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Effects of Seating Position and Appropriate Restraint Use on the Risk of Injury to Children in Motor Vehicle Crashes

Dennis R. Durbin, MD, MSCE*‡; Irene Chen, PhD*; Rebecca Smith, MSPH*; Michael R. Elliott, PhD‡; and Flaura K. Winston, MD, PhD*

ABSTRACT. ***Background.*** **Currently, many states are upgrading their child restraint laws to include provisions for the use of age-appropriate restraints through 6 to 8 years of age, with some also requiring rear seating for children, enabling the laws to be in closer alignment with best-practice recommendations.**

Objective. **To evaluate the relationships of seating position and restraint status to the risk of injury among children in passenger vehicle crashes.**

Methods. **This was a cross-sectional study of children <16 years of age who were involved in crashes of insured vehicles in 15 states, with data collected via insurance claims records and a telephone survey. A probability sample of 17 980 children in 11 506 crashes, representing 229 106 children in 146 613 crashes, was collected between December 1, 1998, and November 30, 2002. Parent reports were used to define restraint status, seating position, and occurrence of clinically significant injuries, with the use of a previously validated instrument.**

Results. **Approximately 62% of the children used seat belts, 35% used child restraints, and 3% used no restraint. Nearly 4 of 5 children sat in the rear seat, with one half of all children being restrained appropriately for their age in the rear, although this varied according to the age of the child. Overall, 1.6% of children suffered serious injuries, 13.5% had minor injuries, and 84.9% did not have any injury. Unrestrained children in the front were at the highest risk of injury and appropriately restrained children in the rear were at the lowest risk, for all age groups. Inappropriately restrained children were at nearly twice the risk of injury, compared with appropriately restrained children (odds ratio [OR]: 1.8; 95% confidence interval [CI]: 1.4–2.3), whereas unrestrained children were at >3 times the risk (OR: 3.2; 95% CI: 2.5–4.1). The effect of seating row was smaller than the effect of restraint status; children in the front seat were at 40% greater risk of injury, compared with children in the rear seat (OR: 1.4; 95% CI: 1.2–1.7). Had all children in the study population been appropriately restrained in the rear seat, 1014 serious injuries (95% CI: 675–1353 injuries) would have been prevented (with the assumption that restraint effectiveness does not depend on a variety of other driver-related, child-related, crash-related, vehicle-related, and environmental factors).**

Conclusions. **Age-appropriate restraint confers relatively more safety benefit than rear seating, but the 2 work synergistically to provide the best protection for children in crashes. These results support the current focus on age-appropriate restraint in recently upgraded state child restraint laws. However, it is important to note that considerable added benefit would be realized with additional requirements for rear seating.** ***Pediatrics*** **2005; 115:e305–e309. URL: www.pediatrics.org/cgi/doi/10.1542/peds.2004-1522;** ***child restraint, seating position, injury, motor vehicle accidents.***

ABBREVIATIONS. OR, odds ratio; CI, confidence interval.

Existing guidelines for the optimal protection of children in automobiles recommend rear seating for all children <13 years of age and the use of age-appropriate restraints, including child safety seats and belt-positioning booster seats.[1,2] Currently, many states are upgrading their child restraint laws to include provisions for the use of age-appropriate restraints through 6 to 8 years of age, enabling the laws to be in closer alignment with best-practice recommendations. At the time of preparation of this report, 26 states recently included provisions for the use of age-appropriate restraints.[3] However, <10 also included a provision requiring rear seating for children. The National Transportation Safety Board recommended that all states enact legislation to require the transport of children ≤12 years of age in a rear seat of a passenger vehicle if a rear seating position is available.[4]

Several studies evaluated the relative safety benefits of rear seating and restraint use for children.[5–12] Although most studies reported that restraint use in rear seats offers the greatest protection to children of any age, Braver et al[8] showed that older children with optimal restraint in the front seat were at lower risk of injury than were unrestrained children in the rear. In addition, the previous studies either did not contain sufficient detail for determination of the age-appropriateness of restraint use[5–8,10] or did not examine the benefits of appropriate restraint and seating position across a wide range of child ages[9,12] or crash types.[11]

Information on the relative benefits of rear seating and appropriate restraint would assist policymakers faced with choices regarding provisions for rear seating or age-appropriate restraint when considering

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enhancements to state child restraint laws. In addition, information on the differential risks of injury for appropriately restrained children in the front seat versus inappropriately restrained children in the rear at various ages might be used to refine current best-practice recommendations, particularly in situations in which parents are faced with more child passengers than available rear seat positions or appropriate restraints.

