Opportunities for Protecting the Right Front Passenger in Frontal Crashes

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ABSTRACT

This paper explores opportunities to better protect belted right front passengers during frontal crashes. Paired comparisons of using NASS CDS 2000-2007 data showed that, across all ages and genders, belted passengers carried a 34% higher serious injury risk than belted drivers. In an effort to explain this difference, we explore crash configurations where right front passengers most often sustain serious injuries. We also identified primary attributes of right front passengers including age and weight to determine how they differ from drivers when serious injuries occur.

When involved in the same crash, right front passengers more often sustain MAIS3+ injuries compared to drivers. However, there are fundamental differences between these populations. First, a higher percentage of right front occupants are injured during angled collisions with a 1 o'clock principle direction of force. These crashes are more serious for occupants seated on the nearside or passenger side of the vehicle. Often these crashes occur at intersections where the struck vehicle initiates a turn.

A second reason for this difference in risk is principally due to the presence of occupants in the passenger location who are more vulnerable to injury than the driver. While only 1 in 10 right front seat occupants involved in frontal crashes are age 65 and older, the elderly population makes up more than 1/3 of the MAIS3+ injured group. When both front seat occupants are elderly, the most vulnerable in terms of age or gender is in the passenger position 85% of the time. The GES data showed that when two elderly occupants (age 65+) were present, the female occupied the right front passenger position 73% of the time.

Analysis of NASS GES data suggests that, when an elderly male occupies the passenger seat he is frequently older than the driver. When investigated further, there was no significant difference in the fatal injury risk of young belted drivers and young belted right front passengers in frontal crashes.

INTRODUCTION

An earlier study found that when both driver and right front passenger were elderly, the right front passenger was more likely to have a lower injury tolerance [Augenstein 2008]. It was noted that the right front passenger has more ride-down room than the driver. Consequently, the safety system for the right front passenger could utilize the additional distance and be more benign than for the driver. The earlier study focused primarily on the needs of the elderly right front passenger. This study is intended to examine the needs of a wider range of belted right front occupants involved in frontal crashes.

Numerous studies have shown higher vulnerability to injury and death for older occupants involved in motor vehicle crashes [Augenstein, 2001; Fildes, 1991; and Mackay 1994, 2001]. Other studies of gender differences indicate that females, like older occupants, are more vulnerable to injury than males of the same age [Lenard 2001; Welsh, 2001]. Evans found that the same physical insult was three times more likely to fatally injure a 70 year old compared with a younger person age 15 to 45. He further showed that women age 15 to 45 were 25% more likely to be killed from a similar physical insult than their male counterparts [Evans 2001, 1991].

Studies of serious injuries by body region for restrained occupants in frontal crashes have shown that for belted occupants age 65+, the chest is the body region most frequently injured at the MAIS 3+ level [Augenstein, 2005]. Similar results were found for belted fatally injured older drivers in frontal crashes [Kent, 2005].

Earlier studies examined changes in chest injury propensity using cadaver testing and found a significant decrease in injury tolerance by age [Zhou, 2001]. For frontal crashes, belt loading was found to more significantly increase the risk of injury compared with loading by air bags. When compared to 16-35 year old occupants or the "young" group, the chest injury threshold for bag loading was reduced to 84% for the 36-65 year old age group and to 79% for the 66-85 year old age group. For belt loading, the reduction was to 47% for the 36-65 year old age group and to 28% for the 66-85 year old age group.

Recent evaluations of NASS CDS data identified that for a given stature, an obese occupant (BMI ≥30) has a 97% higher risk of fatality and 17% higher risk of MAIS3+ injury compared to occupants with a normal Body Mass Index (BMI) [Viano 2008]. The Viano study applied a matched pair methodology controlling for occupant age and gender however safety belt usage and crash type were not considered. A study by Mock et. al. (2002) similarly found that the risk of fatal injury increased 1.013 (95% CI: 1.007, 1.018) for each kilogram increase in body weight. This study controlled for age, gender, seatbelt use, seat position and vehicle curb weight.

Earlier research supports the thesis that females and older occupants of both genders could benefit from restraint systems that apply forces at lower levels than the force allowable for young males. However, restraints design must also adequately treat a population of occupants whose weight is steadily increasing.

