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Paired vehicle occupant analysis indicates age and crash severity moderate likelihood of higher severity injury in second row seated adults in frontal crashes

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ABSTRACT

The majority of advances in occupant protection systems for motor vehicle occupants have focused on occupants seated in the front row of the vehicle. Recent studies suggest that these systems have resulted in lower injury risk for front row occupants as compared to those in the second row. However, these findings are not universal. In addition, some of these findings result from analyses that compare groups of front and second row occupants exposed to dissimilar crash conditions, raising questions regarding whether they might reflect differences in the crash rather than the front and second row restraint systems. The current study examines factors associated with injury risk for pairs of right front seat and second row occupants in frontal crashes in the United States using paired data analysis techniques. These data indicate that the occupant seated in the front row frequently experiences the more severe injury in the pair, however there were no significant differences in the rate of occurrence of these events and events where the more severe injury occurs in the second row occupant of the pair. A logistic regression indicated that the likelihood of the more severe injury occurring in the second row seated occupant of the pair increased as crash severity increased, consistent with data from anatomic test dummy (ATD) tests. It also indicated that the second row occupant was more likely to have the more severe injury in the pair if that occupant was the older occupant of the pair. These findings suggest that occupant protection systems which focus on providing protection specifically for injuries experienced by older occupants in the second row in higher severity crash conditions might provide the greatest benefit.

1. Introduction

For many years Federal Motor Vehicle Safety Standards (FMVSS) have focused on protecting occupants seated in the front row of passenger vehicles. This focus reflects the high occupancy rate for the front row and older field data that indicated a higher injury risk for front row occupants versus persons in the second row (Smith and Cummings, 2004). More recently, studies have suggested an unintended consequence of this regulatory focus. In 2005 Kuppa et al. (2005) performed high speed frontal impacts using matched front and second row Anatomic Test Dummies (ATDs). These tests, in a range vehicles produced in 2004 (i.e. 2004 model year (MY)), indicated that injury risk may be higher for occupants seated in the second row as compared to similar occupants seated in the front row, when exposed to crash simulations at 56 km/h (Kuppa et al., 2005). These findings were noted for 50th percentile (average) male, 5th percentile (small) female and 6 year old ATDs where the measures used to assess the risk for head and neck injury in ATDs were higher than commonly used injury threshold values. Similar trends were noted for a small female ATD in the second row of a Japanese sedan (Mizuno et al., 2007).

In addition to crash tests with ATDs, research groups have utilized field data to document injury and fatality risks for second row occupants. Fatal crash data from frontal crashes in the 2000–2009 Fatal Accident Reporting System (FARS), which documents every fatal crash occurring in the United States each year, suggested that the protective effect offered by second row seating diminished in vehicles produced in 2000–2009 when compared to those produced in 1990–1999 (Sahraei et al., 2010). This finding was also reflected in a study of crashes documented in the National Automotive Sampling System—Crashworthiness Data System (NASS-CDS) where the risk of moderate injury (Maximum Abbreviated Injury Score or MAIS ≥2) for second row occupants increased significantly between groups of 1996–1999 model year (MY) and 2000–2006

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MY vehicles for occupants of age 15–50 years (Esfahani and Digges, 2009). The abbreviated injury scale (AIS) system provides a score from 1 to 6 for injuries, with cuts and bruises rated 1 (minimal threat to life) and unsurvivable injuries rated 6. A long bone fracture is an exemplar AIS 2 injury. The maximum AIS or MAIS is the AIS rating for a person's most severe injury, which provides a rough estimate of a person's overall injury level.

Beyond the reduction of the protective effect of second row seating, analysis of fatal crash data analysis went further, to find that persons over 25 years of age were at a significantly lower risk of fatality in a frontal crash when seated in the right front seat versus the second row (Sahraei et al., 2010). On the other hand, in frontal crashes documented in the NASS-CDS, Esfahani and Digges (2009) found that restrained occupants had a *higher risk* of experiencing a moderate injury (MAIS $\geq$ 2) when seated in the right front seat versus the second row. These NASS-CDS crashes document conditions for a nationally representative sample of crashes where at least one vehicle was towed due to damage. This sample therefore includes a range of crash severities, which may explain the apparently conflicting trends in the findings. For example, the lower severity crashes may present a different relative risk of injury versus the fatal and presumably more severe crashes. On the other hand, the difference could be due to vehicle design changes over time.

