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Rear seat safety: Variation in protection by occupant, crash and vehicle characteristics

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ABSTRACT

Objectives: Current information on the safety of rear row occupants of all ages is needed to inform further advances in rear seat restraint system design and testing. The objectives of this study were to describe characteristics of occupants in the front and rear rows of model year 2000 and newer vehicles involved in crashes and determine the risk of serious injury for restrained crash-involved rear row occupants and the relative risk of fatal injury for restrained rear row vs. front passenger seat occupants by age group, impact direction, and vehicle model year.

Method: Data from the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) and Fatality Analysis Reporting System (FARS) were queried for all crashes during 2007–2012 involving model year 2000 and newer passenger vehicles. Data from NASS-CDS were used to describe characteristics of occupants in the front and rear rows and to determine the risk of serious injury (AIS 3+) for restrained rear row occupants by occupant age, vehicle model year, and impact direction. Using a combined data set containing data on fatalities from FARS and estimates of the total population of occupants in crashes from NASS-CDS, logistic regression modeling was used to compute the relative risk (RR) of death for restrained occupants in the rear vs. front passenger seat by occupant age, impact direction, and vehicle model year.

Results: Among all vehicle occupants in tow-away crashes during 2007–2012, 12.3% were in the rear row where the overall risk of serious injury was 1.3%. Among restrained rear row occupants, the risk of serious injury varied by occupant age, with older adults at the highest risk of serious injury (2.9%); by impact direction, with rollover crashes associated with the highest risk (1.5%); and by vehicle model year, with model year 2007 and newer vehicles having the lowest risk of serious injury (0.3%). Relative risk of death was lower for restrained children up to age 8 in the rear compared with passengers in the right front seat (RR = 0.27, 95% CI 0.12–0.58 for 0–3 years, RR = 0.55, 95% CI 0.30–0.98 for 4–8 years) but was higher for restrained 9–12-year-old children (RR = 1.83, 95% CI 1.18–2.84). There was no evidence for a difference in risk of death in the rear vs. front seat for occupants ages 13-54, but there was some evidence for an increased relative risk of death for adults age 55 and older in the rear vs. passengers in the right front seat (RR = 1.41, 95% CI 0.94–2.13), though we could not exclude the possibility of no difference. After controlling for occupant age and gender, the relative risk of death for restrained rear row occupants was significantly higher than that of front seat occupants in model year 2007 and newer vehicles and significantly higher in rear and right side impact crashes.

Conclusions: Results of this study extend prior research on the relative safety of the rear seat compared with the front by examining a more contemporary fleet of vehicles. The rear row is primarily occupied by children and adolescents, but the variable relative risk of death in the rear compared with the front seat for occupants of different age groups highlights the challenges in providing optimal protection to a wide range of rear seat occupants. Findings of an elevated risk of death for rear row occupants, as compared with front row passengers, in the newest model year vehicles provides further evidence that rear seat safety is not keeping pace with advances in the front seat.

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1. Introduction

Significant progress has been made in reducing the number of drivers and passengers killed in crashes over the past several decades (Insurance Institute for Highway Safety, 2014; Minino, 2012). Much of this progress can be attributed to improvements in state highway safety laws (e.g., seat belt use laws, alcohol-impaired driving laws) (National Highway Traffic Safety Administration, 2012a) and advances in vehicle crashworthiness and vehicle safety technologies including frontal and side airbags and electronic stability control (ESC) (Glassbrenner, 2012). Advances in vehicle safety features have been spurred by federal regulations that govern the performance of vehicle safety technologies, as well as by consumer information programs that evaluate vehicle crashworthiness. These include the New Car Assessment Program (NCAP) operated by NHTSA and the vehicle safety ratings program of the Insurance Institute for Highway Safety. However, most regulations and consumer crash tests have focused on vehicle drivers and front seat passengers due to high occupancy and fatality rates in the front seat. Consequently, there have been innovations in occupant protection in the front seat (e.g., frontal airbags, seat belt pretensioners) while comparatively fewer innovations have been made in the rear row. Earlier research has shown that the rear row is safer for occupants than the front seat (Braver et al., 1998; Durbin et al., 2005), but there is some evidence that improvements in front seat occupant protection in more recent vehicles has resulted in a reduction in the relative safety of the rear vs. front seat in newer model year vehicles (Bilston et al., 2010; Kuppa et al., 2005; Sahraei et al., 2010; Winston et al., 2007).

Enhancing safety in the rear seat is challenging due to the wide range of occupant age and size. The National Highway Traffic Safety Administration (2013a) is currently considering improvements to its NCAP program and has identified rear row occupants as a specific area under consideration. To develop appropriate regulations and possible revisions to the current crash test procedures that might directly evaluate occupant protection for rear row occupants, it is important to understand who travels in the rear and their restraint practices to describe the population at risk.

