Differential Fatality Risk Between Rear and Front Seat Passenger Vehicle Occupants in Frontal Crashes

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Abstract Popular wisdom has long suggested that rear seated occupants are better protected than front seat occupants in the event of a frontal crash. However, relatively recent studies have begun suggesting that the great passive safety advancements seen over the last couple of decades have disproportionately benefited front seated occupants. The objective of this study was to quantify the difference in fatality risk between restrained rear and front seated occupants involved in frontal passenger vehicle crashes by using the most recently available U.S. real-world crash data. Data from the National Automotive Sampling System Crashworthiness Data System and the Fatality Analysis Reporting System were queried, and logistic regression modelling was used to evaluate the relative risk of fatal injury in rear versus front seat occupants. The model was adjusted for occupant age, occupant gender, vehicle model year, and vehicle type. The key finding is that in the newest model year vehicles (2007-2016), the rear seat carries a higher risk of fatality than the front seats (RR 1.65, 95% CI 1.51-1.79). These findings supplement and agree with previous literature and suggest that advances in rear seat occupant protection are falling behind occupant protection for front seat occupants and should be more heavily emphasised in the future vehicle fleet.

Keywords fatality risk, injury risk, occupant protection, passenger vehicle crash, rear seat

I. INTRODUCTION

In any frontal collision – be it with another vehicle or into a roadside object – popular wisdom is that rear seated occupants are at a lower risk of injury in frontal crashes than their front seat counterparts. However, significant advances in passive safety countermeasures, such as advanced airbags, seatbelt pretensioners, and load limiters, primarily benefit front seat occupants. In the U.S., regulatory emphasis in frontal crashes focuses exclusively on front seat occupants. With such safety advances and regulatory emphasis on front seat occupant protection, the differential crash injury risk between the front and rear seat should be revisited.

Current Literature

The performance of rear seat occupant restraint systems in the U.S. has not been studied as widely as those provided to front seat occupants. In the few studies based on real-world data such as the National Automotive Sampling System (NASS) that have probed into rear seat restraint performance, it has generally been found that for adult occupants, especially those over 50-55 years, the *protective effect* of the rear seat decreases with increasing occupant age [1-4]. In restrained, rear seated adults, the most commonly injured body region tends to be the thorax, and the source of injury is the seatbelt itself [5]. This is an indication that the seatbelt technology currently being implemented in front seats, such as load limiters, should be considered for the rear seating restraint systems. Indeed, a number of studies using rear seated crash test dummies in frontal crash tests have provided preliminary evidence that a seat belt system with either only a pretensioner or both a pretensioner and progressive load limiter could benefit rear seat occupants by reducing forward excursion and overall occupant loading, thereby reducing the possibility of sustaining subsequent injuries [6-8].

Recently, an argument has arisen that the standard advances in front seat safety systems have been so great, that they now significantly outpace those safety systems typically provided in the rear seats. This argument has been fueled by a few studies that have found the relative effectiveness of rear versus front seat restraint systems for adults is lower in newer model year vehicles compared to older models [3,4,9,10]. In [9], a matched-cohort approach was adopted on NASS-Crashworthiness Data System (CDS) data from years 1993-2007. They

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evaluated the relative risk (RR) of an Abbreviated Injury Scale (AIS) three or greater (3+) injury in restrained front and rear seat occupants and found that the RR was significantly influenced by occupant age and vehicle model year. The study concluded that for children aged 9-15, the rear seat always carried a lower risk of injury. However, for adults aged 16-50 years, in *newer* vehicles (model year 1997-2007), the rear seat carried a higher risk of injury (RR = 1.98, CI = 1.90-2.06). Likewise, for older adults over the age of 50, the rear seat carried a higher risk of injury. Together, these results suggest that, for vehicle occupants over the age of 15, the front seat is safer than the rear seat. This study did not however report RRs as a function of crash mode. No conclusions were reported on RR in the frontal impact direction.

