of another occupant (not the other target pair member) who might be thrown against the target, as well as the restraint use of this other occupant. A target might be exposed to no other occupant, a restrained other occupant, or an unrestrained other occupant. An occupant was considered restrained if he/she wore a seat belt of any type or used a child car seat.

Author Affiliations: Harborview Injury Prevention and Research Center (Drs Cummings and Rivara) and Departments of Epidemiology (Drs Cummings and Rivara) and Pediatrics (Dr Rivara), University of Washington, Seattle.

Corresponding Author: Peter Cummings, MD, MPH, 250 Grandview Dr, Bishop, CA 93514 (e-mail: peterc@u.washington.edu).

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For front-seat target pairs, the main study exposure was the presence and restraint use of a rear occupant directly behind the target. For example, a driver and a front-seat passenger in the same car constituted a front-seat target pair. If there was no one in the left rear seat of that car, the target driver was exposed to no other occupant. If there was an unrestrained right rear passenger, the target front passenger was exposed to an unrestrained other occupant (Figure 1).

For rear targets, the exposure studied was the presence and restraint use of a front occupant directly in front of the target (Figure 1).

A side target pair consisted of 1 occupant in the front seat and 1 in the back seat, both on the same side of the car (Figure 1). When the target pair was on the left side of the car, the study exposure was the presence and restraint use of any occupants on the right side of the car, in the same front or rear seat row as the target. If the target pair was in the right front and right rear seats, then the study exposure was the presence and restraint use of an occupant in the left front (driver) or left rear passenger seats.

**Study Data**

The National Highway Traffic Safety Administration maintains the Fatality Analysis Reporting System, which has data since 1975 on all crashes on US public roads that resulted in a death within 30 days. We selected records for passenger cars of model years 1975 through 2001 that crashed in 1988 through 2000; convertibles, light trucks, vans, minivans, and sport utility vehicles were excluded. We also excluded records for any state and year if more than 25% of records from that state and year were missing information.

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**Figure 1. Car Seat Configurations Used for Analyses of Front, Rear, and Side Target Occupant Pairs**

<table>
<thead>
<tr>
<th>Other Occupants</th>
<th>None</th>
<th>1 Restrained</th>
<th>1 Unrestrained</th>
<th>1 Restrained</th>
<th>1 Unrestrained</th>
<th>2 Restrained</th>
<th>2 Unrestrained</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Front Target Pairs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>Right</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

The seat position of target pairs is shown, along with the presence and restraint use of other occupants, the study exposure. The dark and light blue tints indicate each target and the seat position of the other occupant to whom each target was exposed. Restraint use of the target occupants is not shown. Figure based on original concept by David W. Ehlert, MAMS.
tion about restraint use. Cars with more than 2 persons in the front or the rear were excluded. We only included vehicles with the following target pairs: (1) driver and front seat passenger; (2) left rear and right rear passenger; (3) driver and left rear passenger; or (4) right front and left rear passenger (Figure 1).

We created a set of data for cars with front-seat target pairs aged 16 years or older, at least 1 of whom died. We excluded 12.1% of eligible cars because of missing restraint information. Front targets in cars with complete restraint information were compared with excluded targets; mean age was 41 years vs 39 years, male proportion was 59% vs 62%, and proportion who died was 59% vs 57%. We excluded a further 0.9% of cars because a front target was missing information about age or sex.

We created a second set of data for rear-seat target pairs, at least 1 of whom died. Rear targets of all ages were included. We excluded 17.2% of eligible cars because of missing restraint information. Rear targets in cars with restraint information were compared with excluded targets; mean age was 25 years for both, male proportion was 52% vs 54%, and proportion who died was 59% vs 59%. We excluded 1.3% of cars because of missing information about rear target age or sex.

We created a third set of data for left-side and right-side target pairs, at least 1 of whom died; all ages were included. We excluded 14.7% of eligible cars because of missing restraint data. Side targets in cars with restraint data were compared with excluded targets; mean age was 30 years vs 29 years, male proportion was 55% vs 56%, and proportion who died was 60% vs 60%. We excluded 1.3% of cars because of missing data about side target age or sex.

We determined front-seat air bag presence using software that can ascertain air bag presence from the vehicle identification number. This study of public data without identifiers was exempted from human subjects review.