When the NASS-CDS frontal crash injury data for occupants in a 15–50 year old age group was subdivided into model year groups, Esfahani and Digges (2009) found that occupants in vehicles produced prior to 2000 were significantly less likely to have moderate to fatal injuries when seated in the second row. For later years there was a lower injury risk for second row occupants, but this protective effect was no longer large enough to be statistically significant. A later study of NASS-CDS crashes re-examined injury risk by seating row, but broadened the study scope to include all crash types. This study created a matched cohort of restrained front and second row occupants in 1993–2007 crashes (Bilston et al., 2010) and used group means to find that the relative risk of serious injury (risk of MAIS $\geq$3 injury in the second row relative to the front row) increased for newer model year groups and that adult occupants were at higher risk for these injuries when seated in the second row. Durbin et al. (2015) examined more recent vehicles (model years 2000–2013) using a combined NASS and FARS data set that included frontal, side, rear and rollover crashes. They found that the difference in injury risk for adults (age $\geq$13 years) was not different between the front right and second row seating positions. However, when they controlled for occupant age and gender in the analysis, they found that the risk of fatality was significantly higher for second row occupants, as compared to front row, in vehicles produced in 2007 and later. On the other hand, each of these studies (Bilston et al., 2010; Esfahani and Digges, 2009; Durbin et al., 2015) noted that younger occupants still enjoyed a protective effect from second row seating.

In a 10-year set of crashes from Australia, Mitchell et al. (2015) utilized a matched cohort of front and rear seat occupants to identify age, model year, airbag deployment and roadways with higher speed limits as contributing to a higher likelihood of the rear seat occupant experiencing the more serious injury in the pair.

While the earlier studies findings are compelling, most based their analysis on compared risk between cohorts of occupants created by grouping based on characteristics (i.e. vehicle model year) rather than examining within vehicle/crash comparisons. In the studies using front and second row pairs, the front and second row occupants were grouped separate from one another and compared. These data therefore provide an estimate of the average risk rather than a within crash comparison of risk between like occupants exposed to like conditions. In addition, there are several questions that remain open. Earlier studies (Durbin et al., 2015; Bilston et al., 2010) compared injury levels for second row seated occupants to either driver or right front occupant, where one might expect to find different injury risks and patterns between the right front and driver due to the presence of the steering wheel and foot controls (Chen and Gabler, 2014; Ye et al., 2015). If one were to consider risk factors for injury to restrained second row occupants, comparisons to the restrained/airbag protected right front occupant should provide a clearer comparison. Some of the studies (Bilston et al., 2010; Durbin et al., 2015) created cohorts that included different types of crashes, mingling side impacts and rollovers with frontal crashes. One might expect the injury risk for occupants in a side impact crash to be strongly influenced by whether that occupant was seated on the struck or far side of the vehicle (Viano and Parenteau, 2010), which was not controlled. One might also expect that occupant injury risk in a rollover will be influenced by the severity of the rollover and the proximity of the occupant's head location to the vehicle's roof (Strashny, 2007). These broad crash groups also make the study findings difficult to compare to prior studies restricted to frontal crashes. The concern of how to draw conclusions across multiple crash types is furthered by data gathered by Hanna and Hershman (2009) who found that the risk of thoracic injury increased with age and was higher in side impact versus frontal crash for older occupants. Further, none of the prior studies employ statistical methods which account for the effect of pairing between their front and second row occupants. The cohorting of occupants might mask crash and vehicle related factors that may make significant contributions to injury risk. A final concern with previous work is that it appears that ejected occupants were not excluded. The injury producing environment therefore was not strictly restricted to the vehicle environment. On the other hand, Kuppa et al. (2005) ATD data most clearly indicates a difference in injury risk, as this utilized the same ATD in front and second row in the same crash.

When examining field data it is likely to be important to match environmental (crash) characteristics and occupant characteristics to clarify whether there is a difference in protection between the front and second row or whether the differences are due to other factors such as different injury tolerance in occupants or different vehicle or crash environments. Beyond occupant age, it is unclear what vehicle or occupant factors are associated with second row injury risk exceeding that of the front row. Examining these questions will help identify at-risk occupants and conditions. The current study seeks to compare injury risk for pairs of restrained adult second row occupants and restrained adult front row passengers in the same frontal crash in recent model year vehicles.

2. Methods

Frontal crash cases were obtained from NASS-CDS years 2008–2014. As crashes can be multi-modal, including several impacts or rollover (which may proceed or follow an impact), several crash descriptors were used to segregate frontal crashes for inclusion in this study. Frontal crashes were defined as those that involved a primary crash force direction corresponding to 11:00–1:00, where 12:00 would indicate an impact force directed perpendicular to the vehicle's front (NASS variable identifier "direction of force" (DOF1 = F)). Within these frontal force cases, only those that involved a primary damage location of "frontal" (NASS variable identifier "general area of damage" (GAD1)) were included. Any cases involving a rollover were excluded. Passenger vehicles with model years older than 2000 were excluded. The inclusion/exclusion criteria used to generate the data set are described in Table 1.

The upper portion of Table indicates the NASS-CDS variables used to as criteria for inclusion in the study (i.e. a crash defined dam-