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Child Passenger Safety: Decisions about Seating Location, Airbag Exposure, and Restraint Use

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The installation of passenger-side airbags in new vehicles complicates efforts to maximize child safety in motor vehicle crashes. It has been recommended by both public and private organizations that children sit in the rear seat with proper restraint to achieve maximum safety. Drivers now need to decide whether a child should be restrained, where the child should be seated (front versus rear), and whether the child should be seated in front of a passenger-side airbag. This research was undertaken to determine which choice minimizes the risk of fatality to children. Using data from the U.S. Fatality Analysis Reporting System for calendar years 1989 to 1998, fatal vehicle crashes with child passengers younger than 13 years were analyzed. The effectiveness of passenger-side airbags and rear seating for children, by age category and restraint use, was estimated using the double-pair comparison method. For each of four age categories, the fatality risk of each possible combination of restraint use, seating location, and airbag presence was also estimated using logistic regression. Passenger airbags were associated with an increase in child fatality risk of 31% for restrained children, and 84% for unrestrained children. Passenger airbags did appear to offer protection to restrained 9- to 12-year-old children. Restraint use and rear seating were associated with statistically significant reductions in the odds of a child dying in a crash. In order to minimize child fatality risk, parents should seat children in the rear of the vehicle while using the proper child restraint system, especially in vehicles with passenger airbags. These findings support current public education efforts in the United States.

KEY WORDS: Motor vehicle; fatality; children; restraint systems; seating position

1. INTRODUCTION

The requirement that all new passenger vehicles sold in the United States be equipped with driver- and passenger-side airbags,[1] and the accumulating evidence that airbags are harmful to children younger than 13 years of age,[2–6] have focused renewed interest on child passenger safety. It has been recommended by both public and private organizations that children sit in the rear seat with proper restraint to achieve maximum safety. Every driver who transports children now needs to make decisions with respect to three issues:

- Should children be restrained?
- Should children sit in the front or the rear of the vehicle?
- Should children sit in a seat equipped with a passenger-side airbag?

The objective of this article is to present the best available answer to the question of what is, mortality wise, the safest way to transport a child in a motor vehicle.

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2. DATA AND METHODS

Child passengers were selected from the U.S. Fatality Analysis Reporting System (FARS), an annual census of fatal vehicle crashes in the United States, for calendar years 1989 through 1998.[7] Children included in the analysis, were younger than 13 years and riding in the passenger compartment of a model year 1990 through 1999[3] car, passenger van, or utility vehicle,[4] for which a valid Vehicle Identification Number (VIN) was available. Seating position and restraint use of child passengers, the restraint use of drivers, crash characteristics, and the level of damage to the vehicle, were also extracted.

For this analysis, children were categorized into four age groups following current child restraint guidelines: infants (younger than 1 year old), 1- to 4-year-olds, 5- to 8-year-olds, and 9- to 12-year-olds. Seating position was categorized as either front or rear. We also categorized children by restraint use (yes, no). Children traveling in a child restraint or safety belt system were classified as restrained even though the restraint may have been used improperly or may not have been appropriate to the child's age.

Using information embedded in the VIN,[8] the restraint system, age, type, and size of vehicles were obtained. Types of restraint systems include seat belts only, driver airbag plus seat belts, and driver and right-front passenger airbags plus seat belts. Vehicle age at the time of the crash was categorized as up to 6 years or 7 or more years old. Vehicles were classified by type (passenger vans, sport utilities, or cars) and size—small: wheelbase <99 in., medium cars and vans: wheelbase of 100 to 109 in., medium utilities: wheelbase of 100 to 119 in., large cars and vans: wheelbase of 110 in. or more, large utilities: wheelbase of 120 in. or more.

It is recognized that the present study addressed relatively rare crashes, because FARS records information about every vehicle in the United States involved in a crash in which at least one person died. For instance, in 1998, the National Highway Traffic Safety Administration (NHTSA) estimated the rate of traffic fatalities to be 1.6 per 100 million miles traveled, and reported 41,471 deaths in 6,334,000 police-reported crashes.[9] It is also important to note that everyone in the child's vehicle may have survived (i.e., a fatality in another vehicle may have triggered the FARS investigation). In the logistic regression analysis, two proxies were used for crash severity: whether the vehicle was disabled, and whether the vehicle rolled over.

The following sections present a descriptive analysis of the data; estimates of airbag and rear seat effectiveness using the double-pair comparison method;[10] and estimates of the fatality risks associated with different combinations of restraint use, airbag presence, and seating location using multivariate logistic regression.