The objective of this study was to evaluate the relationships between seating position and restraint status and the risk of injury to children in passenger vehicle crashes. Specifically, we sought to explore the magnitude of the impact of an incremental improvement in either restraint status or seating position on the risk of injury for children in various age groups.

METHODS

Study Design

This cross-sectional study was performed as part of Partners for Child Passenger Safety, an ongoing, child-specific, crash surveillance system that links insurance claims data to telephone survey and crash investigation data.[13] Crashes qualifying for inclusion were those involving at least 1 child occupant <16 years of age riding in a model year 1990 or newer, State Farm-insured vehicle. Qualifying crashes were limited to those that occurred in 15 states, representing 3 large regions of the United States, between December 1, 1998, and November 30, 2002. Crashes involving children who were treated in emergency departments or physician's offices or who were admitted to the hospital were oversampled to ensure the inclusion of all injured children while maintaining a representative sample of all crashes. Drivers of selected crashes were then interviewed by telephone, with a previously validated assessment instrument.[14] If the driver was not available for any reason, then another adult occupant in the vehicle or another adult member of the driver's household was used as a proxy respondent (necessary in ~7% of cases). The study sample was weighted according to each subject's probability of selection, to reflect the entire eligible population. Children in single-row pickup trucks (n = 259), large vans (seating >7 passengers) (n = 474), compact, extended-cab, pickup trucks (n = 257), or vehicles with unavailable rear seats (n = 12) were excluded from the sample because these vehicles either did not provide back seat locations or did not have standard passenger vehicle interior designs. Also excluded from the analyses were children with missing data on restraint use (n = 105) or seating position (n = 37), accounting for <1% of otherwise eligible children.

Variable Definitions

Children were grouped by age as 0 to 3 years, 4 to 8 years, 9 to 12 years, or 13 to 15 years, because current recommendations for age-appropriate restraint and/or seating position vary according to these age groups.[1,2] Three levels of restraint use were defined, ie, no restraint, inappropriate restraint, and appropriate restraint. Inappropriate restraint was defined as any seat belt use for children 0 to 8 years of age or use of a lap belt or shoulder belt only for children 9 to 15 years of age. Appropriate restraint was defined as the use of a child safety seat or booster seat for children <9 years of age, as adapted from American Academy of Pediatrics and National Highway Traffic Safety Administration recommendations,[1,2] and use of both a lap belt and a shoulder belt for those 9 to 15 years of age.

The seating row for each child was determined in the telephone survey. The second and third rows of seats in the vehicle were combined and defined as the rear rows, because we found no difference in injury risks for children in those 2 rows (odds ratio [OR]: 0.82; 95% confidence interval [CI]: 0.56–1.19). Six combinations of restraint use and seating position were therefore defined, ie, front seat/no restraint, front seat/inappropriate restraint, front seat/appropriate restraint, rear seat/no restraint, rear seat/inappropriate restraint, and rear seat/appropriate restraint.

Survey questions regarding injuries to children were designed to provide responses that were classified according to body region and severity, on the basis of Abbreviated Injury Scale scores,[15] and were previously validated for their ability to distinguish injuries with Abbreviated Injury Scale scores of ≥2 from less severe injuries.[14] For the purposes of this study, children were classified as injured if a parent/driver reported any injury with an Abbreviated Injury Scale score of ≥2 (eg, concussions and more serious brain injuries, all internal organ injuries, spinal cord injuries, and extremity fractures) or facial lacerations.

Statistical Analyses

Because sampling was based on the medical treatment obtained after the crash and thus the likelihood of an injury, subjects least likely to be injured were underrepresented in the study sample, in a manner potentially associated with the predictors of interest.[16] To account for this potential bias and to adjust inferences to account for stratification of subjects according to medical treatment and clustering of subjects according to vehicle, robust χ^2 tests of association and Taylor series linearization estimates of the logistic regression parameter variances were calculated with SAS-callable SUDAAN software, version 7.5 (Research Triangle Institute, Research Triangle Park, NC). Crude logistic regression analyses were used to assess the association between serious injury and the 6 combinations of seating position and restraint status, for the total sample and for each age group. Results of logistic regression analyses were presented as the predicted probability of injury for each restraint use/seating position category. The predicted risks of serious injury were ranked (from the highest to the lowest) separately for the overall sample and for each age group. Because the predicted risk of serious injury decreased with successive restraint use and seating position, 5 pairwise comparisons were conducted in the logistic regression analyses. The t test was used to test the significance of the difference in the predicted risks of serious injury for each pairwise comparison.

