OPPORTUNITIES FOR REDUCING FAR-SIDE CASUALTIES

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ABSTRACT

This paper uses NASS 2004-2013 to estimate the population of belted front seat occupants exposed to far-side crashes and those with serious injuries. The use of the most recent ten years of NASS data permitted an update of the characteristics of far-side crashes that are associated with serious injuries among belted front seat occupants. When compared with earlier studies, it was found that the vehicle category that includes SUV's, pickups and vans, has increased as the collision partner in far-side crashes. There has likewise been an increase in the median crash severity for MAIS 3+ injured. For the 2004-2013 NASS CDS data, the median crash severity for MAIS 3+ injured was a lateral delta V of 36 kph. Chest/abdominal injuries accounted for 43% and head injuries accounted for 23% of the AIS 3+ injuries. Drivers accounted for 79% of the MAIS 3+ injured belted front outboard occupants that were involved in far-side crashes. About 53% of front outboard occupant's chest injuries were caused by contacts with the vehicle center stack or seat back and 21% were associated with contacts with the far-side structure. In regards to head injuries, the far side structure accounts for more than 60% of the AIS 3+ injuries. Of the far side crash involved occupants analyzed, they sustained AIS3+ head or chest injuries from the far side of the vehicle more than 4.4 times more often than were attributed to occupant to occupant contact. Another striking trend is the disproportionate number of AIS3+ injured occupants in light passenger cars where belted front outboard occupants sustained severe injuries at a rate 2.7 times higher than exposed. Finally, this study identified that only 2.25% of belted AIS3+ head injured occupants involved in far-side collisions sustained their injuries due to head to head contact with another front seat occupant.

INTRODUCTION

A purpose of this paper is to investigate the characteristics of belted occupants with MAIS 3+ injuries who were exposed to far-side crashes. Although there is a history of research in far-side analysis and test criteria, this crash mode has not been addressed by safety regulations or consumer information ratings. An extensive international collaborative research project on far-side safety was completed in 2009 [Gabler 2005, Pintar 2007, Fildes 2009, Digges 2009]. Since the 2009 study was published, there have been changes in the composition of the US passenger vehicle fleet and in the safety of the vehicles. Regulatory changes include an increased penetration of vehicles that comply with a near-side impact standard requiring dynamic crash tests and related consumer information tests (FMVSS 214). It is appropriate to update the earlier analyses with the latest decade of NASS CDS data to include the possible affect of these changes, with the goal of understanding the evolution of the far side crash scenario in recent years.

There have been a number of international and US studies of far-side crash data that can provide a basis for comparing how the safety environment in far-side crashes has changed.

Mackay [1991] examined 193 crashes with belt restrained far-side occupants in Birmingham England during the period 1983-1989. The 193 cases contained 150 AIS 2 injuries and 15 AIS 3+ injuries. Among those with AIS 2+ head injuries, 35% came out of the shoulder belt. For those with AIS 2+ abdominal injuries, 72% were from contact with the safety belt. Contact with the belt system was the most frequent source of chest injuries to all involved occupants (59%).

A study using the Australian field data gathered between 1989 and 1992 examined 198 side impact crashes involving 234 occupants [Fildes et al. 1994]. These authors reported that 38% of the injured occupants were on the far side.

Frampton [1998] studied 295 crashes with belt restrained far-side occupants in England between June 1992 and April 1996. These cases included 46 MAIS 2 and 33 MAIS 3+ injuries. The MAIS 2 median delta V was 25 kph. The median MAIS 3+ delta V was 35 kph. Frampton found that the head and chest were the most frequently injured body regions.

Three US studies of far-side crashes [Digges 2001, 2006; Gabler 2005 and Yoganandan 2014] used different years of NASS CDS data. Each of the studies used similar controls that included the following: Passenger Cars or LTVs Only, GAD = Left or Right Side, No Rollovers, Occupant on Opposite Side of Impact, 3-Point Belt Restrained Occupants, Front Seat Outboard Occupants.

An early US analysis of far-side belted occupants in NASS CDS 1988-1998 was reported in a 2001 ESV paper [Digges, 2001]. The paper reported that a median lateral delta-V for AIS 3+ injuries was 30 kph. The most frequently AIS 3+ injured body regions were: chest/abdomen, 58%; head, 24% and spine 16%. The body region/contact combinations associated with the most frequent AIS 3+ injuries were: chest/abdomen to seatbelt, 20.6% and chest/abdomen to seatback and side interior, 17.2%. Occupant to occupant contacts accounted for less than 4%.