Based on an analysis of data from 2001 to 2002 National Household Travel Survey and 2002–2006 crashes included in the National Automotive Sampling System-Crashworthiness Data System (NASS-CDS), approximately 13% of vehicle occupants in 2000–2006 rode in the rear row, representing 39 billion person-trips per year (Trowbridge and Kent, 2009). It was further estimated that nearly 79% of vehicle occupants younger than 12 years of age rode in the rear row compared with 7.4% of occupants ages 12–64 (Trowbridge and Kent, 2009). As adults make more trips than children, there were similar numbers of annual person-trips in the rear row for occupants younger than age 12 years (18.9 billion person-trips) and 12 years of age or older (19.1 billion person-trips) (Trowbridge and Kent, 2009). Analysis of NASS-CDS crash reports from 1993 to 2000 indicated that 62% of rear seated occupants in tow-away crashes were younger than 16 years of age (Smith and Cummings, 2004).

Observed restraint use in the United States among occupants 8 years or older in the rear has improved over time, increasing from 47% in 2004 to 75% in 2012, though it remains lower than front seat restraint use (86% in 2012) (Pickrell, 2014). According to the National Survey on the Use of Boosters, restraint use for children younger than age 8 was more than 90% in 2013, but the study did not specify whether the children were in the front or rear seat when observed (Pickrell and Choi, 2014). Data from the 2012 Fatality Analysis Reporting System (FARS) indicate that of the 21,667 deaths of occupants of passenger vehicles, 1811 (8.4%) were second row occupants (National Highway Traffic Safety Administration, 2014). Of these, 57% were unrestrained, a higher proportion than for occupants who died in the front seat (46%).

Recent studies indicate that newer model year vehicles demonstrate lower protection of belted rear row occupants, particularly adults, as compared to belted front seat occupants (Bilston et al., 2010; Sahraei and Digges, 2009; Sahraei et al., 2010, 2009). For example, Bilston et al. demonstrated that rear row occupant injury risk was nearly two-fold higher than front seat occupant injury risk among belted 16–50 year-olds in model year 1997–2007 vehicles. This is likely attributable, in part, to advances in front seat restraint system performance due to the incorporation of load limiters and pre-tensioners as compared with the rear (Beck et al., 2011; Kent et al., 2007). In addition, vehicle stiffness has increased, which has altered vehicle frontal impact crash pulses (Locey et al., 2012). Since rear row occupants generally do not have the advanced vehicle seat belt systems and frontal airbags available to front seat occupants, which mitigate the effects of more severe frontal crash pulses, there is concern that the changes in crash pulses may increase risk of injury to rear row occupants (Sahraei et al., 2013, 2014).

Most of the studies characterizing real-world rear row occupants and restraint system performance used data that is over a decade old and included vehicles as old as model year 1990, limiting their ability to complement more recent simulation and laboratory-based research supporting efforts to improve rear seat safety. We sought to conduct a more contemporary analysis of real-world crash data in order to inform efforts by NHTSA, auto manufacturers, and restraint system suppliers to identify priority areas to target for improving rear seat safety. The specific objectives of this study were to: (1) describe characteristics of occupants in the front and rear rows of 2000 and newer model year vehicles involved in crashes, in particular rear row occupants with serious (Abbreviated Injury Scale (AIS) score 3+) and fatal injuries; (2) determine the relative risk of serious injury for restrained vs. unrestrained rear row occupants, as well as the risk of serious injury for restrained rear row occupants by occupant age, impact direction and vehicle model year; and (3) determine the relative risk of fatal injury for restrained rear row vs. front row occupants by age group, impact direction and vehicle model year.

2. Methods

2.1. Sources of data

Data were obtained from NASS-CDS, maintained by NHTSA, for crashes occurring during calendar years 2007–2012. NASS-CDS is a nationally representative sample of police-reported tow-away crashes occurring on public roadways in the United States (National Highway Traffic Safety Administration, 2013b). We analyzed data for all passenger vehicles, including passenger cars, minivans, sport utility vehicles (SUVs), and pick-up trucks. Vehicles were restricted to model year 2000 and newer and must have been within the most recent 10 model years relative to the calendar year at the time of the crash. For example, data from crashes occurring during calendar year 2012 included vehicle model years from 2003 to 2012. This restriction was used because as of 2009, NASS-CDS focuses on late model year vehicles, limiting full interior and exterior vehicle inspections to the 10 most recent vehicle model years. As a result, important restraint and crash details are not available for vehicles older than 10 years. For analyses examining serious injuries as the outcome of interest, only NASS-CDS data were utilized. A serious injury was defined as an injury with an AIS score of 3 or greater, generally corresponding to internal organ injuries, spinal cord injuries, traumatic brain injuries, and serious fractures, and included occupants who sustained fatal injuries

(Association for the Advancement of Automotive Medicine (AAAM), 2008).