In [11] NASS-CDS data was also used in combination with Fatality Analysis Reporting System (FARS) data from years 2007-2012 to determine the risk of AIS3+ injury and fatality for restrained rear row occupants. The analysis used traditional logistic regression modelling and was limited to model year 2000 and newer vehicles. In the calculation of the RR of injury and fatality for rear versus front seats, the study only compared the right front seat occupant with all rear seat occupants. The argument for this methodology is that the front passenger position environment is more directly comparable to the rear seat environment due to the lack of a steering wheel/column. When all crash modes were combined, the RR of death was lower for restrained children up to eight years old in the rear compared with passengers in the right front seat but was higher for 9-12 year old children. There was no difference in the RR of death in the rear versus front seat for adult occupants aged 13-54. In newer vehicles (model year 2007 and newer), after controlling for occupant age and gender, the RR of death for restrained rear row occupants was significantly higher than that of front seat occupants. However, when investigating RR by impact direction, the study found no significant difference in the RR of fatal injury for rear versus front seats in frontal crashes (RR = 0.96, CI = 0.75-1.23).

In [12] the same matched-cohort analysis methods were used as in [9] but on a different dataset. This study investigated crashes involving injured rear versus front seat car passengers identified in linked police reports, hospitalisation records, and emergency department records in New South Wales, Australia, from years 2001-2011. Odds ratios (OR) were estimated using logistic mixed models. The study found that rear seat occupants sustained injuries of higher severity than front seat occupants travelling in the same vehicle (OR = 1.10, CI = 1.01-1.21). This study did not report on the overall difference in injury ORs of the rear versus front seat across crash modes, so no conclusions were presented solely for a frontal impact crash direction.

Current U.S. Regulation and New Car Assessment Programme

The chief U.S. standard governing the frontal crash mode is Federal Motor Vehicle Safety Standard (FMVSS) 208, Occupant Crash Protection [13]. One component of this standard prescribes front crash test procedures. FMVSS 208 prescribes a full frontal crash test in which the subject vehicle is impacted into a fixed, rigid concrete barrier at a velocity of approximately 56 km/h (35 mi/h) with 100% overlap. The standard specifies performance requirements for ATDs seated in the tested vehicle. Multiple impact tests are run in the same frontal configuration with different ATD arrangements. Both front seats, the driver and right passenger seat, are either occupied by two 50th percentile male or two 5th percentile female ATDs. In each of these two ATD configurations, FMVSS 208 specifies both belted and unbelted tests.

FMVSS 208 also prescribes an offset frontal impact test. In this test, the subject vehicle is impacted into a deformable barrier at a 40% offset at a velocity of approximately 40 km/h (25 mi/h). Subject vehicles can be tested on either the driver or passenger side. An instrumented 5th percentile female Hybrid III dummy is seated on the impacted side. For both this offset test and the previously described full frontal impact test, there is no standard stipulating ATD performance requirements in the rear seats.

The aforementioned 208 full frontal test configuration of impacting the subject vehicle into a fixed, rigid concrete barrier at a velocity of approximately 56 km/h at 100% overlap is the same configuration used to rate vehicles in a frontal impact condition as part of the current U.S. New Car Assessment Program (NCAP) [14,15]. However, in this NCAP test, only one ATD configuration is used. A 50th percentile male is seated in the driver's seat, and a 5th percentile female is seated in the right front passenger seat. Both ATDs are belted during the NCAP test. While this test does not currently evaluate rear seat occupant protection, NHTSA released a Requests for Comments (RFC) regarding changes to NCAP [16]. One of the proposed changes is to add a 5th percentile female Hybrid III ATD placed in the rear (second row) seat behind the right front passenger seat in the full frontal impact test.

Research Objective

Many of the previous studies suggest that the difference in injury risk between the front and rear seats is elevated in more recent model year vehicles but these studies were based on older crash data. The issue of relative rear seat safety has not been thoroughly investigated within the last decade. The *most recent* model year vehicles are not included in current literature. Therefore, the aim of this study is to use the most recent data available to quantify the difference in fatality risk for front and rear seated occupants in frontal passenger vehicle crashes.