METHODS

The 2000-2007 National Automotive Sampling System, Crashworthiness Data System (NASS CDS) data was used to compare the relative injury risk of belted drivers and right front passengers during frontal crashes. The analysis included restrained occupants involved in frontal crashes by crash severity, gender and age. Subsequently, a comparison of the occupancy of the driver and right front passenger seats by gender and age was made using General Estimates System, GES (2003-2005), data to better understand the demographics of right front seat occupants. We also explored NASS CDS data to further compare differences in driver and right front passenger size for those who are injured and uninjured.

For the NASS data analysis, frontal crashes were defined as any crash where the principal direction of force (PDOF) was 1, 11, or 12 o'clock or the PDOF was 10 or 2 o'clock with the highest deformation location coded as front (F). Typically, crash severity is determined using the coded change in velocity or deltaV. For those cases where delta-V was missing, the NASS researcher supplied estimated delta-V was used. These estimates are available for those cases where delta-V cannot be accurately computed during crash reconstruction. Estimated delta-V values can be partitioned into 3 categories which are 0-15 MPH, 15-25 MPH and 25+ MPH.

The NASS database provided 23,124 raw cases of belted front seat occupants 16 and older exposed to frontal crashes with known or estimated delta-V. Of these occupants, 2,437 suffered MAIS 3+ injuries. When weighted, these cases expanded to 11,768,366 occupants with 189,034 MAIS 3+ injured. Table 1 shows the population of drivers and right front passengers used in the analysis.

Overall, few differences exist in the attributes shown in Table 1 comparing driver crash distributions with those of right front passengers. In terms of crash severity (deltaV), vehicle type and age, the distributions are similar. As discussed in more detail below, the NASS CDS reflects the fact that more females ride in the right front passenger seat while more males are driving when a tow-away crash occurs.

Table 1. Crash exposure of belted front seat occupants involved in frontal crashes (source: NASS CDS 2000-2007)

Front Seat Occupant Category	Drivers		Right Front Passengers	
	Count	%	Count	%
All	9,414,686		2,350,643	
	80%		20%	
DeltaV (mph)				
0-14	5,993,720	64	1,574,201	67
15-24	3,091,409	33	720,926	31
25+	305,898	3	55,516	2
Vehicle Type				
Cars	6,463,688	68	1,574,813	67
SUVs	1,185,574	13	294,122	14
Pickups	1,111,366	12	292,366	12
Vans	614,111	7	188,699	8
Age Group				
16-34	4,965,589	53	1,068,143	54
34-65	3,547,415	38	708,879	36
65+	792,518	9	186,784	10
Gender				
Male	5,078,752	54	989,060	43
Female	4,252,315	46	1,324,584	57

Conversely, Table 2 identifies a few key differences between crashes where drivers are injured and those where right front passengers are injured. Fewer injured right front passengers are pickup truck occupants while a higher proportion ride in cars. When a passenger is injured, Table 2 indicates that higher proportions are age 65+. Seventeen percent (16%) of drivers who sustain an MAIS3+ injury were age 65 and older while over 31% of right front passengers fell into this category. Sixty nine (66%) of injured right front passengers are females compared to only 47% of injured drivers.

Table 2. MAIS3+ injury counts for belted front seat occupants involved in frontal crashes (source: NASS CDS 2000-2007)

MAIS3+ Injured Occupant Category	Drivers		Right Front Passengers	
	Count	%	Count	%
All	156,630		32,404	
	82.9%		17.1%	
DeltaV (mph)				
0-14	30,024	19	5,766	18
15-24	68,657	44	14,527	45
25+	57,949	37	12,111	37
Vehicle Type				
Cars	108,429	69	23,418	72
SUVs	19,125	12	3,504	11
Pickups	20,725	13	2,695	8
Vans	8,260	5	2,753	9
Age Group				
16-34	59778	38	10,185	35
34-65	71,138	45	9,868	34
65+	25,495	16	8,881	31
Gender				
Male	82,759	53	10,943	34
Female	73,871	47	21,435	66

Matched Pair Analysis

In order to evaluate the difference in MAIS3+ injury risk for passengers relative to drivers while controlling for the influential factors identified above, a matched pair analysis using NASS CDS 2000-2007 data was performed. Only those belted drivers involved in frontal crashes with a belted right front passenger present at the time of the crash were retained. In total 11,066 unweighted occupant pairs representing 2,350,643 weighted occupant pairs were available for evaluation.