Gabler [2005], analyzing NASS CDS 1993-2002 data, showed that the median lateral delta-V for belted front seat occupants exposed to a far side impact was 12 km/hr. The median lateral delta-V for serious (AIS 3+) injuries was 28 km/hr. A principal direction of force of 60 degrees was most likely to be associated with serious injury. A PDOF of 60 degrees +/- 15 degrees was experienced by 60% of the seriously injured persons. The body regions with the highest number of AIS 3+ injuries were: chest/abdomen, 41% and head/face, 32%. The contacts for AIS 2+ head injuries were widely distributed with no source exceeding 10%. AIS 2+ head injuries from contacts with other occupants constituted 4.8% of the injuring sources. Unlike head injuries, the contacts for AIS 2+ chest and abdominal injuries were concentrated. For AIS 2+ chest injuries, 48% were attributed to the seat back and 24% to the safety belt. For AIS 2+ abdominal injuries, 87% were caused by the safety belt.

Yoganandan [2013] analyzed the NASS CDS database for the years 2009 to 2012 limited to vehicles of model year less than or equal to 10 years old at the time of the collision. Ejections were excluded. Injuries were coded using AIS 2005 and 2008. For the 519,195 weighted far-side occupants in the database, the authors found that the median lateral delta-V for belted front seat occupants exposed to a far-side impact was 19 km/hr. The median lateral delta-V for serious injuries was 42 km/hr. The most frequently injured body regions at the AIS 3+ level were: thorax, 69%; head, 50%; spine, 14% and abdomen, 13%.

APPROACH

The present study examines far-side occupants in NASS CDS 2004 to 2013. Far-side crashes were selected based on the damage region (left or right side) for the most severe impact event (GAD1) where the occupant was seated in the front row in the outboard position opposite the damaged side of the vehicle. Additionally far-side crashes that were preceded or followed by a rollover were excluded from this analysis. This was the same criteria used by the three studies listed previously. The resulting population of weighted far-side occupants in this new data set was 1,595,533. This larger data set allowed improved resolution for the far-side analysis, including the examination of injuring contacts, which was not available in the Yoganandan paper.

NASS CDS researchers code occupant injury contacts into one of more than 120 possible categories based on evidence within inspected vehicles and the nature of injuries sustained. A listing of the possible contact categories for drivers and right front passengers is included in the Appendix, Table A1. For the purpose of this study, contact sources and populations have been aggregated into 22 categories to allow for a simplified analysis of this data.

In order to maintain a consistent injury coding during the entire NASS period studied, AIS 1998 was applied in each year. The use of the 1998 coding permitted an analysis that was not influenced by changes in the injury coding and it allowed a better comparison with the results of earlier papers by Gabler and Digges. The 2005 and 2008 editions of the AIS code generally result in reducing the severity of selected injuries in the 1998 AIS code. A principal effect of the recent AIS coding changes on longitudinal studies has been to improve the apparent safety performance of vehicles in NASS CDS. This improvement is purely due to the injury coding and not to vehicle safety or human factors. When applied to 2010-2013 far-side data, the AIS 2008 code increased frequency of MAIS 3+ injuries by about 2 kph over the crash severity range from 25 to 50 kph. A comparison of the same NASS CDS data coded with the two different AIS coding systems is shown in Figure 1. The data is for belted MAIS 3+ injured front outboard occupants in far-side crashes. The comparison indicates how the use of two different AIS coding systems in a study can introduce confounding influences.

Beginning in 2010, NASS researchers began coding CDS applicable occupant injuries using AIS 2008 and retained AIS 1998 codes as well. The AIS 2008 coding definitions introduced new injury codes and adjusted AIS injury severity for a subset of existing injuries. The impact of this change was evaluated to determine its effect on the injured population distribution involved in far-side crashes. Figure 1 below shows the cumulative distribution curve for MAIS3+ injured versus lateral deltaV comparing the same population of cases coded in AIS 1998 versus AIS 2008.

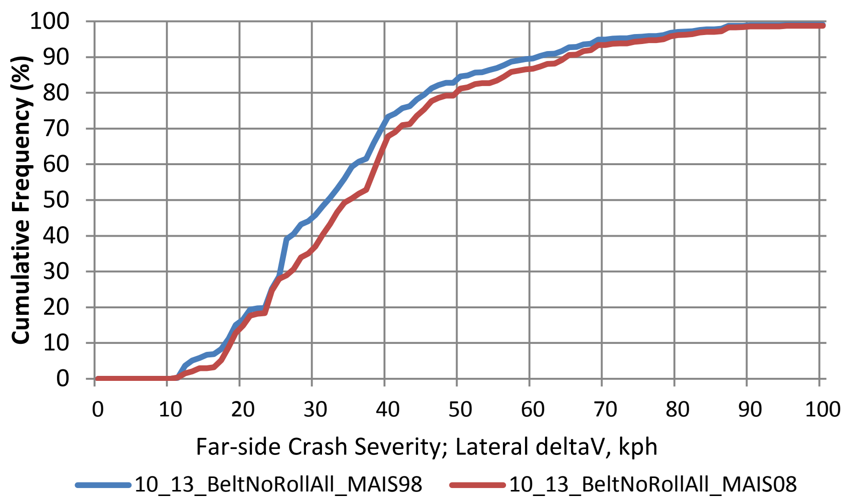

Figure 1. Comparison of NASS CDS 2010-2013 far-side data coded with AIS 1998 and AIS 2008 – Cumulative frequency of MAIS 3+ injured