To determine simultaneously the relative advantages of seating row and restraint status, multivariate logistic regression analysis was used to quantify the independent association of each factor with the risk of injury, with adjustment for age group and vehicle type. Interactions of the child age group, restraint status, and seating position with the risk of injury were also evaluated. Taylor series linearization estimates of the logistic regression parameter variance and ORs (with 95% CIs) from logistic regression models were calculated.

We used weighted logistic regression analyses to calculate the difference in the risk of injury for children who were appropriately restrained in rear seats, compared with those in each of the other restraint/seating groups, with the SE of the risk difference. The estimated number of preventable injuries was calculated by multiplying the total weighted number of those in each restraint/seating group by the risk difference for that group, as well as accounting for age-specific variations in the distribution of restraint/seating groups. The 95% CI of the number of preventable injuries was also calculated.

Verbal consent was obtained from each study participant. The study protocol was reviewed and approved by the institutional review boards of both the Children's Hospital of Philadelphia and the University of Pennsylvania School of Medicine.

RESULTS

Complete data were collected for 17 980 children in 11 506 crashes, representing 229 106 children in 146 613 crashes. Table 1 presents characteristics of the total sample, stratified according to child age group. Overall, ~62% of the children used seat belts, 35% used child restraints (including child safety seats and booster seats), and 3% used no restraint. Nearly 4 of 5 children overall sat in the rear seat, with one half of all children being appropriately restrained in the rear seat. Overall, 1.6% of the children suffered serious injuries, 13.5% had minor injuries, and 84.9% did not have any injury. As age increased, the risks of serious injury and front row seating also increased. Children 13 to 15 years of age had the highest risks of serious injury and front row seating.

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TABLE 1. Characteristics of Total Sample According to Child Age Groups (Unweighted n = 17 980)

	Weighted % (No.)				P Value
	0–3 y (Unweighted n = 4081)	4–8 y (Unweighted n = 5601)	9–12 y (Unweighted n = 4631)	13–15 y (Unweighted n = 3662)	
Injured	1.0 (365)	1.6 (746)	1.7 (694)	2.5 (702)	<.001
Restraint					<.001
Appropriate	89.7 (3524)	23.7 (871)	83.3 (3713)	84.6 (2930)	
Inappropriate	9.5 (507)	74.1 (4479)	12.9 (626)	9.1 (339)	
Unrestrained	0.8 (50)	2.2 (251)	3.8 (292)	6.3 (393)	
Seat row					<.001
Front	2.2 (138)	12.3 (1042)	33.1 (1797)	58.4 (2198)	
Rear	97.8 (3943)	87.7 (4559)	66.9 (2834)	41.6 (1464)	
Seat row/restraint group					<.001
Front/unrestrained	0.2 (15)	0.3 (65)	0.5 (69)	2.4 (173)	
Front/inappropriate	0.7 (45)	11.5 (955)	1.0 (63)	1.7 (96)	
Front/appropriate	1.3 (78)	0.5 (22)	31.6 (1665)	54.4 (1929)	
Rear/unrestrained	0.7 (35)	2.0 (186)	3.3 (223)	4.0 (220)	
Rear/inappropriate	8.8 (462)	62.6 (3524)	12.0 (563)	7.4 (243)	
Rear/appropriate	88.4 (3446)	23.1 (849)	51.6 (2048)	30.2 (1001)	
Vehicle type					<.001
Passenger car	53.9 (2376)	49.8 (3141)	49.3 (2638)	54.2 (2344)	
Minivan	22.3 (861)	27.3 (1350)	27.8 (1158)	22.5 (704)	
Sport utility vehicle	21.2 (739)	19.0 (911)	19.1 (710)	17.6 (495)	
Pickup truck	2.6 (105)	4.0 (199)	3.8 (125)	5.7 (119)	

Children 4 to 8 years of age had the greatest proportion of inappropriate restraint use. As shown in Table 1, the distributions of the 6 combinations of seating position and restraint status differed significantly among the child age groups ($P < .001$). The percentages of children using appropriate restraint in rear seats were 88% for 0- to 3-year-old children, 23% for 4- to 8-year-old children, and 51% for 9- to 12-year-old children, whereas ~84% of those 13 to 15 years of age were appropriately restrained in either the rear or front seats.

