REAL WORLD ANALYSIS OF REAR SEAT OCCUPANT SAFETY IN FRONTAL CRASHES

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ABSTRACT

The National Highway Traffic Safety Administration's (NHTSA) Vehicle Safety Rulemaking and Research Priority Plan 2009 – 2011 describes the projects the agency plans to work on in the rulemaking and research areas in those calendar years. Specific programs identified in the plan included research to improve vehicle safety for rear seat occupants, children, and older people.

In support of the priority plan, an analysis of real-world crash data was conducted to determine the nature of the crash problem and examine the factors that contribute to rear seat occupant injury, including children and older people. A review of the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) and Crash Injury Research and Engineering Network (CIREN) case data was conducted for restrained rear seat occupants in frontal crashes that sustained an Abbreviated Injury Scale (AIS) 3+ injury in 1998 model year and newer vehicles. For each occupant identified, a review of the accompanying investigation was conducted using a methodology similar to that described by Bean *et al*. [2009]. The authors were then able to identify occupant and crash characteristics associated with rear seat occupants commonly sustaining serious injuries in frontal crashes. For each occupant, a primary cause of the most severe injury was assigned and injury sources were identified. This review suggests that in the absence of overly severe frontal crash conditions and vulnerabilities due to advanced age, properly belted adults and children in age- and stature-appropriate child restraints are reasonably well-protected in the rear seat, although improvements could be achieved in some cases.

INTRODUCTION

Fatal crashes decreased by 9.9 percent from 2008 to 2009, and the fatality rate on U.S. roads has dropped to 1.13 per 100 million vehicle miles of travel. The injury rate per 100 million vehicle miles of travel decreased 6.3 percent from the previous year as well [NHTSA, 2010]. While many factors contribute to the reduction in the rate of injurious and fatal crashes, improvements in occupant protection are likely responsible for a sizeable portion of the long-term reduction. Front-row occupant protection in frontal crashes has benefited from recent developments in restraint performance and vehicle crashworthiness, which have been driven partly by manufacturers' efforts to improve vehicle scores in consumer information tests. Sherwood et al. reported in 2009 that 95% of the 2008 model year cars earned four or five stars in NHTSA's New Car Assessment Program and 91% earned the highest frontal crashworthiness rating from the Insurance Institute for Highway Safety. While much of the improvement in performance can be likely linked to improved frontal structures, the restraint systems for the occupants tested in those programs have improved as well. Kent *et al*. [2007] reported steadily increasing availability of seat belt pretensioner and force-limiting mechanisms, which, at the time, were nearing universal availability in the fleet. Since these advanced restraint technologies have typically been installed only in the first row, where their inclusion helps to improve test scores, occupants in the rear seating area have not seen the same benefits as their front seat counterparts.

Many recent studies have focused on the protection offered to rear seat occupants involved in frontal crashes. Some of these studies have found that, for some occupants, rear seating positions are associated with higher injury and fatality risk than front row seating positions. Earlier studies, such as that by Evans and Frick [1988], suggested that rear seat occupants had 30 to 38 percent lower fatality risk compared to front seat occupants. When occupant age was considered, Kuppa *et al*. [2005] found that occupants younger than 50 years of age were more protected in the rear seat, but those above 50 years of age saw greater protection in the front seat. That same study included an analysis of frontal barrier crash data, which indicated that the rear seat dummies in 2004 model year vehicles experienced higher head and neck injury measures compared to the front seat dummies. An analysis of the 1991 through 1998 NASS-CDS by Parenteau and Viano [2003] identified teenage and adult occupants restrained by a lap and shoulder belt in the rear primarily experienced injuries of the thorax related to the shoulder belt. In a follow up study of the 1991 through 1999 NASS-CDS, Parenteau and Viano [2003b] identified head and extremity injuries were the body regions with the most frequent serious injuries (AIS 3+) from interior contact for 4-12 year old occupants in the rear restrained in a lap and shoulder belt.

More recently, Kent *et al*. [2007] concluded that rear seat occupants in newer vehicles were less effectively protected than front seat occupants, which they attributed to a relative decline based on increased effectiveness in the front seating positions due to the inclusion of advanced restraints in the newer vehicles. Bilston *et al*. [2010] explored this further by conducting a matched-cohort analysis of NASS-CDS data to examine the relative risk of AIS 3+ injury in the rear seat compared to the front seat. Their comparison divided the cases into vehicles of model year 1990-1996 and 1997-2007, and found that there was a significant difference in the AIS 3+ injury risk based on the model year with less relative protection in the rear seat of newer vehicles compared to the front seat. The findings echoed those from Kuppa *et al*. in 2005 that showed differences based on whether the occupant is a child or an adult over 50 years of age.

Using NASS-CDS data to calculate trends in injury risk for rear seat occupants, Esfahani and Digges [2009] found that belted and rear-seated adults between 16 and 50 years of age had a higher risk of maximum AIS 2+ (MAIS) injuries in vehicles from the 2000s model years compared to the 1990s, although that risk was still lower than in the right front seat. Further investigating the effects of model year on rear seat occupant protection, Sahraei *et al*. [2009] performed logistic regression analysis on NASS-CDS data and found that newer model year vehicles were associated with a significantly higher AIS 2+ injury risk for belted rear seat occupants. Similar to some of their earlier work, Sahraei *et al*. [2010] conducted an analysis of model year segregated by occupant age group using Fatality Analysis Reporting System data. They found that the relative effectiveness of the rear seat compared to the front has decreased for belted children (less than 8 years of age) and belted adults (25 years and older) for the newer model years. None of the age groups of belted occupants demonstrated significantly better protection in the rear seats of newer vehicles, and of note was a negative effectiveness for belted adult occupants in the rear seat of newer vehicles.