RESULTS

An overview of the NASS CDS 2004 to 2013 data relative to far-side crash and injury frequency is presented in Table 1. Far side crashes that comply with the data restriction of the study constitute 9.5% of the crashes and 8.3% of the MAIS 3+ injured.

Table 1. Exposed Occupants and MAIS 3+ Injured (AIS 1998) for All Crashes and Far-side by Crash Year (weighted data)

Crash Year	All Crashes	Far-side Crashes	Far-side %	All MAIS 3+	Far-side MAIS 3+	Far-side MAIS 3+ %
2004	3,885,615	430,156	11%	97,190	6,781	7%
2005	3,760,785	379,505	10%	93,079	8,300	9%
2006	3,867356	393,353	10%	101,351	9,261	9%
2007	3,941238	405,134	10%	113,438	9,310	8%
2008	3,316723	369,800	11%	92,317	8,767	9%
2009	1,994830	196,864	10%	51,883	3,847	7%
2010	1,731751	162,610)	9%	30,466	1,984	7%
2011	1,687834	181,933	11%	27,346	2,722	10%
2012	3,157945	203,417	6%	24,438	1,308	5%
2013	3,164383	334,753	11%	34,295	2,674	8%
2004-2013	30,508,460	2,894,915	9.5%	665,803	54,954	8.3%

Figure 2 shows the NASS CDS 2004 to 2013 populations of far-side crashes by vehicle model year. As shown, the majority of findings here involve model year 2000-2008 vehicles with a reduced contribution from earlier and later model years. The increased crash count for older vehicles is a function of increased time exposure and does not indicate a reduction in far-side crash involvement for new vehicles as it appears in Figure 2.

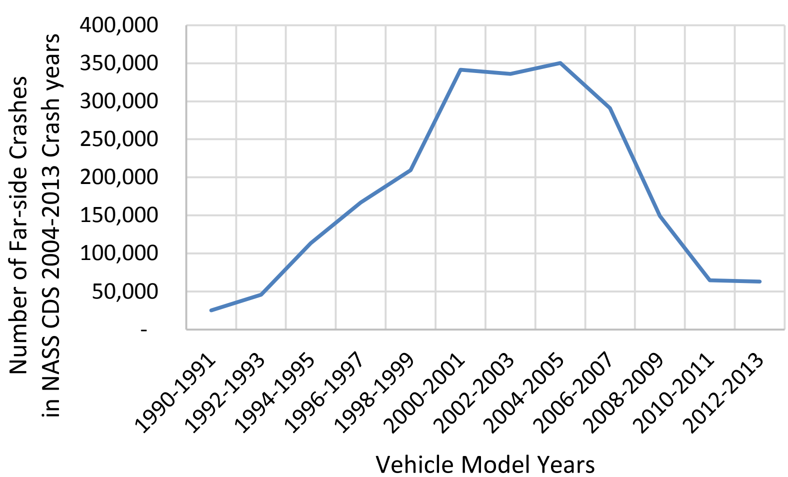

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Figure 2. Population of NASS CDS 2004-2013 light vehicles involved in far-side crashes by vehicle model year

Figure 3a and Figure 3b show the distribution of outboard front seat occupants and the resulting MAIS 3+ injured populations in far-side crashes respectively. Crashes involving rollovers were excluded. The figure shows that 75% of far-side involved occupants are drivers, and drivers make up 79% of MAIS3+ injured occupants.

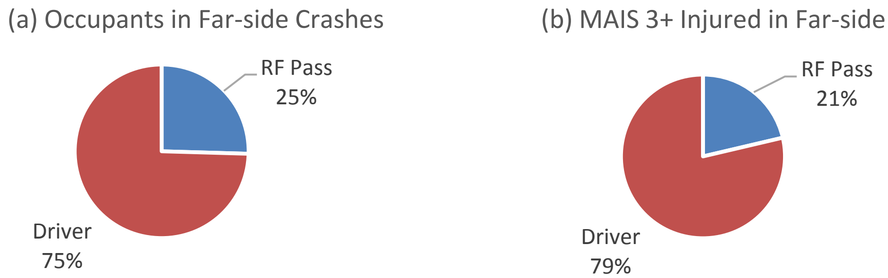

Figure 3. (a) Distribution of belted outboard front seat occupants and (b) MAIS 3+ injured (AIS 1998) belted front seat occupants in far-side crashes NASS CDS 2004 to 2013.