II. METHODS

The following study is based upon data from the NASS-CDS and the FARS. NASS-CDS is a U.S. nationally representative database that comes from a clustered, stratified, and weighted sample of police accident reports (PARs) involving passenger vehicles (cars, light trucks, and vans) in which at least one involved vehicle was towed from the crash scene [17]. The weight assigned to each NASS-CDS case represents the number of actual PARs filed in the U.S. that year which are similar to the selected case. FARS on the other hand is a national census of motor vehicle crashes yielding fatality. Having absolute fatality counts from FARS is invaluable to fatality risk research and can greatly supplement the data collected by NASS-CDS.

For this study, cases were extracted from case years 1999-2015 (inclusive) from both databases. All cases fulfilling the following criteria are included for subsequent analysis:

- Case vehicle was a passenger vehicle (passenger car, minivan, sport utility vehicle (SUV), or pick-up truck) of model year 2000 or newer.
- Vehicle age at the time of the crash was ten (10) or fewer years.
- Frontal impact crash (selected based on the general area of damage variable in NASS-CDS and the initial impact direction variable in FARS).

The vehicle model year restriction of 2000 and later was imposed to help ensure that all vehicles in the resulting dataset were equipped with frontal airbags. Additionally, selected vehicles must have been within the most recent ten (10) model years relative to the crash year, as many crash details are not available in NASS-CDS for vehicles older than ten (10) years.

FARS data on occupants involved in selected cases were substituted for the weighted sample of comparable NASS-CDS fatal cases in order to produce a combined dataset of all occupants exposed to a frontal crash with exact fatality counts. This method has been used previously [11], as it is known that NASS-CDS underreports total fatality counts in its weighted sampling scheme [18]. Replacing NASS-CDS fatality cases with FARS fatality cases will increase the accuracy of our computation of fatality risk. When computing fatality risk estimates, the combined CDS-FARS occupant dataset will comprise the exposure, and the exact fatality counts from FARS will comprise the outcome.

Variables of interest in this study that may affect the risk of injury to occupants include occupant age, occupant gender, vehicle model year, and vehicle type. All of these variables were treated as categorical in this study. Occupant age was categorised into eight (8) groups: 0-3 years, 4-8 years, 9-12 years, 13-19 years, 20-39, 40-54 years, 55-74 years, and 75+ years. These were chosen both for consistency with previous studies and to reflect the age groups that are recommended for different restraint systems, such as different types of child restraint systems (CRSs). Vehicle model years were categorised as 2000-2002, 2003-2006, and 2007-2016. These model year categorisations were chosen to reflect the airbag technology present in case vehicles. Model year 2000-2002 vehicles were equipped with single stage airbags. Model year 2003-2006 vehicles reflect the phase in period for advanced, multi-stage airbags. By model year 2007, all vehicles were equipped with advanced airbags.

The intent of this study was in part to probe the effect that recent changes in vehicle restraint systems have had on injury risk. Therefore, occupants in this analysis were limited to those that were taking full advantage of a vehicle's safety systems by wearing their seatbelt. This includes children seated in a CRS.

Statistical Analysis

The combined CDS-FARS dataset was used along with logistic regression modelling to compute the relative risk (RR) of fatality for restrained rear vs. front seat occupants. RR was calculated between rear seat occupants and 1) all front seat occupants (both drivers and passengers), 2) drivers only, and 3) front passengers, i.e., nondrivers, only. The logistic regression model adjusted for occupant age, occupant gender, vehicle model year, and vehicle type. In the following results, odds ratios from logistic regression were reported as the adjusted RRs. Odds ratios are a good approximation of RRs when the outcome of interest is uncommon, as fatalities are in this study.

All analyses were performed in R and SAS v9.4. The combined CDS-FARS dataset retained the NASS-CDS sampling weights and set case weights in FARS to one (1) as FARS is a census database. All proportion (weighted %) and fatality risk analyses use these sampling weights, unless otherwise noted.