Figure 1 presents the predicted risk of serious injury (and associated 95% CI) for each seating position/restraint category for the overall study sample. For the total sample, decreases in injury risks were found as children were more appropriately restrained and moved to the rear seat. Unrestrained children in the front seat had the highest predicted risk (8.7%) of serious injury, followed by unrestrained children in the rear seat (3.5%), inappropriately restrained children in the front seat (2.6%), appropriately restrained children in the front seat (2.1%), inappropriately restrained children in the rear seat (1.8%), and appropriately restrained children in the rear seat (1.1%). Examination of the incremental differences in risks of injury from one category to an adjacent category revealed that only the differences for unrestrained/front seat versus unrestrained/rear seat groups ($P \leq .001$) and inappropriately restrained/rear seat versus appropriately restrained/rear seat groups were statistically significant ($P = .001$).

Similar analyses stratified according to the 4 age groups showed minor variations in the order of restraint/seating position categories, because of the small sample sizes in some cells (data not shown,

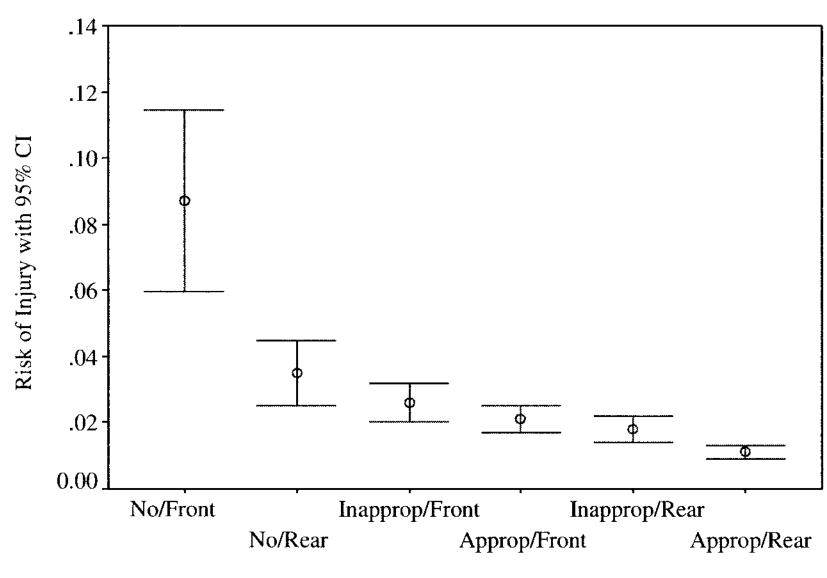

Fig 1. Predicted risk of serious injury for each restraint/seating position group. Inapprop indicates inappropriate; Approp, appropriate.

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available on request). However, unrestrained children in the front seat were always at the highest risk of injury, and optimally restrained children in the rear seat were always at the lowest risk.

The results from multivariate modeling showed that, after adjustment for the age of the child and the type of vehicle, restraint status and seating row were both independently associated with risk of injury (Table 2). Inappropriately restrained children were at nearly twice the risk of injury, compared with appropriately restrained children (OR: 1.8; 95% CI: 1.4–2.3), whereas unrestrained children were at >3 times the risk (OR: 3.2; 95% CI: 2.5–4.1). The effect of seating row was smaller than the effect of restraint status, with children in the front seat being at 40% greater risk of injury than children in the rear seat (OR: 1.4; 95% CI: 1.2–1.7).

These main effects of restraint status and seating row must be viewed as being averaged over the population distribution of restraint status, seating row, and child ages, because their effects were modified by each other and by the age of the child. For example, the effect of no restraint was 1.6 times greater (95% CI: 1.0–2.6) in the front row than in the rear, making the risk of injury for unrestrained children in the front seat 4.3 times greater than that for appropriately restrained children in the front seat. For appropriately restrained 13- to 15-year-old subjects, there was no additional risk for front row versus rear row seating (OR: 1.0; 95% CI: 0.6–1.5). With inappropriate restraint (ie, lap belt-only restraint), however, the excess risk to 13- to 15-year-old youths in the front row increased threefold (OR: 3.0; 95% CI: 1.1–7.8).

On the basis of the number of children in each restraint/seating group and their associated risk of injury, if all children <16 years of age in our study population at the time of the crash had been appropriately restrained in the rear seat, then 1014 serious injuries (95% CI: 675–1353 injuries) would have been prevented (with the assumption that the effectiveness of appropriate restraint in rear seats does not depend on a variety of other driver-related, child-related, crash-related, vehicle-related, and environmental factors). This value represents >27% of the estimated 3665 serious injuries that occurred in the study sample.