Figure 4 through Figure 10 use NASS CDS years 2004-2013 restricted to belted far-side occupants in front outboard seats with rollovers and ejections excluded. The MAIS3+ injured population includes AIS 3-6 and fatally injured coded using AIS 1998 unless otherwise noted.

Figure 4 shows the resulting cumulative frequency of exposed and MAIS 3+ injured occupants. The median delta V for exposed occupants was 15 kph. There has been an increase in the median delta V for MAIS3+ injured occupants since the earlier analyses. The current data shows a delta V increase to 36 kph compared with 28 kph reported in the Gabler study. This implies that 50% of the MAIS3+ population sustained their injuries during crashes with a total deltaV at or below 36 kph.

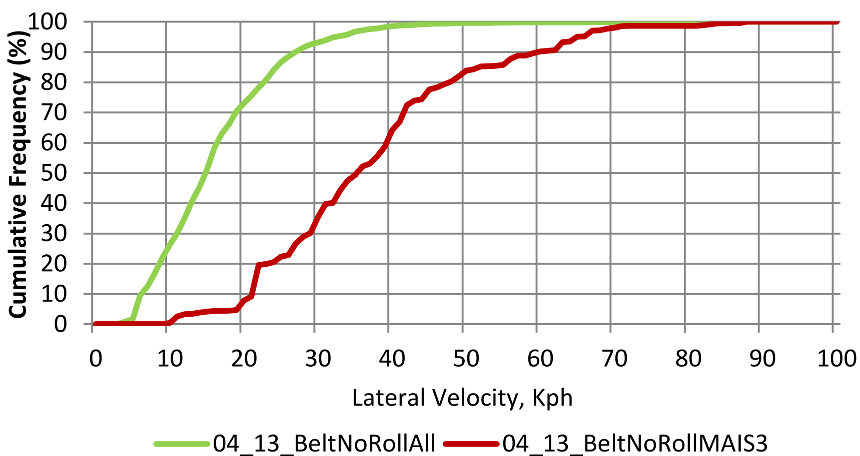

Figure 4. Cumulative frequency of belted outboard front seat occupants and those with MAIS 3+ injuries (AIS 1998) in far-side crashes NASS CDS 2004 to 2013

The distribution of occupants and MAIS 3+ injured by crash impact angle is displayed in Figure 5. For this figure, the left and right impacts angles are both measured as positive angles relative to the frontal direction at zero degrees. For example, pure lateral left side impacts are coded as 270 degrees in NASS but as 90 degrees for this plot. This approach permits left side and right side impacts be overlaid. The most frequent crash and injury direction of 60 degrees is consistent with the earlier findings of Gabler. In the Gabler analysis 60% of the MAIS 3+ injuries occurred at 60 degrees compared with 54% in the NASS CDS 2004 to 2013 data.

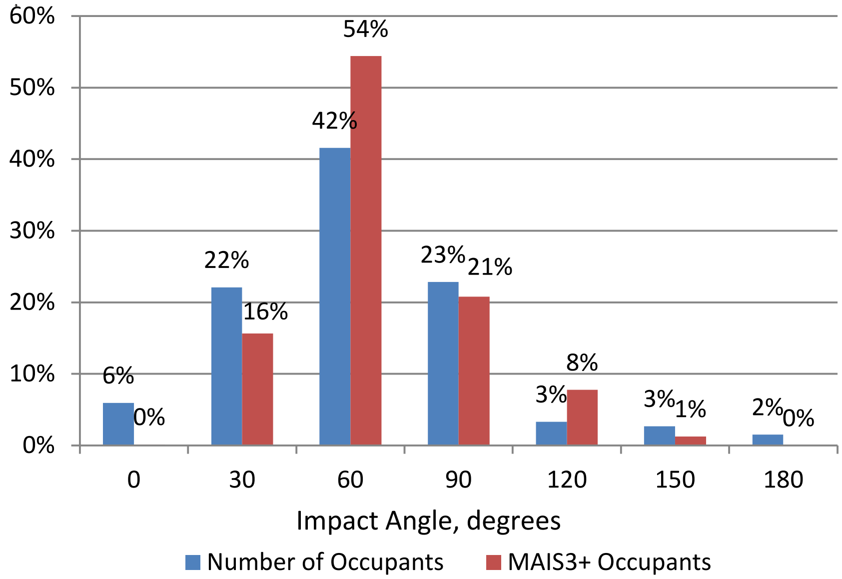

Figure 5. Distribution of belted outboard front seat occupants and those with MAIS 3+ injuries (AIS 1998) in far-side crashes by crash direction, NASS CDS 2004 to 2013