Additional data were obtained from FARS, also maintained by NHTSA, for fatal crashes occurring during calendar years 2007–2012. FARS is a census of all crashes on public roadways resulting in a fatality (motorist or non-motorist) within 30 days of the crash (National Highway Traffic Safety Administration, 2012b). We analyzed FARS data for all passenger vehicles involving at least one occupant fatality. For consistency with the NASS-CDS data set, vehicle model year was restricted to 2000 and newer and the most recent 10 years relative to the calendar year at the time of the crash.

In compiling a dataset on fatalities, FARS data on occupants in passenger vehicles involving a fatality were substituted for the weighted sample of comparable NASS-CDS data on fatal crashes in order to achieve a combined injury and fatality dataset with more accurate fatality counts than are provided by the NASS-CDS data alone. The national estimates produced from NASS-CDS data may differ from the true values because they are based on a probability sample of crashes and not a census of crashes, and previous research has suggested fatalities are underrepresented in NASS-CDS (Braver et al., 2010). FARS is a national census of crashes involving fatalities, providing actual counts of fatalities rather than estimates from a probability sample. For analyses examining fatal injuries as the outcome of interest, fatalities were identified from the FARS database, and NASS-CDS data on a corresponding sample of crashes (e.g., 0–10-year-old passenger vehicles involved in crashes during model year 2007–2012) provided estimates of the total crash-involved population when calculating risk estimates. Because sampling in NASS-CDS is based on model year and the severity of injury (including hospitalization status), case weights equal to the inverse of the probability of selection and adjusted to known crash totals were used to account for the oversampling of serious crashes. Case weights in FARS were set to 1 because FARS is a census of fatalities. A similar methodology for creating a combined NASS-CDS and FARS data set was described in Elliott et al. (2006).

Table 1
Characteristics of all passenger vehicle occupants in crashes in 2007–2012, as well as rear seat occupants with serious (AIS 3+) and fatal injuries.

Sample characteristic	All occupants[a]		p value[b]	Serious injuries in rear seat	
	Front seat N = 30,239 unweighted (weighted %)	Rear seat N = 5196 unweighted (weighted %)		Nonfatal Injuries in the Rear Seat[a] = 354 unweighted (weighted %)	Fatal injuries in rear seat[c] N = 6848 (%)
Occupant age					
0–3 years	21 (0.1)	906 (19.5)	<0.001	18 (5.0)	617 (9.0)
4–8 years	80 (0.2)	994 (24.2)		31 (7.8)	667 (9.7)
9–12 years	257 (1.0)	557 (12.5)		17 (6.0)	400 (5.8)
13–19 years	3533 (12.6)	1060 (18.6)		92 (21.6)	1588 (23.2)
20–54 years	20,192 (65.4)	1291 (17.3)		148 (45.3)	2402 (35.1)
55+ years	5842 (19.1)	278 (3.7)		48 (14.3)	1174 (17.1)
Unknown	314 (1.6)	110 (4.2)		0 (0.0)	
Occupant sex					
Male	15,361 (51.1)	2526 (43.9)	0.08	170 (49.2)	3473 (50.7)
Female	14,708 (48.0)	2614 (55.2)		184 (50.8)	3371 (49.2)
Unknown	170 (0.8)	56 (0.9)			4 (0.1)
Restraint use					
Yes	25,548 (90.2)	3937 (88.0)	0.003	117 (39.0)	2,538 (37.1)
No	4161 (8.4)	1177 (11.1)		224 (58.8)	3,792 (55.4)
Unknown	530 (1.4)	82 (0.8)		13 (2.2)	518 (7.6)
Seating position					
Left	23,602 (80.4)	1961 (37.3)	<0.001	126 (37.6)	2622 (38.3)
Center	36 (0.1)	706 (14.1)		39 (11.8)	1001 (14.6)
Right	6585 (19.4)	2417 (47.1)		173 (45.2)	3089 (45.1)
Unknown	16 (<0.1)	112 (1.6)		16 (5.4)	136 (2.0)
Impact direction					
Frontal	13,395 (42.5)	2154 (41.1)	0.64	101 (23.6)	1929 (28.2)
Left side	3242 (11.0)	547 (8.6)		37 (9.6)	759 (11.1)
Right side	2647 (8.2)	432 (8.6)		35 (12.3)	562 (8.2)
Rear	1801 (6.9)	347 (9.0)		23 (7.6)	602 (8.8)
Rollover	3213 (8.2)	713 (9.3)		108 (31.1)	2806 (41.0)
Other/unknown	5941 (23.2)	1003 (23.4)		50 (15.8)	190 (2.8)
Vehicle type					
Passenger car	19,146 (62.8)	2712 (52.8)	0.001	203 (50.4)	3616 (52.8)
SUV	6169 (20.2)	1393 (25.2)		93 (28.0)	1730 (25.3)
Minivan	1798 (5.7)	757 (14.5)		40 (16.4)	762 (11.1)
Pickup truck	3126 (11.3)	334 (7.5)		18 (5.3)	740 (10.8)
Vehicle model year					
2000–2002	6767 (26.7)	1186 (27.5)	0.12	87 (28.7)	1992 (29.1)
2003–2006	13,310 (45.8)	2399 (48.8)		186 (54.1)	3337 (48.7)
2007–2013	10,162 (27.5)	1611 (23.7)		81 (17.2)	1519 (22.2)