To adequately treat the stratified sampling design of NASS CDS, odds ratio estimates, standard errors and 95% confidence intervals (95% CI) were calculated using Stata Software Version 9.0 (Stata Corporation, 2005).

Odds of right front passenger injury are 34% higher than drivers for belted occupants in frontal crashes. When the sample was further stratified by PDOF, for the risk of MAIS3+ injury for right front passengers it was not statistically different than drivers for 11 or 12 o'clock crashes when age, gender and crash deltaV are controlled for. However, the effect for 1'oclock PDOF crashes is significant having a 2.43 times higher risk of MAIS3+ injury for right front passengers compared to drivers.

The odds of serious injury for female right front passengers relative to female drivers is 1.39 (95% CI: 1.13, 1.69). For elderly passengers versus elderly drivers, the odds of injury were substantially higher at 1.89 (95% CI: 1.29, 2.78).

Table 3. Odds ratios based on matched pairs analysis- Odds of MAIS3+ injury for belted right front passengers in frontal crashes compared with drivers (NASS CDS 2000-2007)

Category	Odds Ratio (95% Conf. Limits)
All Frontal Crashes	**1.34 (1.16, 1.55)**
11 o'clock PDOF	0.86 (0.62, 1.19)
12 o'clock PDOF	1.20 (0.96, 1.50)
1 o'clock PDOF	**2.43 (1.76, 3.36)**
Female Passengers	**1.39 (1.13, 1.69)**
Elderly Passengers	**1.89 (1.29, 2.78)**

Crash configurations for two vehicle crashes where drivers and right front passenger sustain MAIS 3+ injuries are shown in Figure 1. This plot shows results for the crashes used for the matched pair analysis so that the population of crashes where a right front passenger was present is identical to those for the drivers in terms of deltaV, vehicle type and crash configuration. The non-collision category indicates a single vehicle crash event has occurred.

Overall, drivers more often sustain injuries during head on collisions with other vehicles. Right front passengers are injured more frequently than drivers during angled collisions. The vast majority (more than 88%) of angled crashes where right front passengers were injured occurred while turning or at intersections.

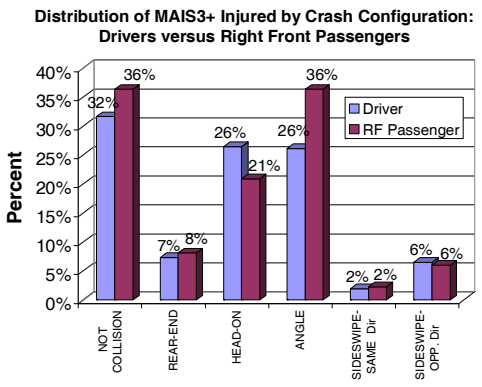

Figure 1. Comparison of crash configurations where drivers and right front passengers sustained one or more MAIS3+ injuries (for crashes where both occupants were present).

Figure 2 shows the distribution of injured occupants by seating position and specific PDOF for the frontal crash event. As mentioned above, right front passengers are more frequently injured in angled collisions associated with turns at intersections supporting the elevated frequency of injuries where the PDOF of the primary impact was 1 o'clock.

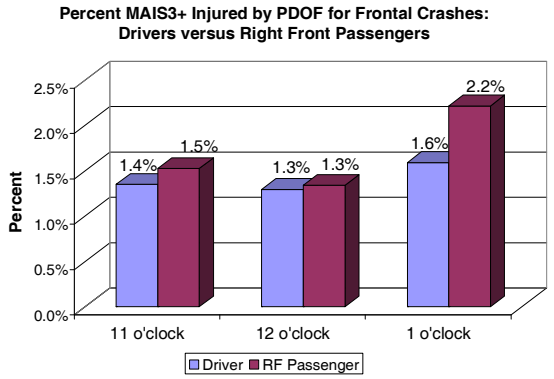

Figure 2. Comparison of primary impact PDOF where drivers and right front passengers sustained one or more MAIS3+ injuries (for subset of crashes where both occupants were present).