Figure 6 presents the horizontal damage area distribution for far-side belted occupants. The horizontal damage area is based on an SAE standard that defines the various horizontal areas of the vehicle as shown in the Figure 6 illustration. The most frequent crash and injury damage area at the Y location is consistent with the earlier findings of Gabler. In the Gabler analysis 42% of the MAIS 3+ injuries occurred in Y damage crashes compared with 34% in the NASS CDS 2004 to 2013 data. The largest change in the recent data was an increase in the MAIS 3+ injuries that occurred with distributed (D) damage. The distributed population of MAIS 3+ increased from 10% in Gabler to 20% in this later analysis.

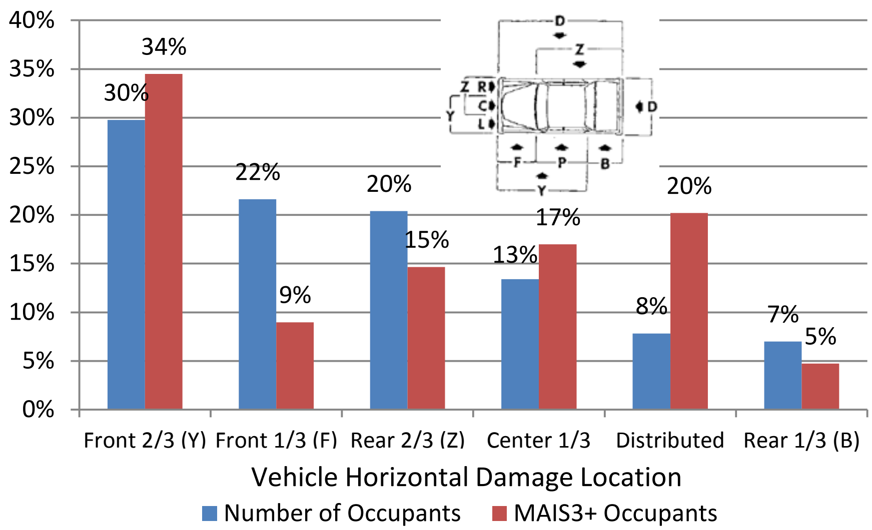

Figure 6. Distribution of belted outboard front seat occupants and those with MAIS 3+ injuries (AIS 1998) in far-side crashes by horizontal damage area, NASS CDS 2004 to 2013

Figure 7 compares the distribution of far-side occupants(a) , MAIS 3+ injured (b) and fatally injured (c) by collision partner and compares the results using older and newer data sets. NASS CDS 1993-2002 crash years were included for comparison with the 2004-2013 crash data. The newer data shows an increase in the population percentage of crashes with LTV's as the collision partner and an increase in the proportion of theMAIS 3+ injured and fatally injured for these collisions. In addition, the population percentage of fatalities during far-side crashes is significantly higher for fixed object crashes in the recent data compared with the earlier crash years.