The findings of several researchers presented above support further analysis of the rear seat occupant environment and injury causation problem. Many have concluded that improvements in the rear seat restraint environment would help to restore the rear seat advantage for all age groups in frontal crashes. The work presented in this paper represents one of the steps necessary to more completely understand the frontal crash experience of rear seat occupants.

METHODOLOGY

Using a technique similar to Bean *et al*. [2009], a detailed review of real-world frontal crashes with restrained, seriously injured rear seat occupants was conducted. The review focused on coded and non-coded data (photographs, summaries, crash diagrams, etc.), and resulted in the identification of critical factors contributing to the serious injuries of restrained rear seat occupants. The cases were selected from the NASS-CDS for the years 1997 through 2009 and the CIREN from 2000 to 2010. The following parameters were required for inclusion in the data set:

- 1998 and newer model year vehicles
- Frontal crash as primary injurious event where the general area of damage (GAD) and principle direction of force (PDOF)
  - GAD1='F'
  - GAD1='R' or 'L' and PDOF between 320 and 40 degrees
- Restrained rear seat (row 2 or higher) occupants
  - Lap and shoulder belts
  - Child restraints
- AIS level 3+ injury sustained

Fifty occupants in 45 vehicles were included in the final NASS-CDS data set. There were 29 occupants in 27 vehicles included in the final CIREN data set. For the NASS-CDS years examined, there were approximately 2,000 restrained rear seat occupants involved in frontal crashes prior to restricting the data set to only those occupants who sustained an AIS 3+ injury. Injured rear seat occupants included both sexes and affected a wide range of ages. The data was divided by age into occupants twelve years of age and under and those over twelve years of age. It was then determined whether the occupant was in an appropriate restraint condition for his or her stature and age. In effect, the data was divided into the following four major groups:

- 12 and under, properly restrained
- 12 and under, improperly restrained
- Over 12, properly restrained
- Over 12, improperly restrained

For ease of discussion, occupants 12 and under will be referred to as "children" while those over the age of twelve are designated "adults."

In order to be classified as properly restrained, the occupant had to be in an age- and size-appropriate restraint that was installed and/or positioned properly during the event. Proper restraint for adult occupants meant a lap-and-shoulder belt was used and positioned properly. Proper restraint for child occupants was assessed according to NHTSA's Car Seat Recommendations for Children [NHTSA, 2011a] along with the age, height, and weight guidelines set forth by the manufacturer of the child restraint system being used (if that information was available in the case). For the purposes of this study, out-of-position occupants wearing their seat belts were still considered properly restrained.

Improperly restrained occupants were not in a restraint that was age- and/or size-appropriate, or the restraint was installed and/or positioned improperly during the event. Lap and shoulder belts, if used, may have been positioned improperly. An incorrect CRS based on the age and/or size of the child may have been used, or a child restraint, if one would have been appropriate, may not have been used at all. Figure 1 demonstrates the age and restraint condition distribution for the 79 total cases in the combined NASS-CDS and CIREN data set.

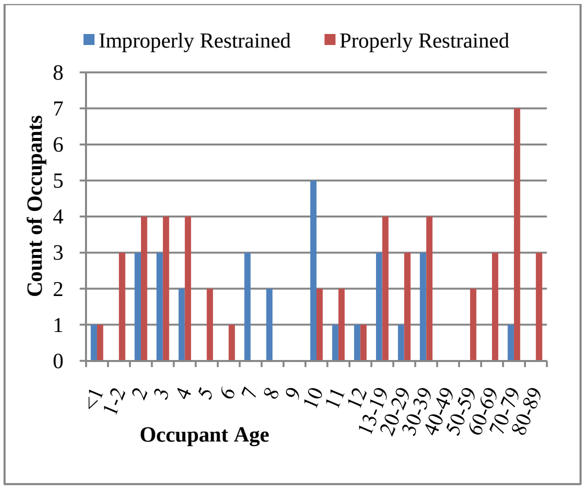

Figure 1. Age and restraint condition distribution for the combined NASS-CDS and CIREN data sets.

The cases were then divided amongst the authors, who then summarized each case using a standard format. The authors then assessed the primary and, if applicable, secondary factors associated with the MAIS injury sustained by the rear seat occupant. The distinction between primary and secondary factors is similar to what was described by Rudd *et al.* [2009].

The following section provides descriptions of the factors associated with injury causation assigned to the rear seat occupants in this data set:

<u>Improper restraint system used:</u> The restraint system (seat belt, child restraint, or combination thereof) was not able to provide adequate protection for the occupant due to occupant size and restraint mismatch, incorrect belt routing, or other factors that interfered with the as-designed performance of the restraint. The type and severity of the occupant's injuries were directly associated with being improper restrainet.

Gross CRS misuse: Particular misuse of the child restraint is likely to result in injury to the occupant if involved in a crash [Decina, 2005]. Due to the general nature of field data collection, "critical" or "gross CRS misuse" was only attributed as a cause of injury in the most obvious of documented cases, and only when the restraint was appropriate for the child. For the purposes of this study, child restraints that were inappropriate for their occupant based on recommended best practices for child passenger safety did not fall under the designation of "gross misuse" but were simply categorized as "improper restraint."