**Table 1. Characteristics of Car Target Occupants and Other Occupants in 1975-2001 Model-Year Passenger Cars That Crashed During 1988-2000: Front-Seat Target Pairs**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Driver (n = 61 834)</th>
<th>Passenger (n = 61 834)</th>
<th>Left (n = 7969)</th>
<th>Right (n = 10 785)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-19</td>
<td>10 475 (17)</td>
<td>11 537 (19)</td>
<td>4096 (52)</td>
<td>5109 (48)</td>
</tr>
<tr>
<td>20-29</td>
<td>17 840 (28)</td>
<td>16 666 (27)</td>
<td>1876 (24)</td>
<td>2694 (25)</td>
</tr>
<tr>
<td>30-64</td>
<td>19 872 (32)</td>
<td>18 528 (30)</td>
<td>1295 (16)</td>
<td>1890 (16)</td>
</tr>
<tr>
<td>≥65</td>
<td>13 647 (22)</td>
<td>15 103 (24)</td>
<td>608 (8)</td>
<td>949 (9)</td>
</tr>
<tr>
<td>Male</td>
<td>42 794 (68)</td>
<td>29 680 (48)</td>
<td>4582 (58)</td>
<td>6146 (57)</td>
</tr>
<tr>
<td>Restrained</td>
<td>28 874 (47)</td>
<td>27 765 (45)</td>
<td>2367 (30)</td>
<td>3218 (30)</td>
</tr>
<tr>
<td>Died</td>
<td>34 123 (55)</td>
<td>38 614 (62)</td>
<td>1745 (22)</td>
<td>2218 (21)</td>
</tr>
</tbody>
</table>

*All data are expressed as number (percentage) of occupants of cars with a driver and front seat passenger aged 16 years or older, 1 or both of whom died.

**Statistical Analysis**

Risk ratios for the death of a target occupant were estimated using conditional Poisson regression with Stata software. All RRs were adjusted for target occupant sex, seat position (left or right, front or back), restraint use, age in years, and the square of age. Further adjustment for air bag presence, the sex and age of occupants who might hit the target, and the interaction of target seat position with principal direction of crash force had little influence on the RR estimates; therefore, this further adjustment was not performed, to minimize loss of records due to missing data. We assessed whether RR estimates varied by the restraint use of targets and other occupants who might hit a target; we added appropriate interaction terms to the regression models and reported different estimates if $P<0.05$ from a likelihood ratio test for the interaction terms.

Conditional Poisson regression can estimate RRs for binary outcomes; however, the variance estimates may be too large. We therefore estimated percentile confidence intervals (CIs) using 2000 bootstrap replications. Our RR estimates were adjusted for the risk of death associated with each target’s own restraint use. But one target could be thrown against the other. We could not also adjust for the risk of death associated with the restraint use of the other target with whom each target was paired; within a target pair, each target’s own restraint use determines perfectly the restraint use to which the other target in the pair is exposed. As a sensitivity analysis, we recalculated the main RR estimates using only target pairs that had the same restraint use: both restrained or both unrestrained. Within those pairs, there can be no confounding either by the target’s own restraint use or by the restraint use of the other target pair member.

**RESULTS**

**Front-Seat Targets**

TABLES 1, 2, and 3 show the characteristics of car target occupants and other occupants according to front-seat target pairs, rear-seat target pairs, and side-seat target pairs, respectively. There were 61 834 cars with 2 front-seat targets; 7969 targets were in front of a left rear occupant and 10 785 were in front of a right rear occupant. Mean target occupant age was 41 years. Most target drivers were male (69%) and most target front passengers were female (52%). Nearly half of the front targets (46%) were restrained and 59% died.

The risk of death for a front target (regardless of his/her own restraint use) with a rear restrained occupant behind them was nearly the same as that of a front target with no one behind them (RR, 1.01) (TABLE 4). The risk of death for a front target with an unrestrained person behind them was greater compared with a target with no one behind them; the RR was 1.05 for unrestrained front targets and 1.21 for restrained front targets.
When a front target with an unrestrained rear occupant was compared with a front target with a restrained rear occupant, the RR for death varied with the target’s own restraint use (RR, 1.04 for a restrained occupant and 1.20 for a restrained front target) (Table 4).