Figure 3 indicates that a higher proportion of right front passengers sustaining MAIS3+ injuries are age 65 and older than in the driver position. Although only 10% of tow-away crash involved right front seat occupants are age 65 and older as shown in Table 1, more than 35% of those who sustain one or more MAIS3+ injury are age 65+. For drivers, the proportion of occupants age 65 and older who sustain MAIS3+ injuries is 16% while the driver position is occupied by those 65 and older 9% of the time.

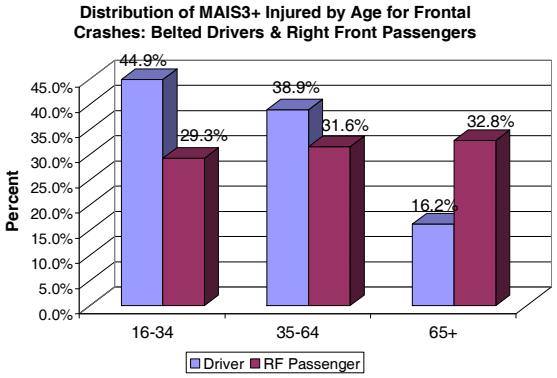

Figure 3. Distribution of occupant ages where driver or right front passenger was MAIS3+ injured (for subset of crashes where both occupants were present).

Figure 4 indicates 16% of adult females seated in the right front passenger seat during any NASS CDS crash were similar in weight to the 5th Percentile Female Dummy (the 5th percentile female weighs 46.7 kg or 102 lbs). A total of 41% were slightly heavier than the 5th Percentile female yet lighter than the 50th Percentile Male dummy. Overall, the 5th percentile female does not represent female occupants most often seated in the right front position well.

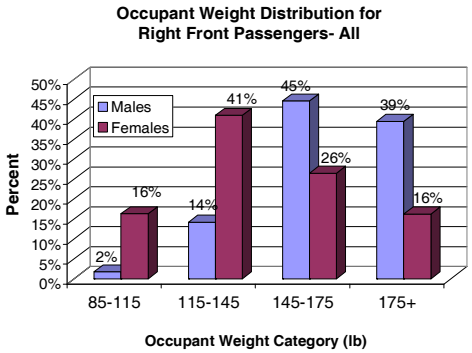

Figure 4. Occupant weight distributions for all NASS CDS crashes.

Within the MAIS3+ injured population, shown in Figure 5, increased percentages by weight for all categories for both males and females can be seen. It should be noted that Figure 5 includes only belted right front passengers involved in frontal crashes while Figure 3 includes the complete NASS CDS population.

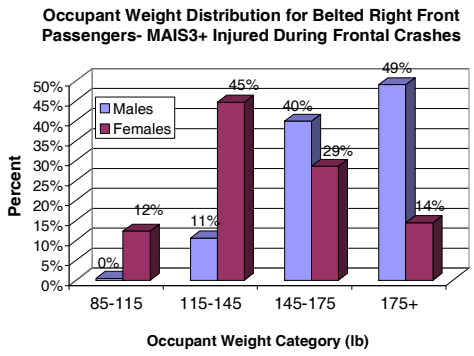

Figure 5. Occupant weight distribution for MAIS3+ injured, belted right front passengers in frontal crashes.

General Estimates System (GES)- Seat Occupancy

Figure 6 shows the distribution of occupants by seating position based on NASS GES data. This data was reviewed to understand frequency of front seat occupancy by age and gender. The subpopulation reviewed includes police reported, crash involved vehicles where the driver and passenger seat were occupied. The analysis considers both injured and non-injured occupants. There were 153,936 unweighted pairs of occupants included representing 1,556,533 drivers in crashes from 2000-2007. Figure 6 shows the percent of crashes where a female driver or male driver was accompanied by a female passenger or male passenger. This data suggests that overall, female passengers occupied the passenger seat during 56% of the crash events.

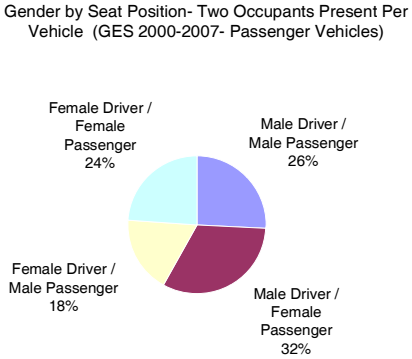

Figure 6. All occupants by seating position (GES 2000-2007).