High velocity change (delta-V): The deceleration of the vehicle during the event was of a severity that was believed to result in a delta-V near to or greater than the 56 km/h frontal impact test speeds in NHTSA's Federal Motor Vehicle Safety Standard No. 208 and the New Car Assessment Program consumer information program. There were no fatalities primarily attributed to high delta-Vs in this data set.

It should be noted that in many cases the delta-V was not estimated or the WinSMASH delta-V estimate was considered unreliable or underestimated due to the offset nature of the crash. In these cases, the barrier equivalent speed, crush measures, occupant compartment intrusion values and photos were used as a surrogate to estimate the severity of the crash. This method is consistent with Niehoff [2006]. The authors investigated the accuracy of WinSMASH as a function of crash mode, vehicle type, and vehicle stiffness and concluded WinSMASH underestimated longitudinal delta-V by 29 percent for crashes with a frontal overlap less than 50 percent.

Exceedingly severe: Similar to the description provided in Rudd *et al*. [2009], exceedingly severe crashes are those that meet any of the following:

- If known, the estimated delta-V crash for this crash was very high (over 64 km/h) and it is not likely the occupant could ride down crash forces and survive in the time and space available,
- All front seat belted occupants sustained incapacitating injuries or fatalities, and
- The occupant compartment at the position in question was compromised due to extensive intrusion.

Cases classified in this way were expected to be certain to produce moderate to severe injury even for a restrained rear occupant. All of the rear seat occupants in crashes classified as exceedingly severe sustained fatal injuries.

Contact with another occupant: The primary source of the occupant's severe injury was from contact with another occupant (restrained or unrestrained) in the vehicle.

Interior contact: The severe injury was sustained due to contact with hard interior surfaces adjacent to the occupant's seating position. In most cases, the direction and/or magnitude of the crash forces produced an occupant trajectory that resulted in contact with hard interior surfaces that led to serious injury. In others, this was due to occupant stature with respect to the rear compartment space.

Rear compartment intrusion: Severe intrusion occurred at the occupant's seating position leading to a reduction in ride-down space. These cases were occasionally characterized by restrained (and in certain cases, unrestrained) occupants in other vehicle seating locations sustaining minor or no injuries.

Occupant out of position: The coding or narrative in the case indicated that the occupant was not in a normal, upright seating position at the time of the event, and likely would not have sustained the same type or level of injury had they been seated properly during the crash.

Cargo intrusion: The primary source of injury was attributed to cargo intrusion into the rear seat as a result of being improperly secured in the trunk or cargo area of a vehicle.

Vulnerable occupant: The occupant was thought to be at higher risk of injury based on their elevated age or poor health condition. There was no specific minimum age for this factor, though typically these occupants were over the age of 65. These occupants' injury patterns and severities were more extensive than what would be expected with a younger occupant in similar crash conditions.

Given the case-review nature of this work, the NASS-CDS and CIREN cases have been combined for analysis and presentation purposes. No statistical analyses have been performed on the combined data, and no assessment of injury risk can be performed since case weights were not used.

RESULTS

The cases were grouped by age and whether the occupant was properly or improperly restrained at the time of the crash. For each grouping, the frequency of the primary and secondary causes of the injuries is tallied and presented below.

Occupants 12 and Under

Of the 79 occupants involved in the study, 24 involved children that were properly restrained (Table 1). The most frequently occurring cause of severe injuries was attributed to a high delta-V crash. There were four cases where none of the factors stood out, and the primary cause was listed as undetermined based on all of the available evidence. These four occupants sustained primarily abdominal injuries, but there were no reasons to expect improper restraint use resulting in poor belt fit or increased risk due to crash severity. A full assessment summary for each case reviewed in the study is available in the Appendix including the type of restraint in use such as lap and should belt, forward facing child seat or booster seat.

Table 1.
Causes of Injury to Properly Restrained Occupants 12 and Under

Cause	Primary	Secondary
High delta-V	8	2
Interior contact	7	1
Exceedingly severe	2	0
Cargo intrusion	1	0
Occupant out of position	1	0
Rear compartment intrusion	1	0
Undetermined	4	0
Total	**24**	**3**

The two most frequently occurring sources of injury in the properly restrained child occupants was the belt restraint and the front seat back support. In general, abdomen and torso injuries were associated with the belt restraint and head and extremity injuries were associated with the back of the front seats. The third most common source of injury was induced tension due to torso restraint, which is when the head pulls on the cervical spine and restrained torso due to deceleration and produces injurious tension and flexion. Injuries due to this mechanism are coded differently in CDS and CIREN, but have been combined for this study. CDS lists the source as "Other noncontact injury," though there is a contact between the occupant's torso and the restraint that leads to the injury. CIREN codes the belt as the injury producing component acting on the thorax, and specifies the tension mechanism in the cervical spine caused by the inertial loading from the head. This mechanism is more common in higher delta-V crashes. It should be noted that if there was evidence suggesting the source of the injury was different from what was coded in the investigation, the authors reassessed the source of injury for that case.

Table 2.
Source of Primary Injury to Properly Restrained Occupants 12 and Under

Source of Primary Injury	No. of Cases
Belt restraint webbing/buckle	8
Seat back support	8
Induced tension due to torso restraint	5
Undercarriage	1
Unknown	1
Unknown (likely driver's seat encroachment)	1
Total	**24**

There were 21 children classified as improperly restrained. The most frequently occurring cause of injury for improperly restrained children was an improper child restraint system being used (according to NHTSA's 4 Steps for Kids campaign). For older children, the vehicle seat belt may have been worn incorrectly (Table 3). Of interest, an improper restraint system being used was also determined to be a secondary cause of injury in six cases. In three cases it was assessed that the child seat was incorrectly installed.