[a] Data obtained from NASS-CDS. Numbers provided are unweighted observations and sample-weighted proportions.
[b] p value for the difference in variable distribution between front and rear seat occupants.
[c] Data obtained from FARS. Numbers provided are observed counts.

2.2. Variable definitions

For each source of data, we categorized occupant age into groups, roughly corresponding to different recommended restraint systems: 0–3 years (young children who should use child restraints with internal harnesses), 4–8 years (children who should use child restraints or booster seats), 9–12 years (pre-teens who should use booster seats or vehicle seat belts), 13–19 years (adolescents who should use vehicle seat belts), 20–54 years (adults who should use vehicle seat belts), and 55 and older (older adults who should use vehicle seat belts). Restraint status for each age group was then categorized as restrained or not, based on the NASS-CDS variable for manual belt system use (MANUSE) or FARS variable for restraint system use (REST_USE) for whether a safety belt and/or child safety seat was used, without any further attempt to distinguish the specific type of restraint system that was used. When MANUSE was missing or unknown in NASS-CDS, restraint status was determined from the variables for child seat used (CHUSED) or type of child safety seat (CHTYPE) for children younger than 9 years, and from police reported restraint use (PARUSE) for occupants 9 years and older. For vehicles with three rows of seats (minivans and some SUVs), occupants in both the second and third rows were considered to be in the rear row. Impact direction was categorized as frontal, left side, right side, rear, rollover, and other/unknown based on the general area of damage (GAD1) in NASS-CDS and initial impact direction (IMPACT1) in FARS. Crashes were categorized as rollovers if a rollover occurred during the crash (variable ROLLOVER in NASS-CDS and FARS), regardless of the impact direction indicated by GAD1 or IMPACT1. Vehicle model year was categorized as 2000–2002, 2003–2006, and 2007–2013.

2.3. Statistical analyses

The NASS-CDS sample was described using proportions for categorical variables. Estimates of AIS 3+ injury rates, with corresponding 95% confidence intervals (95% CI) were determined for various sample strata defined by occupant age, restraint status, vehicle model year, and impact direction. In addition, we calculated the relative risk of AIS 3+ injury to restrained vs. unrestrained occupants in the rear row. Chi-squared tests were performed to assess the differences in distributions in the bivariate analyses.

Using the combined NASS-FARS database, fatality risk estimates were calculated using counts of deaths from FARS and whole sample estimates of occupants from NASS-CDS. Logistic regression modeling was used to compute the relative risk (RR) of death for restrained occupants in the rear vs. front row by occupant age, impact direction and vehicle model year. Analyses calculating relative risk of fatality by occupant age were further restricted to non-drivers of the corresponding age group in the front seat when comparing with rear seat occupants. All models were adjusted for vehicle type and occupant gender and, where appropriate, models were adjusted for occupant age, impact direction, and vehicle model year. To estimate adjusted RRs, we used odds ratios from logistic regression; odds ratios will approximate RRs when the outcome is uncommon, as it was in this analysis (Hosmer and Lemeshow, 2000). To adjust inference to account for the disproportional probability of selection of subjects and stratification and clustering of subjects by geographic region and vehicle, robust χ^2 tests of association and Taylor series linearization estimates of the logistic regression parameter variances were calculated using SAS-callable SUDAAN: Software for the Statistical Analysis of Correlated Data, version 9.1 (Research Triangle Institute, Research Triangle Park, NC).