We classified crash angle as frontal if the principal impact angle was 11, 12, or 1 o’clock (47% of cars) (Figure 2). The RR for death of a restrained rear target with an unrestrained occupant behind, compared with a restrained target with a restrained occupant behind, varied with the crash angle: 1.26 (95% CI, 1.13-1.41) in frontal crashes and 1.12 (95% CI, 1.00-1.25) in other crashes ($P = .006$ for a likelihood ratio test that the model with these RRs differed from a model with no crash angle terms).

### Rear-Seat Targets

There were 5278 cars with 2 rear targets; all left rear targets had a driver in front of them and 90% of right rear targets had a passenger in front of them (Table 2). Mean rear target occupant age was 25 years, 52% were male, 29% were restrained, and 59% died.

The risk of death for a rear target (regardless of the target’s own restraint use) with a restrained occupant in front was nearly the same as that of a rear target with no one in front (RR, 1.01; 95% CI, 0.86-1.18) (Table 4). For restrained side targets, the risk of death was less if the target was beside an unrestrained occupant compared with a target beside a restrained occupant (RR, 0.85; 95% CI, 0.80-0.92).

We classified crashes as near-side impacts if the principal impact was 2, 3, or 4 o’clock for targets on the right or 8, 9, or 10 o’clock for targets on the left (Figure 2); 16% of crashes were near-side impact. The RR for death of an unrestrained rear target compared with an unrestrained occupant beside them was 1.03 (95% CI, 1.00-1.06) (Table 4). For restrained rear targets, the risk of death was greater if the target had an unrestrained occupant beside them (RR, 1.07; 95% CI, 1.04-1.12) (Table 4). For restrained side targets, the risk of death was greater if there was an unrestrained occupant beside them (RR, 1.07; 95% CI, 1.04-1.12) (Table 4). For unrestrained side targets, the risk of death was less if the target was beside an unrestrained occupant compared with a target beside a restrained occupant (RR, 0.85; 95% CI, 0.80-0.92).

### Table 2. Characteristics of Car Target Occupants and Other Occupants in 1975-2001 Model-Year Passenger Cars That Crashed During 1988-2000: Rear-Seat Target Pairs

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Rear-Seat Targets</th>
<th>Front-Seat Occupants</th>
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</thead>
<tbody>
<tr>
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<td>Left (n = 5278)</td>
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<td>976 (18)</td>
<td>1061 (20)</td>
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<td>30-64</td>
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<td>795 (15)</td>
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<td>502 (10)</td>
</tr>
<tr>
<td>Male</td>
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<td>2706 (51)</td>
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<tr>
<td>Restrained</td>
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<td>1538 (29)</td>
</tr>
<tr>
<td>Died</td>
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<td>3090 (59)</td>
</tr>
<tr>
<td>Age, y</td>
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<td></td>
</tr>
<tr>
<td>20-29</td>
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<td>4291 (20)</td>
</tr>
<tr>
<td>30-64</td>
<td>6201 (29)</td>
<td>3430 (16)</td>
</tr>
<tr>
<td>≥65</td>
<td>2492 (12)</td>
<td>2284 (11)</td>
</tr>
<tr>
<td>Male</td>
<td>11609 (55)</td>
<td>11478 (54)</td>
</tr>
<tr>
<td>Restrained</td>
<td>9645 (46)</td>
<td>6344 (30)</td>
</tr>
<tr>
<td>Died</td>
<td>13741 (65)</td>
<td>11177 (53)</td>
</tr>
</tbody>
</table>

*All data are expressed as number (percentage) of occupants of cars with 2 rear-seat target occupants, all ages, 1 or both of whom died.

### Table 3. Characteristics of Car Target Occupants and Other Occupants in 1975-2001 Model-Year Passenger Cars That Crashed During 1988-2000: Side-Seat Target Pairs

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Front Seat (n = 21 127)</th>
<th>Rear Seat (n = 21 127)</th>
<th>Other Occupants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
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<tr>
<td>0-19</td>
<td>6420 (30)</td>
<td>11 122 (53)</td>
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<tr>
<td>Restrained</td>
<td>9645 (46)</td>
<td>6344 (30)</td>
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</tr>
<tr>
<td>Died</td>
<td>13 741 (65)</td>
<td>11 177 (53)</td>
<td></td>
</tr>
</tbody>
</table>

*All data are expressed as number (percentage) of occupants of cars with 2 target occupants on the same side (1 in front, 1 in back), all ages, 1 or both of whom died.