In order to measure the effectiveness of restraint systems, traffic safety researchers using FARS data have traditionally relied on double-pair comparisons.[4,11,12] This method compensates for the lack of data on nonfatal crashes, but has limited ability to control simultaneously for multiple confounders. Using this method, "matched" pairs of drivers and right-front occupants from the same vehicle are selected. Only pairs in which both driver and child were restrained and pairs in which both were not restrained were included in the present analysis. The ratios of child passenger to driver deaths among those riding in vehicles equipped with only a driver-side airbag, and among those riding in vehicles with dual airbags, were computed. The percentage difference between these two ratios constitutes the "airbag effectiveness." This difference is zero if the passenger-side airbag has no net effect, positive if the airbag has a net protective effect, and negative if the airbag has a net harmful effect. Estimates of passenger airbag effectiveness and their 95% confidence intervals (CIs) are presented by child age category and restraint use.

Multivariate logistic regression is widely used in public health research and has been previously employed in the injury prevention literature.[13,14] This method is used to estimate the probability of a child dying in a crash, while controlling for vehicle age, type, and size, whether the crash was a rollover or led to vehicle disablement, and whether the driver was wearing a seat belt. The child's age category, restraint use, seating position, and exposure to a passenger-side airbag are allowed to interact by creating 24 dichotomous variables for each of the possible combinations of four age categories (infant, 1- to 4-year-olds, 5- to 8-year-olds, 9- to 12-year-olds), two restraint categories (restrained, unrestrained), and three seating

[3] The model year restriction limited the study to vehicles manufactured after shoulder belts (in addition to lap belts) were required for rear outboard seating locations.

[4] Pickup trucks were excluded for two reasons: (1) For most of the study period, switches were available to disable the passenger-side airbag, however FARS did not collect information on the status of the airbag switch; and (2) many children traveling in pickups are seated in the cargo area, which exposes them to a different type of risk than children seated inside passenger compartments of vehicles.

location/presence-of-an-airbag categories (front seat with airbag, front seat without airbag, and rear seat). Results of the multivariate logistic regression analysis are presented as adjusted odds ratios (ORs) and their 95% CIs, as well as the absolute probabilities (and their 95% CI) of death in a particular type of crash and vehicle.

Table I. Children, Vehicle, and Crash Characteristics (N = 16,177)

Variable	n	Percent	Percent died
All children	16,177	100.0	18.7
Age (years)			
<1	1,114	6.9	32.8
1–4	5,645	34.9	18.4
5–8	4,819	29.8	17.3
9–12	4,599	28.4	17.1
Seating location			
Front seat	4,238	26.2	25.5
Rear seat	11,939	73.8	16.3
Passenger-side airbag			
Yes	848	5.2	29.0
No	15,329	94.8	18.1
Restraint status			
Restrained	10,804	66.8	14.1
Not restrained	4,456	27.6	29.2
Unknown restraint	917	5.7	22.3
Vehicle age			
1 to 3 years	10,739	66.4	18.6
4 to 6 years	4,409	27.3	18.7
7 or more years	1,029	6.4	19.6
Vehicle size			
Small car	3,349	20.7	27.0
Medium car	5,541	34.3	20.6
Large car	1,166	7.2	13.6
Van	3,399	21.0	14.2
Utility vehicle	2,722	16.8	12.6
Model year			
1990–1997	15,808	97.7	18.8
1998	342	2.1	15.5
1999	27	0.2	11.1
Crash severity/rollover			
Rollover collision	3,486	21.5	23.5
No rollover collision	12,691	78.5	17.4
Crash severity/disabled			
Vehicle disabled	12,533	77.5	22.2
Vehicle not disabled	3,644	22.5	6.9
Driver safety belt use			
Used	11,837	73.2	16.6
Not used	3,411	21.1	24.4
Driver belt use missing	929	5.7	24.1

Data source: NHTSA,[7] vehicle model years 1990–1999, children younger than 13 years, VIN available (n = 16,177).

3. RESULTS

3.1. Descriptive Statistics

A total of 16,177 children under 13 years of age met the study's inclusion criteria. Table I summarizes the characteristics of these children, the vehicles in which they were passengers, and the crashes in which they were involved. About 60% of the children were in a vehicle in which at least one death occurred (including that of the child). A total of 3,027 children (19%) died as a consequence of an accident. Most children (58%) were over 4 years old. The majority (74%) were seated in the rear of the vehicle. Restraint use was reported to be 67%, with restraint status unknown for 6% of the children. A majority of the children (58%) were being transported in vehicles that were less than 7 years old. The crash was severe enough to disable the vehicles of 78% of the children; 22% of the crashes involved a vehicle that rolled over.