3. Results

3.1. Sample characteristics

Table 1 presents the characteristics of all occupants ($n = 35{,}435$ observed, 12,775,274 estimated) in tow-away crashes during 2007–2012 from NASS-CDS data, as well as the characteristics of rear row occupants with AIS 3+ injuries ($n = 354$ observed, 21,021 estimated in NASS-CDS) and fatal injuries ($n = 6848$ observed in FARS). Among all vehicle occupants in crashes during 2007–2012, 12.3% were in the rear row. Rear row occupants differed markedly from front row occupants with regard to age group: very few front row occupants were younger than 13 years of age (6.6% of all non-drivers in the front), in contrast to 56.2% of rear row occupants. An additional 18.6% of rear row occupants were adolescents ages 13–19 years, resulting in adults accounting for only 21.0% of rear row occupants (age was not known for 4.2% of rear row occupants). While children younger than 13 accounted for 56.2% of rear row occupants, they accounted for only 18.8% of serious injuries and 24.5% of deaths, suggesting that adults are over-represented among rear row occupants with serious or fatal injuries. The majority (55.2%) of rear row occupants were female. In the rear, there was a notable preference for the right outboard seating position, (47.1% of rear seat occupants), followed by the left outboard (37.3%) and the center (14.1%). Overall restraint use in the rear was slightly lower than in the front (88.0% vs. 90.2%, $p = 0.003$), and use varied by occupant age; 98.6% of 0–3 year-olds, 96.1% of 4–8 year-olds, 93.3% of 9–12 year-olds, 80.7% of 13–19 year-olds, 70.4% of 20–54 year-olds, and 85.6% of 55+ year-olds were restrained. The distribution of impact direction was similar ($p = 0.64$) for front and rear row occupants, with frontal crashes the most common impact direction for both (impact direction was other or unknown for about 23% of occupants in the front and back seats). Rollover crashes were the most common impact direction among rear row occupants with serious or fatal injuries. While passenger cars were the most common vehicle type for front and rear row occupants, SUVs and minivans were more common ($p = 0.001$) among rear row occupants than among front row occupants. The distribution of model year was similar for front and rear row occupants ($p = 0.12$).

3.2. Risk of serious injury in the rear row

The estimated 21,021 (354 observed) rear row occupants with serious injuries accounted for 8.6% of all occupants with serious injuries during the time period of study. Among occupants in tow-away crashes, the overall risk of serious injury among occupants in the rear row was 1.33%. Unrestrained occupants in the rear were significantly more likely to suffer a serious injury than restrained occupants in the rear (unrestrained risk = 7.0%, restrained risk = 0.6%; adjusted RR 7.93, 95% CI 5.12–12.27).

Table 2 provides the observed number and estimates of risk of AIS 3+ injury for the estimated 8188 (117 observed) restrained rear row occupants (39.0% of all rear row occupants) with injuries by age, impact direction, and vehicle model year. Among restrained rear row occupants, the risk of serious injury varied by occupant age ($p < 0.001$), with older adults at the highest risk of serious injury. Risk of serious injury also varied by impact direction ($p < 0.001$), with rollover crashes associated with the highest risk, and by vehicle model year ($p = 0.055$), with model year 2007 and newer vehicles having the lowest risk of serious injury.

3.3. Fatal injury analyses

The 6848 rear row occupants with fatal injuries accounted for 10.1% of all fatally injured occupants during the time period of

Table 2
Estimates of AIS 3+ injury risk for restrained rear seat passenger vehicle occupants by occupant age, vehicle model year and impact direction.

Sample characteristic	Number with AIS 3+ injury[a] N = 117 (weighted%)	Risk of AIS 3+ injury (95% CI)
Occupant age		
0–3 years	15 (12.4%)	0.33% (0.11–0.98)
4–8 years	20 (16.0%)	0.36% (0.20–0.64)
9–12 years	9 (7.3%)	0.32% (0.15–0.70)
13–19 years	24 (17.0%)	0.59% (0.26–1.32)
20–54 years	26 (29.6%)	1.26% (0.50–3.15)
55+ years	23 (17.7%)	2.89% (1.09–7.42)
Vehicle model year		
2000–2002	14 (19.2%)	0.56% (0.23–1.36)
2003–2006	77 (68.8%)	0.75% (0.54–1.05)
≥2007	26 (11.9%)	0.30% (0.12–0.76)
Impact direction		
Frontal	33 (22.4%)	0.32% (0.17–0.63)
Left side	13 (11.4%)	0.77% (0.28–2.07)
Right side	12 (12.7%)	0.88% (0.30–2.56)
Rear	11 (4.7%)	0.29% (0.10–0.84)
Rollover	27 (21.2%)	1.54% (0.91–2.61)
Other/unknown	21 (27.7%)	0.67% (0.24–1.81)

[a] Data obtained from NASS-CDS. Numbers provided are unweighted observations and sample-weighted proportions.

study. Table 3 provides a description of the sample of 2538 restrained rear row occupants (37.1% of all rear row deaths) who died in crashes, and estimates of the risk of fatal injury for restrained occupants by age, vehicle model year, and impact direction. In addition, the relative risk of death for rear vs. front row (non-driver) restrained occupants is provided.