Table 3.
Causes of Injury to Improperly Restrained Occupants 12 and Under

Cause	Primary	Secondary
Improper restraint system	12	6
Gross CRS misuse	3	0
Rear compartment intrusion	2	0
Interior contact	1	4
Cargo intrusion	1	0
Contact with another occupant	1	0
Occupant out of position	1	0
High delta-V	0	3
Total	**21**	**13**

The seat back support (i.e., the front seat back) was attributed as the primary source of injury for eight occupants (Table 4). In most cases, the occupant was not properly restrained or in an improper child seat and slipped out of the restraint system during the crash, making contact with the seat back. In the majority of the cases the occupant sustained head or neck injuries, though, as with the properly restrained children, extremity injuries occurred as well.

Table 4.
Source of Primary Injury to Improperly Restrained Occupants 12 and Under

Source of Primary Injury	No. of Injuries
Seat back support	8
Belt restraint webbing/buckle	5
Hardware or armrest	2
B-pillar	1
CRS	1
Ground	1
Other occupants	1
Interior surface, excluding hardware or armrest	1
Floor or front center console	1
Total	**21**

For presentation purposes, Figure 2 combines data for the properly and improperly restrained children 12 and younger by primary injury cause and body region experiencing most severe injury. The data shows that the extremities are the most frequent maximum injured body region for children, occurring in 16 of the 45. Extremity injuries were typically associated with interior contact. Head injuries were the most significant injury for 11 of the child occupants, and occurred most often in crashes where the primary cause was improper restraint system used; they also occurred in cases of CRS misuse and in exceedingly severe crashes.

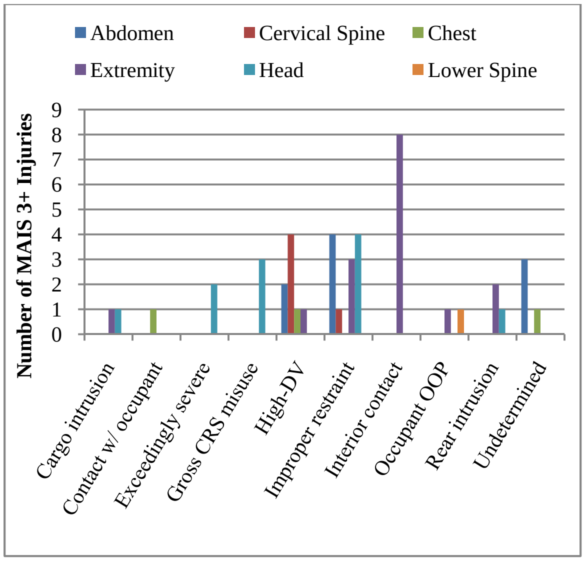

Figure 2. Injury Distribution by Primary Injury Cause for All Occupants 12 and Under.

Occupants Over 12

Twenty-six adult occupants were in the properly restrained category. The most prominent factor (present in ten of the cases) for adults who were properly restrained, was occupant vulnerability due to elevated age (Table 5). Crash severity (seven cases) and interior contact (five cases) were also common factors. It should be noted that high delta-V was identified as a secondary contributory factor to injury in four cases.

Table 5.
Causes of Injury to Properly Restrained Occupants Over 12

Cause	Primary	Secondary
Vulnerable occupant	10	1
High delta-V	7	4
Interior contact	5	0
Rear compartment intrusion	2	0
Exceedingly severe	1	0
Occupant out-of-position	1	0
Cargo intrusion	0	3
Total	**26**	**8**

For the properly restrained category, the restraint system itself was the most frequent source of the severe injuries, in 16 of the 26 cases (Table 6). Considering that induced tension injuries due to the torso restraint are also caused by the belt restraint, the total number becomes 18. The right side door (three cases) along with various other hard contact points were also noted as injury sources.

Table 6.
Source of Primary Injury to Properly Restrained Occupants Over 12

Source of Primary Injury	No. of Injuries
Belt restraint webbing/buckle	16
Right side door	3
Induced tension due to torso restraint	2
Seat back support	2
Fold down armrest left	1
Interior B-Pillar	1
Unknown	1
Total	**26**

For improperly restrained adult occupants, the improper restraint condition was noted as the primary factor in four cases and a high delta-V was attributed as the cause in four of the eight cases reviewed (Table 7). In three of the cases, an improper restraint system was the secondary cause of the injury.

Table 7.
Causes of Injury to Improperly Restrained Occupants Over 12

Cause	Primary	Secondary
Improper restraint system used	4	3
High delta-V	4	1
Interior contact	0	1
Vulnerable occupant	0	1
Total	**8**	**6**

For improperly restrained occupants, the source of the injury was attributed to the restraint system in five cases (Table 8). As further discussed in the paper, generally these were high delta-V crashes associated with injuries exclusive to the abdomen from the lap belt portion of the belt system.

Table 8.
Source of Primary Injury to Improperly Restrained Occupants Over 12

Source of Injury	No. of Injuries
Belt restraint webbing/buckle	5
Seat back support	3
Total	**8**

For presentation purposes Figure 3 combines the data for the properly and improperly restrained adults by primary injury cause and injured body region. The most injured body region was the chest with fourteen cases; eight of those were related to occupant vulnerability. The second most common cause of chest injury was a high delta-V crash. In six cases, the occupant sustained abdominal injuries because of a high delta-V crash or being improperly restrained. Interior contact was primarily responsible for the extremity injuries. The findings are consistent with Parenteau and Viano [2003].