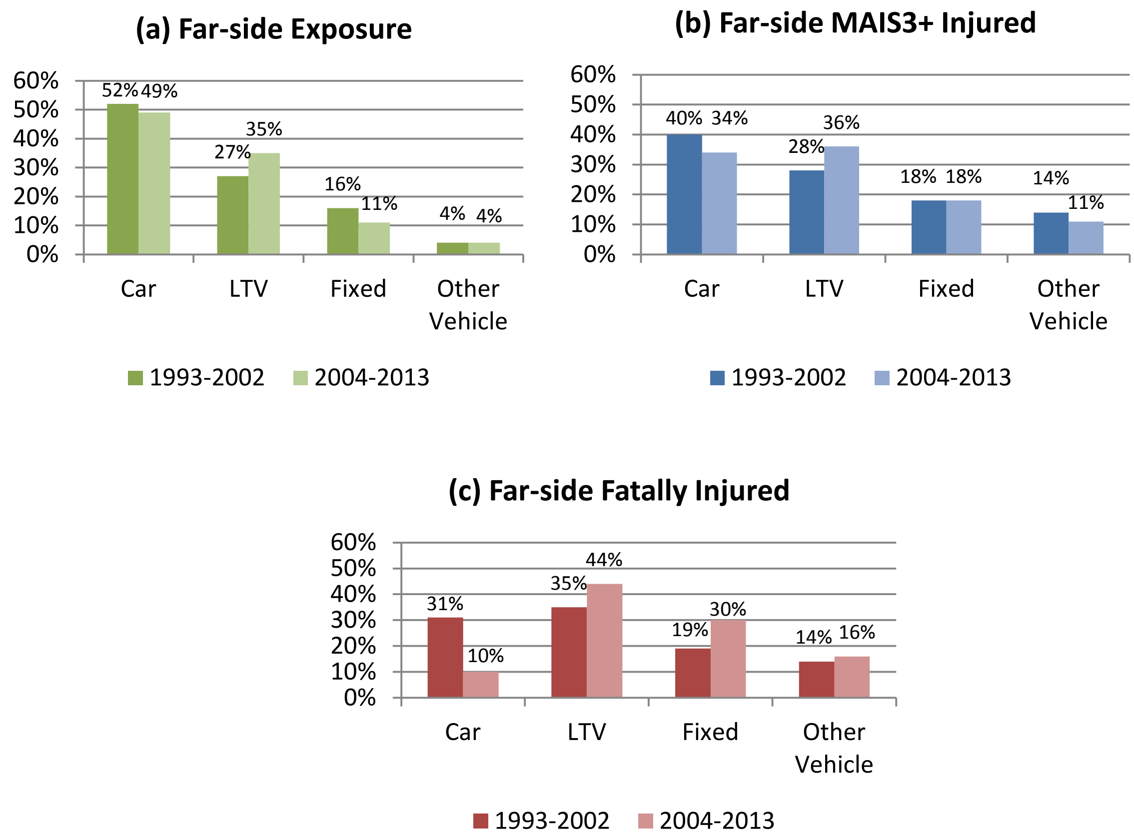

Figure 7. (a) Distribution of belted outboard front seat occupants by collision partner, (b) those with MAIS 3+ injuries (AIS 1998) and (c) those fatally injured in far-side crashes by collision partner, NASS CDS (1993-2002 vs. 2004 to 2013).

Figure 8 shows the annualized distribution of AIS3+ injuries in the population of exposed far-side occupants by injured body region. The injury distribution is generally consistent with earlier studies. Chest+Abdomen accounts for 43 % and head for 23%. In the earlier paper by Gabler, MAIS 3+ chest injuries were reported at 34 % and head injuries at 27%, showing a shift towards chest injuries in the more recent data.

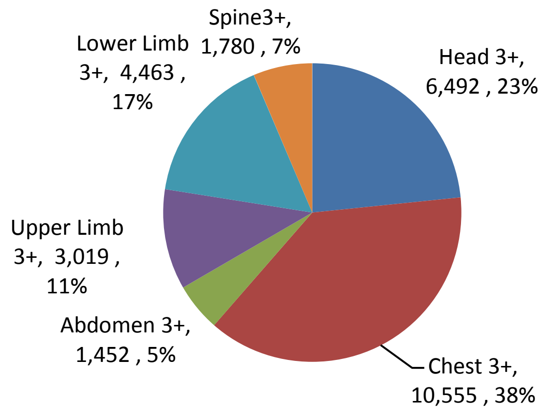

Figure 8. Distribution of AIS 3+ injuries (AIS 1998) by body region, belted front seat outboard occupants in far-side crashes NASS CDS 2004-2013 (Annualized data, weighted).

Figure 9 and Figure 10 display the aggregated injuring contacts for head and chest injuries. For belted front outboard occupants, occupant to occupant contact is responsible for 13.6% of the AIS 3+ head injuries and 4.9% of the AIS 3+ chest injuries suffered in far-side crashes. The far side structure was by far the most frequent head injury contact, causing close to 62% of the AIS3+ injuries. The front seat back was the most frequent source of chest injuries and in combination with the center stack, accounted for over 53% of the AIS3+ injuries, followed by the far side structure and belt/restraints.

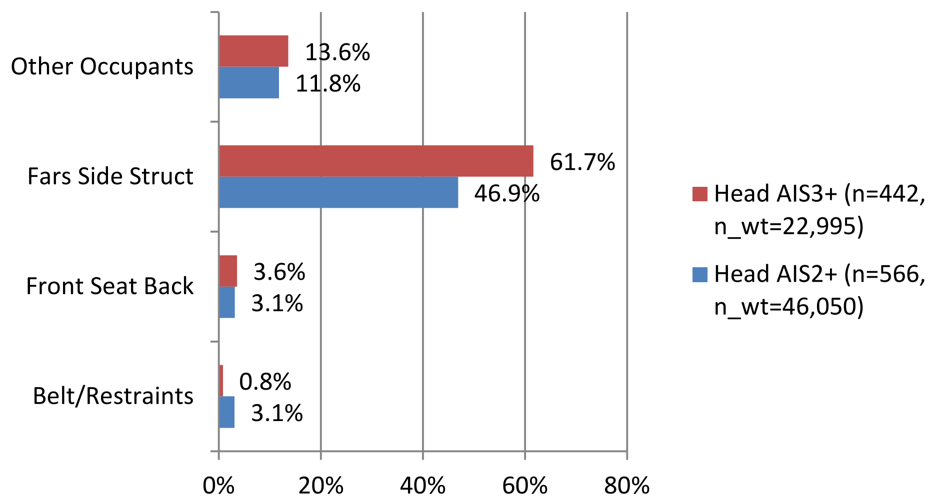

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Figure 9.Top 4 Contributors Amenable to Far-side Countermeasures: AIS 2+ and AIS 3+ head injuries (AIS 1998) by injuring contact for belted front outboard seat occupants in far-side crashes NASS CDS 2004-2013