Children younger than 13 years of age accounted for nearly half (42.9%) of the deaths among restrained occupants in the rear row, with adults accounting for 41.8% and adolescents 15.2%. Contrast this to the age distribution among all fatally injured rear row occupants noted in Table 1, where children are relatively underrepresented due to the fact that proportionately more fatally injured children than adults are restrained. The estimate of risk of fatal injury among restrained rear row occupants age 55 and older (1.2%) was notably higher than the estimated risk for the age groups younger than 55 (≤0.3%). There was a clear fatality risk reduction for restrained children ages 0–8 years in the rear as compared with the front. Of note, the relative risk of death for restrained 9–12 year-old children was higher in the rear vs. front row (RR 1.83, 95% CI 1.18–2.84). This was due primarily to an unusually small fatality risk in the front row for restrained 9–12 year-olds (<0.1%), rather than an elevated risk in the rear. There was no clear evidence for a difference in risk of death in the rear vs. front row for restrained older adolescents and adults ages 20–54. There was some evidence for an elevated relative risk of death for restrained adults ages 55 and older in the rear vs. the front row (RR 1.41, 95% CI 0.94–2.13), though we could not exclude the possibility of no difference.

There was variability in the relative risk of death for restrained rear row occupants vs. front row passengers (non-drivers) by model year of vehicle. Model year 2000–2002 vehicles demonstrated some evidence for a lower risk of death in the rear vs. the front (RR 0.79, 95% CI 0.61–1.02), though we could not exclude the possibility of no difference. Model year 2003-2006 vehicles demonstrated no evidence for a difference in rear vs. front row safety (RR 1.10, 95% CI 0.83–1.45). There was evidence that restrained rear row occupants in 2007 and newer vehicles were at a higher risk of death than front row occupants (RR 1.46, 95% CI 1.11–1.92).

The risk of death among rear-seated occupants was lowest in frontal crashes and highest in rollovers, with other impact directions having similar risks of fatality. When examining the relative risk of death for rear vs. front row occupants by impact direction, there was a significant difference in risk for rear impacts, in which rear seated occupants were at a higher relative risk of death than front row occupants (RR 2.05, 95% CI 1.22–3.43). In addition, there was evidence for an elevated risk of death for rear vs. front row occupants in right side impact crashes (RR 1.85, 95% CI 1.08–3.16).

4. Discussion

A variety of legislative and education efforts have largely succeeded in getting children younger than age 13 in the rear seat; in the current study, adults accounted for the vast majority of right

Table 3
Risk of fatal injury for restrained rear seat passenger vehicle occupants and relative risk of death for rear vs. front seat restrained passengers by occupant age, impact direction and vehicle model year.

Sample characteristic	Number with fatal injury in rear seat N = 2538 (%)	Risk of fatal injury in rear seat (95% CI)	Relative Risk of fatal injury (95% CI) for rear vs. front seat[a]
Occupant age			
0–3 years	471 (18.6%)	0.15 (0.09–0.28)%	0.27 (0.12–0.58)
4–8 years	412 (16.2%)	0.11 (0.06–0.20)%	0.55 (0.30–0.98)
9–12 years	207 (8.2%)	0.11 (0.06–0.20)%	1.83 (1.18–2.84)
13–19 years	387 (15.2%)	0.16 (0.09–0.29)%	0.90 (0.72–1.13)
20–54 years	473 (18.6%)	0.25 (0.16–0.39)%	1.03 (0.78–1.35)
55+ years	588 (23.2%)	1.17 (0.69–1.97)%	1.41 (0.94–2.13)
Vehicle model year			
2000–2002	653 (25.7%)	0.17 (0.09–0.31)%	0.79 (0.61–1.02)
2003–2006	1238 (48.8%)	0.18 (0.10–0.32)%	1.10 (0.83–1.45)
≥2007	647 (25.5%)	0.20 (0.12–0.32)%	1.46 (1.11–1.92)
Impact direction			
Frontal	863 (34.0%)	0.15 (0.09–0.26)%	0.96 (0.75–1.23)
Left side	345 (13.6%)	0.28 (0.17–0.48)%	0.73 (0.49–1.10)
Right side	290 (11.4%)	0.24 (0.13–0.45)%	1.85 (1.08–3.16)
Rear	321 (12.6%)	0.24 (0.12–0.50)%	2.05 (1.22k3.43)
Rollover	672 (26.5%)	0.59 (0.26–1.35)%	1.17 (0.86–1.60)
Other/unknown	47 (1.9%)	0.01 (0.01–0.03)%	0.63 (0.37–1.09)

[a] In addition to including all variables noted in the table, analyses were also adjusted for vehicle type and occupant gender. Analyses were restricted to non-drivers in the front seat.

front seat passengers, while 86% of children younger than age 13 were in the rear. More than half of all rear row occupants were younger than age 13, and 3 out of 4 were younger than age 20. While children younger than age 9 were clearly better protected in the rear vs. front seat, older adults (age 55+ years) do not appear to be as well protected in the rear. They had the highest risk for any age group of both serious and fatal injuries. We also noted a higher relative risk of death to 9–12 year-olds restrained in the rear as compared with the front seat as well, though this resulted from an unusually low risk of death to restrained 9–12 year-olds in the front passenger seat, which may represent a statistical aberration for the time period of study, due to relatively sparse data. Additional research is needed to clarify whether this unexpected finding is maintained with larger samples of crashes.