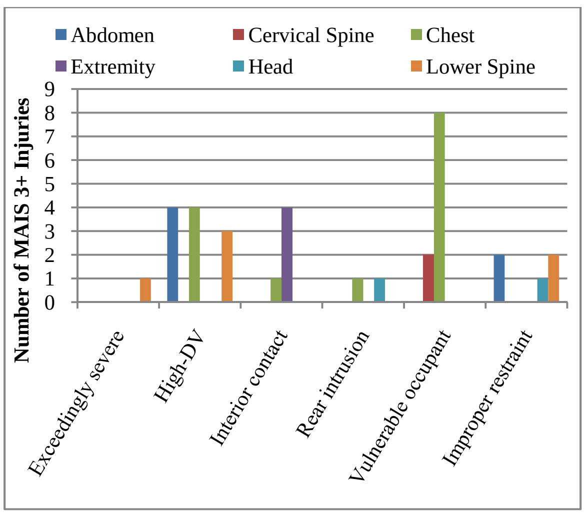

Figure 3. Injury Distribution by Primary Injury Cause for All Occupants Over 12.

DISCUSSION

The objective of this study was to identify specific factors that lead to injuries for restrained rear seat occupants in frontal crashes in order to better understand some of the recent statistical analyses that have suggested decreased protection in the second and third rows of newer vehicles. The following sections offer insight to some of the specific issues that were found in the combined NASS-CDS and CIREN data set.

Improper Restraint

Though this data set was limited to restrained occupants, closer inspection revealed that the coded restraint status for some of the occupants did not reflect their actual status at the time of the crash. This was especially the case with occupants twelve and under: 21 out of 45 had their injuries attributed to being improperly restrained in some way. Premature graduation, as discussed in NHTSA [2001], was responsible for 18 of these 21 cases, while the remaining three were attributed to gross misuse of the child restraint. The most common type of premature graduation was booster-aged children being restrained only by the vehicle seat belt (as demonstrated in CDS case 2000-13-222 or CIREN 286006919).

The most common serious injuries for improperly restrained children were brain injuries, which occurred in seven of the 21 cases where the children were improperly restrained. Two of the properly restrained children sustained severe head injury, but they were in what was considered exceedingly severe crashes. In addition, a skull fracture and a facial fracture were also observed for improperly restrained children. The next most common injury for improperly restrained children were extremity fractures. These findings are also consistent with Paranteau [2003].

Of the three cases of injury assigned to gross CRS misuse, two of these children were seated in child restraints secured by a seat belt whose retractor was never properly locked. The third child in question (CDS No. 2006-12-161) was an infant restrained rear-facing (RF) in an infant-style CRS that did not receive the proper recall repair (per NHTSA recall No. 03C005000). The carrier separated from the base without this repair in place. The child was subsequently ejected from the vehicle and sustained fatal injuries.

Improper restraint was also observed for seven of the 34 adult occupants. For teenagers and adults, improper positioning of the vehicle seat belt was considered as such, if at the time of the event the harness was not worn properly across the chest or there was potential slack in the shoulder harness. Though poor belt fitment or discomfort due to restraint routing geometry is usually thought of as a problem for smaller-statured occupants, individuals of a wide range of ages and statures were noted placing the shoulder belt portion under their arm or allowing the lap belt to sit too high on their abdomen (CDS No. 2009-11-113). Furthermore, slack in the shoulder harness may allow the occupant to slip out of the shoulder harness and sustain abdominal injuries from the lap belt especially in oblique or offset frontal impacts (CDS No. 2008-75-08). Although it cannot be conclusively determined from the data, the seated posture of the occupant at the time of the crash event may have contributed to the inadequate restraint of the upper body. Generally, these occupants sustained either abdominal injuries from the lap portion of the restraint or cervical spine injuries from impacting the front seat back because the upper torso was not properly used.

As a result of improper positioning or seat belt misuse during the event, injuries to both children and adults occurred. When improper seat belt positioning was observed in this data set, occupants may have sustained more serious injuries than if their seat belt had been positioned correctly, and especially experienced a high frequency of injuries to the soft tissues and organs of the lower abdomen. Improper positioning or intentional misuse of the shoulder belt portion of the seat belt puts a greater reliance on the lap belt to distribute loading, hence the propagation of injury to the areas of the body the lap belt covers. Occupants improperly using the shoulder belt also rarely sustained even minor upper torso injuries. The injury patterns were also similar to those occupants in a vehicle equipped with a lap only belt [Paranteau 2003b]. It is a reasonable assumption that if their seat belts were positioned properly, their injury patterns would have been different, even if they eventually sustained similar levels of injury.

Poorly installed CRS: Given known rates of poor CRS installation at 72.6 percent [Decina, 2005], this data implies that CRS being installed with minor misuses are still offering some level of protection to children. It is also of interest to note that there were only three cases containing a Lower Anchors and Tethers for Children (LATCH) installed CRS in this data set. This may be due to the relatively recent introduction of the system in vehicles and on CRS, or it also may be a real-world indicator that there is a reduced chance of gross misuse with LATCH installations and therefore reduced chances of serious injuries occurring [Decina, 2006].