III. RESULTS

The resulting sample for analysis is provided in Table I. During the time period of study from 1999-2015, there were 27,698 observed (11,319,068 estimated) restrained occupants involved in frontal impact tow-away crashes from NASS-CDS. From FARS, there were 35,717 observed restrained occupants who sustained fatal injuries as a result of a frontal crash. An important occupant characteristic that is notably different between front and rear seat restrained occupants involved in frontal crashes is age. Since the introduction of airbags and CRSs, NHTSA and other public health agencies have strongly recommended that children should be seated in the rear row of vehicles in a CRS appropriate for the child's age and/or size [19]. This is reflected in the NASS-CDS occupant dataset, as over 60% of rear seated occupants were under the age of 13. In contrast, this age group makes up just over 1% of all front seated occupants. As expected, adults over the age of 20 comprise a vast majority of front row occupants at approximately 85%. However, adults make up a mere 19% of all rear seated restrained occupants experiencing a frontal crash. When looking at these age distributions in the fatally injured occupant population from FARS, adults over the age of 20 comprise almost half of those fatally injured in the rear seats. This is an indication that adults are over-represented in fatality outcome when rear seated. This may speak to the effectiveness of CRSs and is an early clue that the adult population may be at a disproportionately high risk of fatality when rear seated. Distributions of occupant sex and vehicle model year are much more consistent between both the front and rear seat occupant populations as well as the exposed and fatally injured occupant populations.

TABLE I
SAMPLE CHARACTERISTICS

	All Exposed Occupants from NASS-CDS observed (weighted %)		Fatally Injured Occupants from FARS observed (%)	
	Front Seat N = 24,147	Rear Seat N = 3,551	Front Seat N = 33,475	Rear Seat N = 2,242
Occupant Age				
0-3	11 (0.03)	735 (22.29)	28 (0.08)	390 (17.40)
4-8	91 (0.31)	800 (26.17)	80 (0.24)	341 (15.21)
9-12	225 (0.84)	458 (13.21)	82 (0.24)	158 (7.05)
13-19	2,877 (12.94)	683 (16.71)	2,139 (6.39)	286 (12.76)
20-39	10,980 (46.33)	546 (13.45)	10,253 (30.63)	289 (12.89)
40-54	5,229 (20.60)	128 (2.44)	6,775 (20.24)	143 (6.38)
55-74	3,566 (14.08)	111 (2.57)	8,635 (25.80)	319 (14.23)
75+	1,068 (4.40)	28 (0.53)	5,483 (16.38)	316 (14.09)
Unknown	100 (0.48)	62 (2.63)	-	-
Occupant Sex				
Male	11,938 (49.40)	1,686 (45.54)	19,914 (59.49)	970 (43.26)
Female	12,164 (50.45)	1,830 (53.97)	13,560 (40.51)	1,272 (56.74)
Unknown	45 (0.14)	35 (0.49)	1 (0.00)	0 (0.00)
Vehicle Model Year				
2000-2002	8,098 (32.33)	1,190 (35.36)	10,793 (32.24)	662 (29.53)
2003-2006	9,099 (36.60)	1,457 (37.91)	12,903 (38.55)	878 (39.16)
≥ 2007	9,288 (31.06)	10,556 (26.74)	9,779 (29.21)	702 (31.31)

Table II probes further into the sample of 2,242 restrained rear row occupants who were fatally injured in frontal impacts over the time period of study. Estimates of the risk of fatal injury for these restrained rear row occupants by age, sex, and vehicle model year are provided as well as the RR of fatality for rear vs. front row restrained occupants. For occupants up to the age of 39, it appears that there is a benefit in being rear seated in the event of a frontal collision, as the RR of fatal injury for the rear seats is significantly lower than one (1). However, restrained rear seat occupants aged 40 and older, especially those over 75, display a significantly higher risk of fatal injury than their younger counterparts. In addition, occupants over the age of 40 exhibit significantly greater risk of fatal injury in the rear seats than the front seats. Again, this is exceptionally higher for elderly occupants over the age of 75.