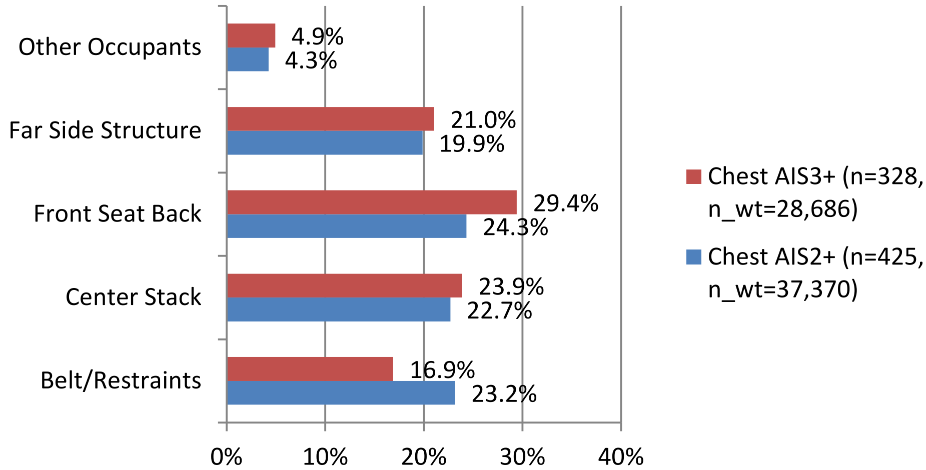

Figure 10. Top 5 Contributors Amenable to Far-side Countermeasures: AIS 2+ and AIS 3+ chest injuries (AIS 1998) by injuring contact for belted front outboard seat occupants in far-side crashes NASS CDS 2004-2013

An in-depth review was conducted including all NASS CDS 2004-2013 cases where more than one front seat occupant was present and one or more AIS3+ head injury was sustained by either occupant. Overall, 310 raw cases representing 17,047 AIS3+ head injured occupants were analyzed. Overall, 383 total weighted occupants (2.25% of all MAIS3+ injured) were flagged as having AIS3+ head injuries with evidence of head to head contact within this sample.

Figure 11and Figure 12 compare crash severity for occupants and MAIS 3+ injured when exposed to near-side and far-side crashes. The median crash severity for the exposed populations was 15 kph vs 17 kph for near-side vs. far-side belted front outboard occupants. For the MAIS 3+ injured, the median near-side crash severity was 31.5 kph compared with 36 kph for far-side occupants.

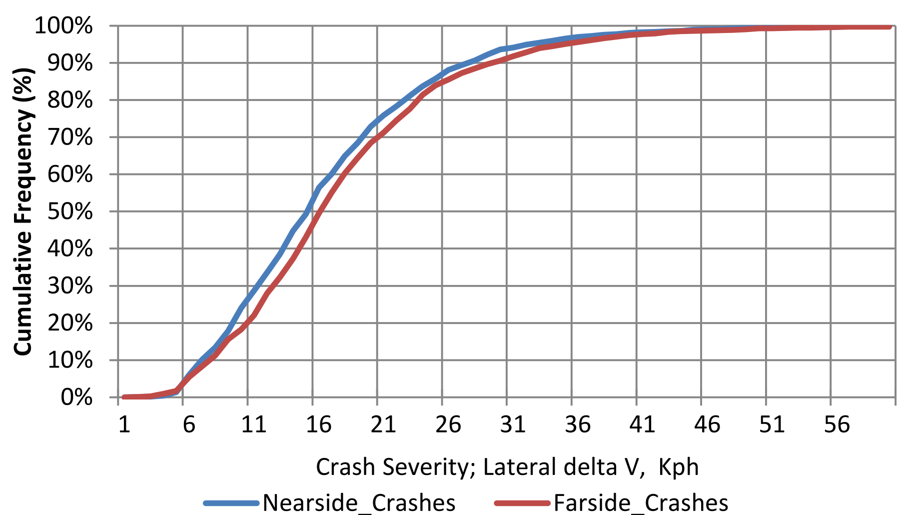

Figure 11. Cumulative frequency of belted outboard front seat occupants in near-side and far-side crashes NASS CDS 2004 to 2013