Booster-aged children in seat belts alone: Though not recommended by NHTSA or other child passenger safety groups, the small number of fatal injuries seen in this data set for children of booster age may be evidence that lap and shoulder belts have the ability to offer some protection to children who would be best restrained by a booster seat. This is encouraging given that children between the ages of four and seven are only using booster seats and other CRS 55 percent of the time, with another 32 percent using seat belts only and thirteen percent completely unrestrained [NHTSA, 2010]. The children in this study that had prematurely graduated out of a booster seat typically sustained abdomen injuries due to poor lap belt fit and interaction with the pelvis.

Child passenger safety best practices: There was one case in this data set (CDS No. 2007-12-122) where two properly restrained children in the same vehicle suffered tension-based spinal injuries due to restraint of the torso and motion of the head. For each occupant, there is the possibility that they may not have experienced these injuries had they been in more “optimal” restraints. In the left rear seat of the vehicle in question (a 2006 Dodge Caravan), a 11 kg (24 lb), 86 cm (34”) tall 18 month-old female was properly restrained in a forward-facing convertible seat, but suffered an AIS 3 cervical spine fracture attributed to a high delta-V. Though she met the minimum requirements to ride forward facing, she would likely have benefitted from remaining rear-facing in that convertible, as NHTSA’s Car Seat Recommendations for Children state, “[c]onvertible and 3-in-1 car seats typically have higher height and weight limits for the rear-facing position, allowing you to keep your child rear-facing for a longer period of time.” Though the make and model of her CRS was unknown, according to NHTSA (Ease of Use Ratings, 2011) the majority of convertibles in the U.S. market would have continued to accommodate a child of her size rear-facing for some time.

In the right rear of the same vehicle, a 109 cm (43"), 20 kg (44 lb) three year-old male was restrained in a booster of unknown make and model and similarly suffered an AIS 3 cervical spine fracture. By most recommended child passenger safety best practices, he was too young for a booster seat; however, it is possible that he met the height and weight requirements of the booster seat he was using. He would likely have benefitted from being restrained in a five-point harness and may not have suffered the cervical spinal fracture if he had been.

Another similar case, CIREN 286037005, was a crash with a two year-old female seated in a five-point harness forward-facing seat who was 97 cm (38") tall and 14 kg (31 lb). Next to her, in the right seat position, was a three year-old male of 104 cm (41") height weighing 17 kg (37 lb) seated also in a five-point harness forward-facing seat (CIREN No. 286036859). She sustained upper cervical spine fractures and dislocations in a moderate severity crash, while the three year-old male in the next seat sustained only upper extremity fractures due to front seat back contact. Her tension-related neck injury may have been prevented had she been seated rear-facing (as long as her CRS could have accommodated her).

Interior Contact

Another common cause of injury in both the child and adult cases was interior contact. The cases in this study demonstrate that the most common maximum injuries for restrained occupants 12 and under were upper and lower extremity fractures, most commonly sourced to the seat back. As demonstrated in Parenteau [2003], the majority of injuries to properly restrained (lap-shoulder belted) children in the rear seat are upper and lower extremity injuries.

Properly restrained adults also sustained injuries due to interior contact, with four sustaining extremity fractures associated with seat back or door panel contact. Though the extremity injuries seen in this study are AIS 3, many of the occupants sustaining these injuries were not injured significantly otherwise. Given that the restraint of extremities is difficult in the rear seat environment, efforts to address the stiffness of various contact points may help to ameliorate some of these injuries.

Vulnerable Occupants

Twelve of the 34 adult occupants in this data set experienced injury due in some way to physical vulnerabilities as a result of age. They included eight women and four men, and ranged in age from 64 to 86 years. Eleven were properly restrained, and most sustained their highest AIS injury as a result of seat belt loading on the thorax, which led to rib fractures, lung contusions, other thoracic cavity injuries, and in three cases fatal heart lacerations. The two CIREN cases in which occupant vulnerability was a primary cause involved occupants who had been clinically diagnosed with osteoporosis, which was a critical factor in their injury. Of the five fatalities to adult occupants observed in this data set, four were attributed directly to the occupant's vulnerability and the fifth was to a 75 year old female in an exceedingly severe crash due to the intrusion (CDS No. 2001-73-141). It should be noted that there was a 22 year old male seated next to the 75 year old female who sustained abdominal injuries sourced to improper restraint. This occupant was not exposed to the significant intrusion and for his position the event was not considered exceedingly severe. CDS case 2004-3-096 was fairly benign, with an estimated 32 km/h (20 mph) delta-V; however, the 72 year-old rear seat occupant sustained fatal thoracic injuries sourced to the seat belt. CDS case 2007-08-118 is another example where the risk of injury to older rear seat occupants is seen. Though the event was relatively severe, with an estimated 53 km/h (33 mph) delta-V, the front seat occupants suffered moderate belt-related injuries while the 86 year-old occupant in the right rear sustained a fatal heart laceration along with numerous rib fractures, a basilar skull fracture, and brain injuries. This occupant's chest, because of age-related vulnerabilities, was not able to handle the severe loading from the shoulder belt. The elevated risk for older occupants in the front versus the rear seat has been documented in many recent studies[Kuppa *et al.*, 2005; Sahraei *et al.*, 2010; Bilston *et al.*, 2010] and the review of these field crashes affirms those findings.

Efforts to address the increased risk to vulnerable occupants in all seating positions are underway and further justified by these findings. Based on the earlier findings in the statistical analyses by Kuppa *et* *al*. [2007] and Sahraei *et al*. [2010], there may be a need to encourage older, and potentially more vulnerable, adult occupants to occupy first row seats whenever possible so they may benefit from features of advanced restraint systems.