3.2. Double-Pair Comparison Method

The selection of pairs of drivers and child right-front passengers for the analysis of passenger airbag effectiveness yielded 1,329 pairs in which the driver or the child passenger or both died. There were 869 pairs in which both the driver and child passenger were restrained, and 460 pairs in which both were unrestrained. Table II shows that negative airbag effectiveness was found when all ages were combined for both restrained children (−31%, 95% CI −75 to 12) and unrestrained children (−84%, 95% CI −162 to −6). An analysis by age confirms the airbag negative effectiveness, with the exception of restrained 10- to 12-year-olds for whom the airbag appears protective (39%, 95% CI 7 to 72).

The analysis of rear seat effectiveness was based on 2,019 pairs riding in vehicles with only manual belts, and 917 pairs in vehicles with dual airbags (Table III). For children through age 12, the rear seat offered a protective benefit to both the restrained (21%, 95% CI 7 to 35) and unrestrained (29%, 95% CI 11 to 47). When an airbag was introduced into the right-front seat, the protective value of the rear seat increased for infants through age 9 for both restrained and unrestrained children, suggesting that the airbag increased the risk of the front seating position. For the 9- to 12-year-old category, rear seat effectiveness became negative, suggesting that the airbag affords this age group more protection than the rear seat.

Table II. Protective Effect of Airbag for Children by Age Category and Restraint Type and Use Comparison of Vehicles with Driver Only Airbags to Vehicles with Dual Airbags

Age (years)	Dual airbags		Driver-Only Airbags		Effectiveness	95% CI
	Child deaths	Driver deaths	Child deaths	Driver deaths		
Restrained pairs of passenger and driver						
<1	17	3	8	5	−254	−748–239
1–4	27	11	27	28	−155	−342–33
5–8	27	28	24	44	−77	−184–31
9–12	27	50	39	44	39	7–72
Total	98	92	98	121	−31	−75–12
Unrestrained pairs of passenger and driver						
<1	3	1	11	3	18	−160–197
1–4	31	12	19	16	−118	−289–54
5–8	22	15	15	24	−135	−316–47
9–12	12	18	16	33	−38	−146–71
Total	68	46	61	76	−84	−162–−6

Data source: NHTSA,[7] vehicle model years 1990–1999, children younger than 13 years, VIN available (n = 16,177).

3.3. Multivariate Logistic Regression Method

Restrained 9- to 12-year-olds seated in the rear were chosen as the reference category for a multivariate logistic regression model, which estimated the OR of a child dying by restraint use, seating position, airbag exposure, and age category (Table IV). The model adjusted for crash severity (whether the vehicle was disabled or rolled over), driver safety consciousness (whether the driver wore a seat belt), and vehicle characteristics (type and size). Because depowered airbags began to enter the fleet in model year 1998, the analysis was controlled for model years 1998 and 1999 to allow for the possibility that depowered airbags differ from those installed in earlier model years. In fact, a decreased risk of death was found in model years 1998 (OR = 0.9, 95% CI 0.7 to 1.3) and 1999 (OR = 0.5, 95% CI 0.1 to 2.3).

Restrained 1- to 12-year-old children seated in the rear seat experienced a nearly equal risk of dying, with OR of 1.0 (95% CI 0.8 to 1.2) for 1- to 4-year-olds and 0.8 (95% CI 0.7 to 1.0) for 5- to 8-year-olds, when compared to restrained 9- to 12-year-olds. The OR of an unrestrained child dying was always higher

Table III. Protective Effect of Rear Seating for Children by Age Category, Airbag Exposure, and Restraint Use, Double-Paired Comparison Method

Age (years)	No airbags		Dual airbags	
	Effectiveness	95% CI	Effectiveness	95% CI
Restrained pairs of passenger and driver				
<1	18	−30–68	67	29–104
1–4	32	12–53	73	56–90
5–8	18	−7–43	17	−20–55
9–12	20	−12–52	−48	−139–43
Total	21	7–35	25	4–46
Unrestrained pairs of passenger and driver				
<1	−18	−143–107	17	−179–212
1–4	16	−23–56	75	57–93
5–8	39	15–63	61	36–85
9–12	15	−30–61	−27	−138–84
Total	29	11–47	56	39–74

Data source: NHTSA,[7] vehicle model years 1990–1999, children younger than 13 years, VIN available (n = 16,177).