### Side-Seat Targets

There were 9648 cars with 2 left-side targets and 11 479 cars with 2 right-side targets (Table 3). Mean target occupant age was 30 years, 55% were male, 38% were restrained, and 59% died.

The risk of death was greater for a side target (regardless of the target’s own restraint use) if there was an unrestrained occupant seated in the same seat row beside the target compared with a side target with no one beside them (RR, 1.07; 95% CI, 1.02-1.12) (Table 4). For restrained side targets, the risk of death was less if the target was beside an unrestrained occupant compared with a target beside a restrained occupant (RR, 0.85; 95% CI, 0.80-0.92). For a restrained side target, the risk of death was greater if the target had an unrestrained occupant beside him/her compared with a target next to a restrained occupant (RR, 1.15; 95% CI, 1.08-1.22) (Table 4). For an unrestrained side target, the risk of death was less if the target was beside an unrestrained occupant compared with a target beside a restrained occupant (RR, 0.85; 95% CI, 0.80-0.92).
The same regression models were used to estimate the RR for death of each of 3 categories of target compared with a baseline category of targets who were unrestrained and exposed to an unrestrained other occupant (Table 5): (1) unrestrained targets exposed to a restrained other occupant; (2) restrained targets exposed to an unrestrained other occupant; and (3) restrained targets exposed to a restrained other occupant. Restrained targets had a lower risk of death compared with unrestrained targets. The risk of target occupant death was lowest when the target and the other occupant were both restrained.

**Comment**

We found evidence that a person’s risk of death in a crash is associated with the restraint use of other occupants. In this study, the risk was lowest when all occupants were restrained.

Restraint use by rear occupants might influence the risk of death of a front target if some rear occupants were catastrophically. This mechanism is consistent with our finding that the risk of front target occupant death associated with a rear occupant was greater when the rear occupant was not restrained. The increase in risk was confined chiefly to restrained front target occupants (RR, 1.21); these targets remain fixed in the path of a rear occupant who is thrown forward.

Front occupants might be hurled against a target in the rear seat, especially when the impact is from the rear. In a rear-angle impact, rear targets may be relatively fixed in place by the seat belt. The increase in risk was confined chiefly to restrained front target occupants (RR, 1.21); these targets remain fixed in the path of a rear occupant who is thrown forward.

For the analysis of front-seat target pairs, a front-angle crash was defined as 11, 12, or 1 o’clock. For rear-seat target pairs, a rear-angle crash was defined as 4, 5, 6, 7, or 8 o’clock. For side-seat target pairs, a near-side-angle crash was 2, 3, or 4 o’clock for targets seated on the right and 8, 9, or 10 o’clock for targets on the left. These categories are not mutually exclusive.

Additional RR Estimates

Sensitivity Analysis

We reestimated the RR estimates in Table 4 without the target pairs that were discordant on restraint use: 16% of front target pairs, 12% of rear target pairs, and 29% of side target pairs. For the front and rear target pairs, no RR estimate in Table 4 changed by more than 0.02. For unrestrained side targets, the RR comparing a target next to a restrained occupant with a target next to an unrestrained occupant changed from 0.85 (Table 4) to 0.94 (95% CI, 0.87-1.02). For restrained side targets, the RR comparing a target next to a restrained occupant with a target next to an unrestrained occupant changed from 1.15 (Table 4) to 1.21 (95% CI, 1.12-1.30).

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The matched cohort design allowed us to estimate RR for targets in the same car\cite{5-8}; therefore, confounding by car or crash characteristics, including crash severity, should be minimized. We expected that the risk of front (or rear) target death would not be much affected by the presence of a restrained rear (or front) occupant, as most restrained occupants could not be thrown far from their own seat. Finding RRs of 1.01 for these associations, close to the expected value of 1, offers some reassurance that our estimates were not seriously biased by confounding.