High Delta-V and Exceedingly Severity Crashes

Twenty-nine of the 79 rear seat occupants' maximum injuries were due either primarily or secondarily to a high level of compartment deceleration during the crash, which was based on delta-V or crush. Five were sourced to intrusion of the rear seat compartment at the occupant's location, which caused injury due to a reduction in the occupant's ride-down space. Another three were deemed exceedingly severe, or close to unsurvivable as was described by Bean *et al*. [2009].

Due to limitations associated with comparing delta-V in field crashes to those in laboratory tests, the extent to which some of these crashes were more severe than consumer information or regulatory tests could not be determined. The crashes in which occupant injuries were attributed to a high delta-V were potentially of a similar severity as that present in NCAP or IIHS frontal tests. There is potential for rear occupant crash protection improvements in some of these crashes, since some of them had front occupants who sustained less severe injuries. The injuries in these crashes were typically sourced to the belt restraint, suggesting that attention should be paid to fit or energy management of rear seat belts in order to increase rear occupant protection.

Exceedingly severe crashes where properly restrained rear seat occupants suffer a fatality are likely to show corresponding front seat fatalities. For example, the rear seat injuries in CDS case 2002-12-186 were attributed to the exceedingly severe nature of the crash. In this case, all three occupants (driver, right front passenger, and right rear passenger) sustained fatal injuries.

Undetermined Cause

A few of the cases included in this study did not exhibit any of the other factors previously discussed, and were therefore not categorized with the other cases. All of the cases involved properly restrained child occupants, and the severity levels of these crashes were not believed to be high. CIREN cases 286000006 and 608090285 involved ten year-old males wearing the three-point lap and shoulder belt (both were at or above the recommended height of 145 cm for graduation out of a booster) who sustained abdominal injuries attributed to the lap belt. CIREN cases 377037363 and 608063219 involved four and five year-old females who were properly restrained in booster seats. CIREN case 377037363 was borderline high severity in an underride situation, but the restrained driver sustained very minor injuries while the booster-seated four year-old female sustained multiple rib fractures and lung contusions from belt loading. CIREN case 608063219 involved a five year-old female who sustained a bladder rupture in a very minor crash in which all of the other properly restrained occupants were not injured. She exhibited abrasions over her waistline from lap belt contact. The CIREN center noted that the belt fit may have been sub-optimal, but the child was in an appropriate restraint. Regardless, these four cases suggest that even properly restrained children in moderate severity crashes are sustaining injuries due to the restraints.

CONCLUSION

Given the relatively large number of occupants injured as a result of perceived improper restraint use, there is a potential need to reinforce NHTSA's CRS use recommendations as well as increase awareness of proper belt use by adults seated in the rear seat. While proper restraint use may not have protected the occupant from all injuries, the conditions of the cases in this study did suggest that many of the injuries were directly related to a failure to use the restraint system appropriately.

Of the adult occupants in this dataset, physical vulnerabilities due to advanced age were responsible for a large number of the major injuries. Injuries from interior contact, typically involving the extremities, were also common when crash severity was not considered an issue. The majority of the remaining adult cases were attributed to crash severity, which was considered high enough that the level of injury sustained was not unexpected. Many children were also considered to be injured due to high delta-V and exceedingly severe crashes.

While many of the crashes were considered to be a higher severity, this does not, however, suggest there is no room for improvement in the area of rear seat occupant protection. As suggested by the data shown by prior researchers, the relative protection in the rear seat has decreased in newer model year vehicles. Furthermore, there is concern that as vehicle front structures become stiffer to manage intrusion in the occupant compartment, the vehicle crash pulse will also increase in magnitude. This may increase the risk of serious injury to rear seat occupants whose primary protection is only the seat belt. Incorporation of enhanced occupant energy management features to improve ride-down and better distribute the loading across the chest, along with improved fitment of the restraints to reduce slack and improved belt positioning across the torso, may have mitigated the serious injury sustained by some of the occupants in these crashes.