Table IV. Adjusted Odds Ratios and Estimated Probability of Death

Airbag	Age (years)	Adjusted OR (95% CI)	Probability of Death (95% CI)
Restrained children			
Front seat			
Yes	<1	12.0 (5.3–27.0)	0.70 (0.53–0.87)
	1–4	2.1 (1.3–3.2)	0.29 (0.21–0.37)
	5–8	1.6 (1.0–2.3)	0.23 (0.17–0.29)
	9–12	1.0 (0.7–1.6)	0.17 (0.12–0.22)
No	<1	2.5 (1.7–3.6)	0.33 (0.26–0.40)
	1–4	1.8 (1.4–2.2)	0.26 (0.23–0.29)
	5–8	1.5 (1.2–1.9)	0.23 (0.20–0.26)
	9–12	1.3 (1.0–1.7)	0.21 (0.18–0.24)
Rear Seat			
N/A	<1	1.8 (1.5–2.3)	0.27 (0.24–0.30)
	1–4	1.0 (0.8–1.2)	0.16 (0.15–0.17)
	5–8	0.8 (0.7–1.0)	0.14 (0.13–0.15)
	9–12	1.0	0.17 (0.15–0.19)
Unrestrained children			
Front Seat			
Yes	<1	22.3 (5.6–88.8)	0.81 (0.59–1.00)
	1–4	12.2 (7.1–20.8)	0.71 (0.61–0.81)
	5–8	8.5 (5.0–14.7)	0.63 (0.51–0.75)
	9–12	3.2 (1.7–6.0)	0.39 (0.26–0.52)
No	<1	12.3 (7.6–19.7)	0.71 (0.62–0.80)
	1–4	3.5 (2.6–4.7)	0.41 (0.35–0.47)
	5–8	3.4 (2.5–4.7)	0.40 (0.34–0.46)
	9–12	3.4 (2.5–4.6)	0.40 (0.34–0.46)
Rear seat			
N/A	<1	9.2 (5.8–14.3)	0.64 (0.55–0.73)
	1–4	2.2 (1.8–2.6)	0.30 (0.27–0.33)
	5–8	1.9 (1.6–2.3)	0.28 (0.25–0.31)
	9–12	1.8 (1.5–2.2)	0.27 (0.25–0.29)

Data source: NHTSA,[7] vehicle model years 1990–1999, children younger than 13 years, VIN available (n = 16,177). *Note:* Odds ratios are adjusted for crash severity (disablement and rollover), driver belt use, vehicle age, size, and type. Estimated probability of death is in a midsized car, disabled, no rollover, pre-1998 model, with a restrained driver.

than the OR of a restrained child of the same age, seating position, and airbag category. Airbag exposure raised the odds of dying for front-seated children under 9 years of age: for infants the OR increased from 2.5 to 12.0 (restrained) and from 12.3 to 22.3 (unrestrained); for 1- to 4-year-olds the OR increased from 1.8 to 2.1 (restrained) and from 3.5 to 12.2 (unrestrained); and for 5- to 8-year-olds, from 1.5 to 1.6 (restrained) and from 3.4 to 8.5 (unrestrained). Within the 9- to 12-year-old category both restrained and unrestrained children in the right-front seat were less likely to die if there was an airbag. Airbag-exposed children in all but one age category and restraint category were more likely to die than the child's counterpart in the rear seat. The one exception was that restrained 9- to 12-year-olds in the front and exposed to an airbag were at equal risk of death (1.0, 95% CI 0.7 to 1.3) as a restrained 9- to 12-year-old in the rear.

Also illustrated, as an example, were the implications of the ORs derived from the multivariate logistic regression model. Specifically, the probabilities of death were computed (with 95% CIs) for children of different age categories riding with a belted driver, in a midsized car less than 7 years old that was involved in a disabling collision with no rollover—the most common scenario as indicated in the descriptive analysis. The probabilities of a child dying in this type of accident were estimated to range from 0.14 for a 5- to 8-year-old restrained in the rear seat, to 0.81 for infants unrestrained in front of an airbag. Regarding children from 1- to 12-years-old, the added risk of death incurred by changing a child's restraint status from restrained to unrestrained in the rear seat was about equal to the added risk of moving the child to a restrained position in the front seat. For infants, the increase in risk associated with changing from restrained to unrestrained in the rear (0.27 to 0.64) was larger than the increase of moving a restrained infant to the front seat (0.27 to 0.70).