Perhaps more importantly, there is significant evidence that restrained rear row occupants in model year 2007 and newer vehicles are at a higher risk of fatality than front row occupants. Among restrained rear row occupants, the absolute risk of fatality varied slightly by vehicle model year, with the oldest model year vehicles appearing to have the lowest risk of fatality. To further probe into this model year effect on the risk of fatal injury in the rear seats, a logistic regression model was run all restrained rear seat occupants in the study sample controlling for occupant age, gender, and vehicle type. Odds ratios were calculated for each of the model year groupings, using model years 2000-2002 as the reference in order to compare the influence of each model year range on fatality outcome. Compared to model years 2000-2003, restrained rear seat occupants in vehicle model years 2003-2006 and vehicle model years ≥ 2007 have the same odds of fatality (OR 1.000, 95% CI 0.998-1.003). Therefore, there is no statistically significant difference in the odds of fatality for restrained rear seat occupants between vehicle model years, suggesting that the overall safety of the rear seat has remained static over time.

TABLE II

RISK OF FATAL INJURY IN FRONTAL IMPACTS FOR RESTRAINED REAR SEAT PASSENGER VEHICLE OCCUPANTS AND RELATIVE RISK (RR) OF FATALITY FOR REAR VS. FRONT SEAT RESTRAINED OCCUPANTS BY OCCUPANT AGE AND VEHICLE MODEL YEAR

Sample Characteristic	Risk of Fatal Injury in Rear Seat (95% CI)	Relative Risk (RR) of Fatal Injury (95% CI) for Rear Seat Occupants vs.		
		All Front Seat Occupants	Drivers	Front Seat Passengers
Occupant Age				
0-3	0.14% (0.13-0.15)	-	-	0.22 (0.15-0.34)
4-8	0.10% (0.09-0.12)	-	-	0.47 (0.37-0.61)
9-12	0.10% (0.08-0.11)	-	-	0.92 (0.70-1.20)
13-19	0.14% (0.12-0.15)	0.87 (0.77-0.98)	0.92 (0.81-1.04)	0.78 (0.68-0.90)
20-39	0.17% (0.15-0.19)	0.83 (0.74-0.94)	0.86 (0.77-0.97)	0.70 (0.62-0.79)
40-54	0.47% (0.39-0.55)	1.64 (1.38-1.92)	1.70 (1.44-2.01)	1.44 (1.21-1.72)
55-74	0.99% (0.88-1.10)	1.83 (1.64-2.05)	2.06 (1.84-2.31)	1.16 (1.02-1.31)
75+	4.54% (4.05-5.03)	4.07 (3.62-4.57)	4.70 (4.17-5.29)	3.02 (2.66-3.42)
Occupant Sex				
Male	0.17% (0.16-0.18)	1.08 (1.00-1.17)	1.18 (1.09-1.28)	1.06 (0.98-1.16)
Female	0.19% (0.18-0.20)	1.41 (1.32-1.50)	1.70 (1.59-1.81)	1.05 (0.98-1.12)
Vehicle Model Year				
2000-2002	0.15% (0.14-0.16)	1.03 (0.94-1.12)	1.20 (1.10-1.30)	0.77 (0.70-0.85)
2003-2006	0.19% (0.17-0.20)	1.24 (1.15-1.34)	1.44 (1.33-1.56)	1.04 (0.96-1.13)
≥ 2007	0.21% (0.19-0.23)	1.65 (1.51-1.79)	1.84 (1.69-2.00)	1.58 (1.44-1.74)

When looking back at the calculated RRs in Table II, in the oldest model year vehicles with single stage airbags, model years 2000-2002, the front and rear seats pose a similar fatality risk (RR 1.03, 95% CI 0.94-1.12). However, during the phase-in of advanced airbags in model years 2003-2006, a difference in fatality risk arises, with a greater RR of fatal injury being seen in the rear seats (RR 1.24, 95% CI 1.15-1.34). The trend continues when looking at the newest model year vehicles where the RR of fatality becomes even higher in the rear seats (1.65, 95% CI 1.51-1.79). These findings are statistically significant and clearly show that the RR of fatal injury for rear vs. front seat occupants has been increasing in newer model year vehicles. Recall the finding shown in Table III that the risk of fatality in the rear seat is the same for all vehicle model years. When considered jointly, these findings illustrate that the increase in RR of fatality for rear vs. front seat occupants is due to a lower fatality risk in the front seat – a sign of improved safety – rather than an increased risk in the rear. Finally, across all sample characteristics, the estimate of RR of fatal injury among rear seat occupants versus drivers is notably higher than the estimated risk for rear seat occupants versus front seat passengers.