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Appendix

	PROPERLY RESTRAINED OCCUPANTS	
CAUSE OF INJURY	**UNDER 12**	**OVER 12**
Cargo intrusion	*Primary* • NASS 2007-75-146 (2L, UE, FF)	*Secondary* • NASS 2000-12-086 (2R, AB) • NASS 2008-13-134 (2R, TH) • CIREN 459042257 (2L, LS)
Exceedingly severe	*Primary* • NASS 2000-11-130 (2L, H, RF) • NASS 2002-12-186 (2R, H, L&S)	*Primary* • 2001-73-141 (2R, LS)
High severity delta-V	*Primary* • NASS 2007-41-218 (2L, LE, RF) • NASS 2007-12-122 (2L, CS, FF) • NASS 2007-12-122 (2R, CS, B) • NASS 2008-13-222 (2R, TH, B) • CIREN 286037005 (2L, CS, FF) • CIREN 554089295 (3L, AB, L&S) • CIREN 842003310 (2R, AB, L&S) • CIREN 842023821 (2C, CS, B) *Secondary* • NASS 2006-12-161 (2L, LE, FF) • CIREN 286036859 (2R, UE, FF)	*Primary* • NASS 2008-73-176 (2L, TH) • NASS 2000-12-086 (2R, AB) • NASS 2004-43-036 (2R, TH) • CIREN 100121436 (2L, AB) • CIREN 459042257 (2L, LS) • CIREN 830069711 (2R, LS) • CIREN 852174467 (2L, TH) *Secondary* • NASS 2000-12-091 (2R, TH) • NASS 2009-81-70 (2C, TH) • NASS 2006-48-261 (2L, CS) • CIREN 591142661 (2L, AB)
Interior contact	*Primary* • NASS 2007-78-102 (2R, LE, B) • CIREN 160139577 (2L, UE, B) • CIREN 286008946 (2L, LE, FF) • CIREN 286035771 (2L, LE, B) • CIREN 286036859 (2R, UE, FF) • CIREN 558020414 (2L, LE, FF) • CIREN 608042073 (2L,UE, FF) *Secondary* • NASS 2007-41-218 (2L, LE, RF)	*Primary* • NASS 2002-43-095 (2R, UE) • NASS 2005-09-028 (2R, UE) • NASS 2004-48-059 (2R, UE) • NASS 2003-75-031 (2L, TH) • CIREN 551091328 (2R, UE)
Occupant out of position	*Primary* • NASS 2006-48-19 (2L, UE, FF)	*Primary* • CIREN 591142661 (2L, AB)
Rear compartment intrusion	*Primary* • NASS 2006-12-161 (2L, LE, FF)	*Primary* • NASS 2005-02-011 (2L, H) • NASS 2004-45-227 (2R, TH)
Undetermined	*Primary* • CIREN 286000006 (2R, AB, L&S) • CIREN 377037363 (2L, TH, B) • CIREN 608063219 (2C, AB, B) • CIREN 608090285 (2R, AB, L&S)	
Vulnerable occupant		*Primary* • NASS 2009-82-163 (2L, TH) • NASS 2000-12-091 (2R, TH) • NASS 2004-03-096 (2L, TH) • NASS 2009-81-70 (2C, TH) • NASS 2006-48-261 (2L, CS) • NASS 1999-45-809 (2L, TH) • NASS 2008-13-134 (2R, TH) • NASS 2007-08-118 (2R, TH) • CIREN 165428 (2L, CS) • CIREN 591139732 (2R, TH) *Secondary* • CIREN 551091328 (2R, UE)

	IMPROPERLY RESTRAINED OCCUPANTS	
CAUSE OF INJURY	**UNDER 12**	**OVER 12**
Cargo intrusion	*Primary* • NASS 2006-12-070 (2R, H, L&S)	
Contact with another occupant	*Primary* • NASS 2004-79-188 (2L, TH, L&S)	
Gross CRS misuse	*Primary* • NASS 2006-12-161 (2L, H, RF) • NASS 2001-04-065 (2L, H, FF) • NASS 2005-48-125 (2L, H, B)	
High severity delta-V	*Secondary* • NASS 2008-13-222 (2R, H, B) • NASS 2004-04-069 (2L, H, B) • CIREN 591152151 (2R, AB, L&S)	*Primary* • NASS 2008-75-08 (2R, AB) • NASS 2002-79-016 (2R, LS) • NASS 2002-79-016 (2L, AB) • NASS 2001-73-141 (2L, TH) *Secondary* • NASS 2000-81-053 (2L, AB)
Improper restraint system	*Primary* • NASS 2008-13-222 (2R, H, B) • NASS 2004-04-069 (2L, H, B) • NASS 1999-45-190 (2C, CS, L&S) • NASS 2000-13-222 (2L, AB, L&S) • NASS 2002-43-127 (2L, H, L&S) • NASS 2006-13-117 (2R, UE, L&S) • CIREN 286006919 (2R, AB, L&S) • CIREN 286016523 (2L, H, L&S) • CIREN 286021930 (2L, LE, L&S) • CIREN 286021946 (2R, LE, L&S) • CIREN 377044044 (2L, AB, B) • CIREN 591152151 (2R, AB, L&S) *Secondary* • NASS 2000-12-157 (2R, LE, L&S) • NASS 2004-79-188 (2L, TH, L&S) • NASS 2002-78-151 (2R, H, L&S) • NASS 2004-48-94 (2R, OS, L&S) • NASS 2004-73-122 (2L, LE, L&S) • NASS 2006-12-070 (2R, H, L&S)	*Primary* • NASS 2009-11-113 (2R, LS) • NASS 2000-81-053 (2L, AB) • NASS 1999-73-062 (2L, LS) • CIREN 286020311 (2R, H) *Secondary* • NASS 2008-75-08 (2R, AB) • NASS 2002-79-016 (2R, LS) • NASS 2002-79-016 (2L, AB)
Interior contact	*Primary* • NASS 2000-12-157 (2R, LE, L&S) *Secondary* • NASS 2002-43-127 (2L, H. L&S) • CIREN 286016523 (2L, H, L&S) • CIREN 286021930 (2L, LE, L&S) • CIREN 286021946 (2R, LE, L&S)	*Secondary* • CIREN 286020311 (2R, H)
Occupant out of position	*Primary* • NASS 2004-48-94 (2R, LS, L&S)	
Rear compartment intrusion	*Primary* • NASS 2002-78-151 (2R, H, L&S) • NASS 2004-73-122 (2L, LE, L&S)	
Vulnerable occupant		*Secondary* • NASS 2001-73-141 (2L, TH)

2 - Second row, 3 - Third row, L – Left side position, C - Center position, R - Right side position, UE - Upper extremity injury, H - Head injury, LE - Lower extremity injury, CS - Cervical spine injury, TH - Thorax injury AB - Abdomen injury, LS - Lower spine injury, RF – Rear-facing restraint, FF – Forward-facing restraint, B – Booster, L&S – Lap and shoulder