TABLE 2. Results of Multivariate Logistic Regression Analysis

	Adjusted OR for Injury (95% CI)
Child age	
0–3 y	Reference
4–8 y	1.1 (0.7–1.6)
9–12 y	1.5 (1.1–2.0)
13–15 y	1.9 (1.4–2.7)
Restraint status	
Appropriate	Reference
Inappropriate	1.8 (1.4–2.3)
Unrestrained	3.2 (2.5–4.1)
Seating position	
Rear	Reference
Front	1.4 (1.2–1.7)
Vehicle type	
Minivan	Reference
Passenger car	1.9 (1.6–2.4)
Pickup truck	1.4 (0.7–2.8)
Sport utility vehicle	1.3 (0.9–1.8)

DISCUSSION

This study demonstrates that age-appropriate restraint confers relatively more safety benefit than does rear seating but the 2 work synergistically to provide the best protection for children of all ages in crashes. At any age through 15 years, unrestrained children in the front were always at the highest risk of injury and appropriately restrained children in rear seats were always at the lowest risk. Inappropriately restrained children were at nearly twofold greater risk of injury, compared with appropriately restrained children, whereas children in the front seat were at 40% greater risk of injury, compared with children in the rear seat. These results support the current focus on age-appropriate restraint (as opposed to seating position) in recently upgraded state child restraint laws. However, it is important to note that considerable added benefit would be realized with requirements for rear seating.

Our results support current recommendations from the National Highway Traffic Safety Administration and the American Academy of Pediatrics that all children <13 years of age ride in the rear seats of vehicles.[1,2] We found significant increases in risks of injury for all age groups of <13 years for children in the front seat. Among 13- to 15-year-old subjects, however, there was no difference in risks of injury for appropriately restrained children in the front seat versus the rear seat. Currently, most child passenger laws do not cover older children up to 15 years of age.[3] Our results may assist states interested in closing additional loopholes in child passenger laws for children up to 15 years of age.

Previous research characterized the relationships of restraint use and seating position to both fatal and nonfatal injuries among children.[5–8,10] Those studies all found unrestrained children (particularly those in the front seat) to be at the greatest risk of injury. The results from our multivariate analyses extend those of prior studies by providing additional details on the effects of age-appropriate restraint (not available in other national sources of crash data) and by examining the relative benefits of appropriate restraint and seating position for relevant age groups. These more-specific results might be used by legislators to upgrade child restraint laws to be in closer alignment with current best-practice recommendations. In addition, we accounted for the effect of vehicle type in our analyses, because the risks of injury to children vary according to vehicle type[17,18] and both restraint status ($P = .02$) and front row seating ($P < .001$) varied according to vehicle type in this study.

Although our results support the current recommendations of the National Highway Traffic Safety Administration for optimal protection of children, these recommendations should be reevaluated as new safety features are introduced into the vehicle fleet. For example, airbag technologies and enhancements to the rear seats of vehicles, including the addition of lap and shoulder belts in center rear

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seating positions, continue to evolve in the vehicle fleet and might have significant effects on the safety of child occupants. In addition, the types of vehicles on the road continue to evolve, with increasing numbers of sport utility vehicles and light trucks, which might change the relative benefits of riding as an occupant in any given type of vehicle.[19]

This study relied on driver reports for information on injuries, restraint use, and seating positions of children and might be subject to information bias. However, ongoing comparisons of driver reports of child restraint use and seating positions with evidence from crash investigations, performed as part of this research project, have demonstrated a high degree of agreement ($\kappa = 0.99$ for seat row; $\kappa = 0.74$ for restraint use). In addition, our results on age-specific restraint use and seating position are similar to those of recently reported, population-based studies of child occupants, in which estimates of 83% to 99% for restraint use among children $<$8 years of age were noted.[20–22] The current study included children involved in crashes of newer insured vehicles, and results might not be generalizable to children riding in older or uninsured vehicles. Our source of data provides comprehensive information, particularly regarding the type of restraint used, for a large representative sample of children in crashes. Other national sources of child crash data, such as the National Automotive Sampling System and the Fatality Analysis Reporting System, both operated by the National Highway Traffic Safety Administration, either contain relatively few children or lack sufficient detail with which to replicate these analyses.

On the basis of these findings, educational campaigns, anticipatory guidance, and legislative interventions should continue to emphasize age-appropriate restraint but should add an additional focus on the promotion of rear row seating, with appropriate restraint, for all children $<$13 years of age. Future work will need to evaluate effectiveness estimates given ongoing changes in airbag, seat belt, and child restraint designs.

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