A limitation of our study design was that we could estimate RR for targets in the same car\cite{5-8} but not absolute risks because most crash survivors were not in the Fatality Analysis Reporting System data. A second limitation was that we could not simultaneously estimate the RR associated with an occupant seated diagonally across from the vehicle from a target; for example, if a right rear occupant hit a target driver. Within a target pair, each target's position in front of, behind, or to the side of another occupant determines perfectly the other target's relationship to a diagonal occupant. A third limitation was that it was not possible to adjust RR estimates simultaneously for the restraint use of each target (the adjustment we did make) and for the restraint use of the other target in each matched target pair. However, we re-computed our analyses without the target pairs that were discordant on restraint use, eliminating target restraint use as a confounder. For the front and rear target pairs, these restricted analyses yielded RRs quite close to those in Table 4. For side target pairs, the RR estimates from the pairs concordant on restraint use differed somewhat from the estimates in Table 4. These differences might be due to some confounding bias in the estimates in Table 4 or bias in the restricted analysis due to selection of only 71% of the available pairs. Regardless of which estimates are more accurate, the risk of death for a restrained side target was greater if an occupant seated beside him or her was unrestrained compared with restrained: one RR estimate was 1.15 and the other was 1.21.

Our matched cohort design estimated average RRs for all pairs similar to those that were studied (Figure 1), including all pairs without a death\cite{5-8}. This is a useful feature of the matched-pair design, as only a small fraction of the pairs who both survived a crash were in the data source we used. Our results have no application to vehicles with just a driver, as there is no other occupant in such a vehicle. Our results may not apply to vehicles with 3 or 4 occupants; we did not study these vehicles. Two common target configurations could not be included in our matched design: rear targets alone in the rear seat and side targets in the front seat with no side target in the rear seat.

Some data were missing for 13% to 19% of the target pairs in each analysis; this might have biased our RR estimates. However, targets with complete information about restraint status were similar in regard to age, sex, and death compared with targets excluded by missing restraint data.

Information about restraint use may be misclassified in some police crash reports. But crashes with a death are investigated more intensely than minor crashes. In a study of front occupant
pairs, at least 1 of whom died, the police report regarding restraint use agreed well with the restraint use determination made by special crash investigators. This suggests that our present study, which used data from target pairs with at least 1 death, may not have serious bias due to misclassification of restraint use.

Park studied Fatality Analysis Reporting System data from 1978 through 1983 using a matched-pair cohort method and estimated that the risk of death was greater for an unrestrained target in front of an unrestrained rear occupant compared with an unrestrained target in front of an empty rear seat (RR, 1.04). This is similar to our estimate of 1.05. Park’s study was limited to unrestrained subjects, as restraint use was rare in crash data during 1978-1983.

Iichikawa et al studied crashes in Japan and estimated that the risk of death was greater for a restrained target in front of an unrestrained rear occupant compared with a restrained target in front of a restrained rear occupant (RR, 4.58; 95% CI, 2.55-8.22). This does not agree well with our estimate of 1.20. Their estimate suggests that a front target gets more benefit from having a rear occupant buckle up than from wearing his/her own restraint. Iichikawa et al selected only cars with 2 injured rear occupants who had the same restraint use. This selection process may have biased their estimates. Furthermore, they did not adjust for any possible confounding factors.

If the associations we have estimated are causal, use of restraints by rear seat occupants may prevent about 1 in 6 deaths of restrained front targets that would otherwise occur when a rear occupant is present. Use of restraints by front-seat occupants may similarly reduce the risk of death for all rear targets. Persons who wish to reduce their risk of death in a crash should wear a restraint and should ask others in the same car to use their restraints.

Author Contributions: Dr Cummings 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. Dr Cummings used publicly available data from the National Highway Traffic Safety Administration. Study concept and design: Cummings. Acquisition of data: Cummings. Analysis and interpretation of data: Cummings, Rivara. Drafting of the manuscript: Cummings. Critical revision of the manuscript for important intellectual content: Cummings, Rivara. Statistical expertise: Cummings. Obtained funding: Cummings, Rivara. Administrative, technical, or material support: Cummings. Funding/Support: This work was supported by grants R49/CCR002570 and R49/CCR019477-01 from the Centers for Disease Control and Prevention, Atlanta, Ga, and by the Crash Injury Research and Engineering Network of the National Highway Traffic Safety Administration.

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