Figure 7 indicates that, when both front seat occupants were 65 and older, a female occupied the right front passenger seat 73% of the time. Both driver and passenger were elderly males in 10% of these cases.

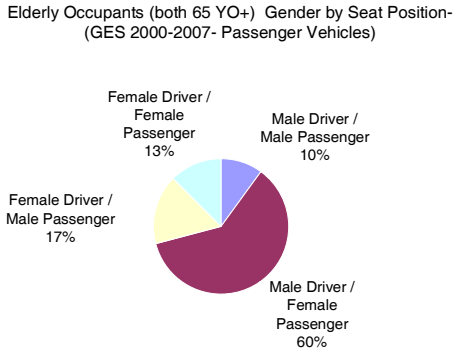

Figure 7. Elderly occupants by seating position (GES 2000-2007).

DISCUSSION

In this study, the risk of MAIS3+ injury was compared for right front passengers and drivers using matched pairs analysis. Crashes where both the driver and right front passenger were present and restrained were retained.

Fundamental differences in crash configurations appear to impact the frequency that right front passengers are injured. As may be expected, the right front passenger is much more likely than the driver to be injured in a 1 o'clock crash. When examining the 11 o'clock crash the driver would be expected to have a higher risk. However, the driver's increased risk was not statistically significant. The right front passenger's increased frequency of injuries is further illustrated in Figures 1 and 2. The energy absorbing steering column may provide some benefit to the driver in the angular collision that is absent for the right front passenger. Further, compartment intrusions at the right front passenger position could impact injury risk. This result suggests the need to provide some additional protection to the right front passenger in the 1 o'clock frontal angular collisions.

Table 2 shows the predominance of females and elderly females among right front passengers with MAIS 3+ injuries.

The analysis of GES (Figures 7 and 8) indicates that, when all ages are considered, 56% of the right front passengers are female. In NASS CDS, 57% of the right front passengers in tow-away crashes are female. However, when examined by age, the female occupancy rate increases dramatically for older occupants. GES (Figure8) shows that when both

front seat occupants were 65 and older, a female occupied the right front passenger seat 73% of the time. This result is consistent with NASS data that shows that among right front passengers age 65 and older, 81% are female. For age 50 and older, the percentage of female passengers in NASS remains about the same.

An earlier study using paired comparison analysis of FARS for belted drivers and right front passengers showed that when all ages of occupants were considered, the passenger position had a slightly higher risk of being fatally injured [Augenstein 2008]. There was no difference in the risk when both occupants were young. However, when both occupants were 65 and older, the odds ratio for the passenger was much higher – 1.42. This result further supports the hypothesis that when elderly occupants occupy both front seats, the most vulnerable to injury is the passenger, not the driver.

It is interesting to examine the injuries and fatalities that occur to belted elderly occupants in the lower severity crashes. An earlier study found that 58% of the frontal crash fatalities among belted front seat occupants aged 65+ occurred in crashes less severe than 25 mph [Augenstein, 2006]. The earlier paper showed that, for an elderly occupant, sustaining an MAIS 3+ injury carries a much higher risk of death compared with the same injury in a younger occupant. The paper suggested that reductions of chest injuries in lower severity frontal crashes offered a large opportunity for improvement.

Figure 3 shows the weight distribution for injured males and females in the right front occupant position. The distribution suggests the need for tests with a dummy heavier than the 5th percentile female. It also suggests the need to tailor the restraint system for both the weight of the occupant and the severity of the crash.

These results suggest that an opportunity exists for providing age, weight and gender appropriate restraint systems for the right front passenger. These restraint systems could be more focused on reducing the forces on the body in low severity crashes while maintaining the current level of safety in high severity crashes.

CONCLUSIONS

Occupants of the right front passenger position have different restraint needs compared with the driver. The NASS paired comparison analysis indicates that the right front passenger is more vulnerable to frontal angular crashes than the driver. Additional protection for the 1 o'clock angular crash would be beneficial.

The right front passenger is more likely to have a lower injury tolerance than the driver. This difference suggests the need for a more benign restraint system. However, occupants of the right front passenger position exhibit a wide range of sizes. The broad population suggests the need for tests with a variety of dummy sizes.

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