4. DISCUSSION

Overall, the present risk analysis replicated earlier findings from case investigations and statistical analyses reported by the federal government and the insurance industry.[2–5,14,15] Fully powered passenger-side airbags pose a significant risk to children, and the rear seat is the safest location for children. Unrestrained children exposed to airbags were found to be 84% more likely to die than unrestrained children in the front seat without airbags. In addition, restrained 9- to 12-year-olds were found to be 39% safer when they had an airbag. Restrained infants were found to be 254% more likely to die if placed in front of an airbag.

Restraint use reduces the risk of death for each circumstance analyzed: children in every age category, with or without passenger-side airbags, and in any seating location. The rear seat reduces the risk of death both to restrained and unrestrained children aged 1 to 12 years.

The present analyses contain more years of FARS data than any of the previously reported research,[2–6] allowing statistical significance of the adverse effect

of airbags on children to be established. The two complementary analytical methods produce similar findings, increasing confidence in the veracity of the results. A particularly interesting and useful feature of the current study is the simultaneous analysis of the effects of restraint use, seating position, and airbag exposure (by allowing the terms to interact in the multivariate logistic regression model) on child safety.

There are limitations to this study that are inherent to the data used. First, the logistic regression results should be interpreted with caution because many child survivors are not covered by FARS data, that is, children who survive crashes because they are in the rear, restrained, or are protected by an airbag are not included in FARS if no death occurs. Interestingly, if the percentage reductions in risk associated with the rear seat are computed using the probabilities of death estimated with logistic regression, the point estimates are similar to those calculated using the double-paired comparison methodology. For instance, restrained infants are 18% safer in the rear than in the front without an airbag—(0.27 − 0.33)/0.33—the same point estimate produced by the double-paired method. Rear seat effectiveness estimates for the remaining age categories and airbag status groups calculated in this way all fall within the CI of the double-paired estimates.

The second limitation is the possibility of misclassification of restraint use in the FARS data; drivers may report that a child was restrained to avoid penalties and personal responsibility. The FARS data collection protocol provides for the resolution of conflicting reports from parents, police, and emergency rescue workers, and the use of multiple data sources may reduce the extent of this problem. Nonrandom classification of unrestrained children as restrained may cause downward biases in both the estimates of restraint effectiveness and the estimates of airbag effectiveness for restrained children.

Finally, it was assumed that passenger airbags are homogenous even though there are some anecdotal reports of variations in passenger airbag design, for example, bag deployment speed, bag trajectory into the passenger compartment, and bag volume. The lack of specific airbag design information in FARS prevented an analysis of these differences. To facilitate future evaluations, the federal government should require vehicle manufacturers to publish comparable data on the design of airbag systems.

In summary, fully powered passenger air bags pose a statistically significant risk of death to front-seated, unrestrained children. Airbags also pose an increased risk of death to restrained children aged 0 to 8 years, while protecting children aged 9 to 12. There is some weak evidence that depowered airbags pose less of a risk than fully powered airbags. Additionally, there is no compelling safety advantage to placing restrained children under the age of 9 in an airbag-equipped seat, and significant risk attached to placing unrestrained children as old as 12 in front of an airbag. In order to minimize fatality risk, parents should be advised, when feasible, to place all children in the rear seat to take advantage of the relative safety of that location and to avoid the increased risk associated with airbags. Previous research has demonstrated that lack of rear seating capacity—whether because of lack of seats or too many passengers—is rarely a valid explanation for seating children in the front.[16]

There is some resistance to the idea that the rear seat is a safer location.[17] The primary concern is that the center rear seat, equipped only with lap belts, is less safe than the lap/shoulder belt in the right-front seat because of the association between lap-only belts and "seat belt syndrome."[18] Although the present study does not directly address this concern, other research has. Population-based studies[19–21] have found that the incidence of seat belt syndrome injuries is very low, that overall nonfatal injury severity is higher in the front seat, and that spinal injuries occur with almost equal frequency in the front and rear. It seems unwise, therefore, for parents to give up the significant fatality reduction of the rear seat because some may not have a shoulder restraint for the child to wear.

Future research on airbags and child safety should address whether depowered airbags and the installation of airbag switches reduce the risk of fatality and injury to children.[22,23] Recent proposals to mandate advanced ("smart") airbag systems could introduce unintended trade-offs between child and adult passenger protection and thus should be analyzed carefully prior to their implementation.[24] Given the well-recognized effectiveness of legislation in increasing seat belt usage rates,[25] legislative efforts to promote seating children in the rear of the vehicle interior should be evaluated.[5]

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