IV. DISCUSSION

It is clear from these results that children remain better protected in the rear versus front seats, displaying a lower risk of fatality in the rear seat than the front. Though occupants aged 39 and under benefit from being rear seated in a frontal crash, quite the contrary is true for their older counterparts. Older occupants (40+ years) are at a significantly higher RR of fatality when rear seated, and this difference in rear versus front seat fatality risk is much more exaggerated in the elderly population (75+ years).

Though the absolute risk of fatality in the rear seat appears to be slightly lower in the oldest vehicle model year category of 2000-2002, the odds of fatality among model year groupings for all restrained rear seat occupants in our study sample showed no statistically significant difference. This finding suggests that the overall safety of the rear seat has remained static across all model year vehicles.

The results of this study further show that the RR of fatality for a restrained occupant involved in a frontal collision in a rear versus front seating position has significantly increased in newer model year passenger vehicles compared to older ones. Since it is shown that the risk of fatality in the rear seat is not changing with time, this difference in risk must be a result of improved safety and subsequent reductions in fatality in the front seats. These findings are consistent with prior research and continue to highlight the growing disparity in the crash protection afforded to occupants of front and rear rows of passenger vehicles. Current U.S. occupant protection regulation in a frontal impact condition (FMVSS 208) and the forward crash NCAP test do not consider the safety of occupants seated in the rear. This appears to be reflected in many current vehicle designs. For example, seatbelt reminders, pretensioners, and load limiters are all nearly standard equipment in the front seats of new vehicles today. However, in the U.S., these technologies are seldom carried into the rear seats.

This issue of disparate front versus rear seat safety is not unique to the U.S. vehicle fleet. In an effort to better restraint systems in the rear seats, the Euro NCAP added a frontal full width rigid barrier test in 2015 [20]. In this test, the subject vehicle is impacted into a rigid barrier at a velocity of approximately 50 km/h (31 mi/h) with 100% overlap. The rating earned considers performance requirements for two 5th percentile female dummies – one seated in the driver's seat and one seated in the rear passenger side (right side) seat. Just two years later in 2017, of the 51 new model year vehicles tested by Euro NCAP, 48 (94%) of the new vehicles had rear seat pretensioners and load limiters as standard equipment [21]. By contrast, in the U.S. in 2013, the National Transportation Safety Board (NTSB) reported that only 11 of the 35 (31%) common vehicle brands offered rear seat pretensioners and load limiters as either *optional* or standard equipment [22]. Currently, the U.S. NCAP is entertaining the idea of including a rear seated 5th percentile female Hybrid III dummy and corresponding injury criteria as part of their frontal crash test rating system [15,23].

V. CONCLUSIONS

In newer model year passenger vehicles, the relative risk of fatality for a restrained occupant involved in a frontal crash is higher in the rear than the front seats. This appears to be an issue primarily for adults aged 40 and over, with a huge increase in risk for those over the age of 75. Children under the age of 13 – who comprise a majority of rear seated occupants – continue to experience a great safety benefit in the event of a frontal crash by being rear seated. These results agree with previous studies and continue to highlight the challenge in implementing rear seat occupant protection systems that benefit all ages. Overall, passenger vehicle passive safety improvements have greatly improved over the last couple decades, but the increase in RR in newer model year vehicles found here shows that rear seat occupants are not experiencing the same benefit as front seated occupants. Implementing the advanced restraint systems currently commonplace in the front seats into the rear row(s) of passenger vehicles would be a great first advancement to rear seat restraint systems.

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