Similar to previous research, older occupants in crashes had increased risks of injury and death when compared with younger occupants (Kent et al., 2009; Li et al., 2003), and this difference was even more pronounced in the rear seat. The increased relative risk of serious and fatal injuries in the rear for older occupants is consistent with previous research on frontal impacts showing the outboard rear seat positions were less safe than the front passenger seat for the oldest occupants, with significantly decreased effectiveness in reducing the risk of death among adults age 50 years or older (Bilston et al., 2010; Sahraei et al., 2010). Prior studies have also indicated that adult occupants in the rear are more likely than adult occupants in the front to sustain chest injuries, and that the specific types of chest injuries suffered by restrained occupants varies by occupant age (Kuppa et al., 2005; Parenteau and Viano, 2003). When Kuppa et al. (2005) examined crash test data from several model year 2004 vehicles, there was an elevated risk of head and neck injury for restrained 5th percentile adult female anthropomorphic test devices (ATDs or crash test dummies) in the rear seat compared with restrained (airbag and seat belt) 5th percentile adult female ATDs in the front, suggesting that head protection in the rear has not kept pace with improvements in the front. However, the risk of chest injury to ATDs in the crash tests was not appreciably higher in the rear compared with the front, indicating some discrepancy between the testing environment and the real world.

In the current study, rear row occupants accounted for 12.3% of all vehicle occupants in tow-away crashes and 8.6% of the serious injuries during the study period. Children younger than age 13 accounted for a significant proportion of the serious injuries (35.7%) and deaths (42.9%) to restrained rear row occupants (though proportionately fewer of the overall injuries and deaths in the rear due to the relatively high restraint use rates for children), highlighting the challenges vehicle and restraint system manufacturers have in providing optimal protection to a wide range of rear row occupants. A particular challenge will be identifying mechanisms by which vehicle restraint systems in the rear can better protect older adults, who were at higher risk of serious injury and death than younger occupants, while preserving the relatively good performance of seat belt systems for adolescents and younger adults, as well as the ability to install child restraint systems for the youngest occupants.

One option for advancing the performance of rear seat restraint systems is to bring existing front seat restraint system technologies such as load limiters and pretensioners into the rear row environment (Beck et al., 2014; Forman et al., 2008, 2009). Load limiters help manage thoracic forces, a desired objective for older adults, while pretensioners help control head excursion, a desired objective for all occupants. There is some evidence that load-limiters in the front seat are associated with increased fatality rates in some circumstances, likely due to increased excursion (Brumbelow et al., 2007). This is an important consideration in the rear seat, particularly since airbags are not currently available to help reduce forward head excursion. Another option is to develop additional advanced restraint systems unique to the rear seat environment, such as inflatable belts, that both manage thoracic forces as well as help to control head excursion (Sundararajan et al., 2011). Further research is needed to identify specific testing procedures that might be used to evaluate the dynamic performance of restraint systems in the rear row for occupants age 9 and older. Additionally, the influence of these advanced restraint systems on the use and performance of child safety seats would need to be evaluated.

Rear row occupants accounted for 10.1% of all deaths in crashes during the study period. A third of the deaths to restrained rear row occupants occurred in frontal (34.0%) crashes. Currently, the performance of rear seat occupant restraint systems in frontal impacts is evaluated only in *static* tests as per Federal Motor Vehicle Safety Standard (FMVSS) no. 209 – seat belt assemblies and FMVSS no. 210 – seat belt anchorages. Neither rule requires an assessment of the risk of injury to occupants. FMVSS no. 208 – occupant crash protection and the frontal crash component of the U.S. NCAP program evaluate only front seat occupant protection. In contrast, European, Chinese, and Australian NCAPs each assess rear seated child occupant injury in frontal crash tests using 18 month-old and 3 year-old ATDs. Note, however, that Euro NCAP has recently announced its intention to move away from assessing rear seat occupant safety using ATDs in child restraints to assessing seat belt-restrained ATDs representing older children or adults. The specific size of the ATD (e.g., 10 year-old vs. 5th percentile adult female vs. 50th percentile male) has yet to be determined. Since 2009, the Japanese NCAP testing requires rear seat occupant protection testing in frontal crashes using a 5th percentile adult female Hybrid III ATD. NHTSA should consider incorporation of a *dynamic* assessment of restraint system performance as part of either its regulatory or consumer information testing programs.

Over half of the serious injuries (58.8%) and deaths (55.4%) in the rear row were among unrestrained occupants, highlighting the continued challenge of increasing restraint use. This is particularly challenging among rear row occupants whose overall restraint use in observational studies is lower than that of front seat occupants, likely owing in part to a perception of the rear seat being safer than the front. Clearly, any safety advantage of the rear seat is compromised by failing to use a restraint system, as unrestrained occupants in the front or rear seat are at a substantially increased risk of serious injury than those who were restrained. Additionally, unrestrained rear seat occupants increase the risk of injury to front seat occupants (Bose et al., 2013). Extending primary enforcement seat belt use laws to include all rear row occupants should be considered by state legislatures. To date, only 16 states have this provision (Governors Highway Safety Association, 2014). In addition, enhanced seat belt reminders that have been effective in increasing belt use in the front seat should be considered for the rear seat (Freedman et al., 2007). Only 3 percent of 2014 vehicle models in the United States had reminder systems that detected safety belt use for back seat passengers, yet drivers are generally supportive of rear belt reminders for children. In a 2012 Insurance Institute for Highway Safety survey, more than three-quarters of drivers supported belt reminders that would alert them when children in back seats are not buckled (Kidd and McCartt, 2014). Congress enacted a requirement that NHTSA begin rulemaking to require back seat belt reminders, but a rule has not been proposed yet (Moving Ahead for Progress in the 21st Century Act (MAP-21), 2012).

Our analysis of rear seat safety by vehicle model year extends results of prior studies that focused on older model year vehicles (generally grouping vehicles from model year 2000–2009). We found that restrained rear seat occupants in the most recent model year vehicles (2007–2013) were at an increased relative risk of death when compared with right front seat passengers. Of note, the risks of serious injury and fatality in the rear seat were similar for all vehicle model year categories, suggesting that the elevated relative risk of death for rear vs. front row occupants in model 2007 and newer vehicles is due to improved safety in the front seat, not an increase in crash pulse severity for the rear row. Given the variability in apparent rear seat safety by occupant age group and vehicle model year, NHTSA's current interest in revising NCAP testing to include specific evaluation of rear seat safety (including safety belt performance, seat designs, occupant kinematics, sources of occupant contact, airbag performance, inflatable belts, etc.) appears well-justified.

A number of limitations should be considered in the interpretation of findings from this study. First, we did not identify the specific restraint type for children, combining young children who were appropriately restrained in car seats and booster seats with those inappropriately using the vehicle seat belt system. This likely resulted in conservative estimates of the relative advantage of the rear row for restrained children. In addition, despite combining 6 years of data from a nationally representative crash surveillance system (NASS-CDS), observed counts of several strata of interest, particularly those involving children, are relatively small, resulting in large sample weights and wide confidence intervals around several estimates or comparisons of interest related to serious injury risk. Combining FARS data with NASS-CDS data helped to overcome some of these limitations in the analyses of fatalities. However, certain data in FARS, particularly those related to restraint system use, are likely not as reliable as those in NASS-CDS, since FARS data are obtained primarily from the police crash report, while NASS-CDS involves an in-depth investigation of the crash, including photographs of the vehicle and restraints, and an examination of detailed injury data. Analyses comparing the relative risk of death in the rear vs. right front seat combined all possible seating positions in the rear, potentially masking some variation in safety of a specific rear seating position. For example, in side impact crashes, both struck side and far side rear seating positions were combined, even though there may be differences in safety when compared with the right front seat depending on the direction of impact. However, the analyses in this study were designed to assess the population-level impact of seating position on safety, not the performance of restraint systems under specific crash circumstances. Finally, given that a primary objective of this study was to provide more contemporary analysis of real-world crash data to identify priority areas for improving rear seat safety, our analyses focused on restrained occupants in vehicles that were 10 years old or newer at the time of the crash, and did not address the relative risk of the rear vs. front seat for the many people who continue to ride unrestrained or in older vehicles. Prior studies have shown rear seats to be safer compared with the outboard front passenger seats in crashes for unrestrained occupants of all ages (Durbin et al., 2005; Kuppa et al., 2005).

5. Conclusion

Results of this study extend prior research on the relative safety of the rear row as compared with the front by examining restraint system performance in a more contemporary fleet of vehicles. The rear row is primarily occupied by children and adolescents and clearly remains a relatively safe seating position for children younger than age 9. However, the increased risk of serious and fatal injuries for occupants 55 and older highlights the challenges for vehicle and restraint system manufacturers in providing optimal protection to a wide range of rear row occupants. Findings of an elevated risk of death for rear row occupants, as compared with front row passengers, in the newest model year vehicles provides further evidence that rear seat safety is not keeping pace with advances in the front seat, and highlights the need to continuously re-examine findings such as those presented here with more recent data. Continued research is needed to identify the best means by which to preserve the safety of the rear row for the youngest occupants, while improving the performance of restraint systems for the oldest occupants.

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