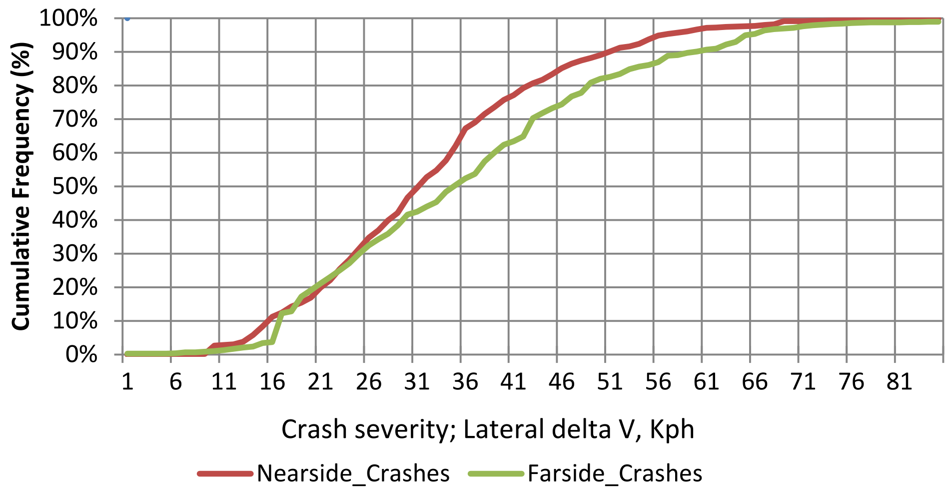

Figure 12. Cumulative frequency of belted outboard front seat occupants with MAIS 3+ injuries in near-side and far-side crashes NASS CDS 2004 to 2013

Figure 13 provides a summary of the odds of MAIS3+ injury by model year grouping. This result is based on a multivariate logistic regression model controlling for deltaV, specific horizontal location of damage to the vehicle, extent of damage, occupant age and model year group. The comparison group is the model year 2000-2004 category controlling for other factors. As shown, there is a statistically measurable decrease in the odds of MAIS3+ injury during nearside crashes for the model year 2005-2014 group, which cannot be seen in the far side crash data set.

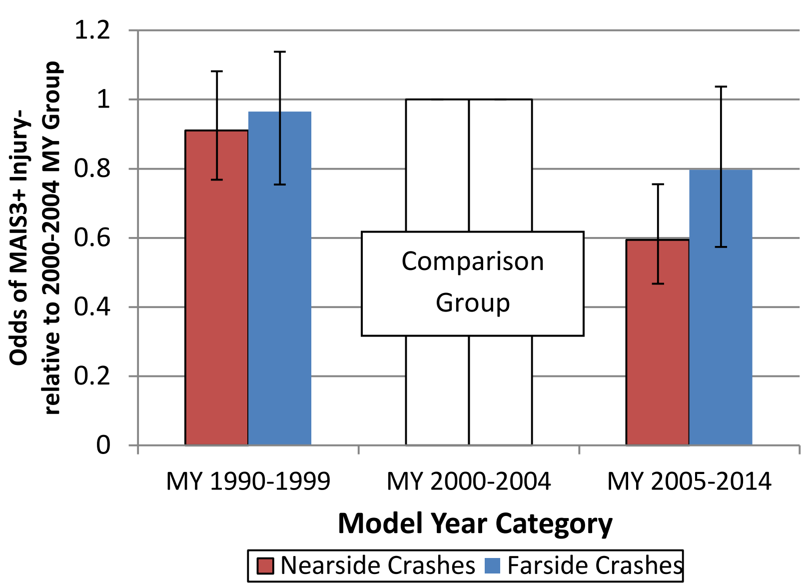

Figure 13. Far-side involved versus MAIS 3+ injuries by vehicle model year group NASS CDS 2004 to 2013

Figure 14 compares front outboard crash involved populations with MAIS3+ injured population by US NCAP vehicle size category for the impacted vehicle. Category sizes are as follows:

- Passenger cars mini (PC/Mi) (1,500–1,999 lbs.)
- Passenger carslight(PC/L) (2,000–2,499 lbs.)
- Passenger cars compact(PC/C) (2,500–2,999 lbs.)

- Passenger cars medium (PC/Me) (3,000–3,499 lbs.)
- Passenger cars heavy (PC/H) (3,500 lbs. and over)
- Sport utility vehicles(SUV)
- Pickup trucks(PU)
- Vans(VAN)

As seen in Figure 14, the light vehicle population is overrepresented in the MAIS3+ injured category relative to the occupants exposed (7.4% of the involved and 20.0% of the MAIS3+ injured). Due to the reduced occupant comparment size for Passenger cars in the Light vehicle category, improved far-side crash protection may have an even greater impact on occupants riding in vehicles within this category.

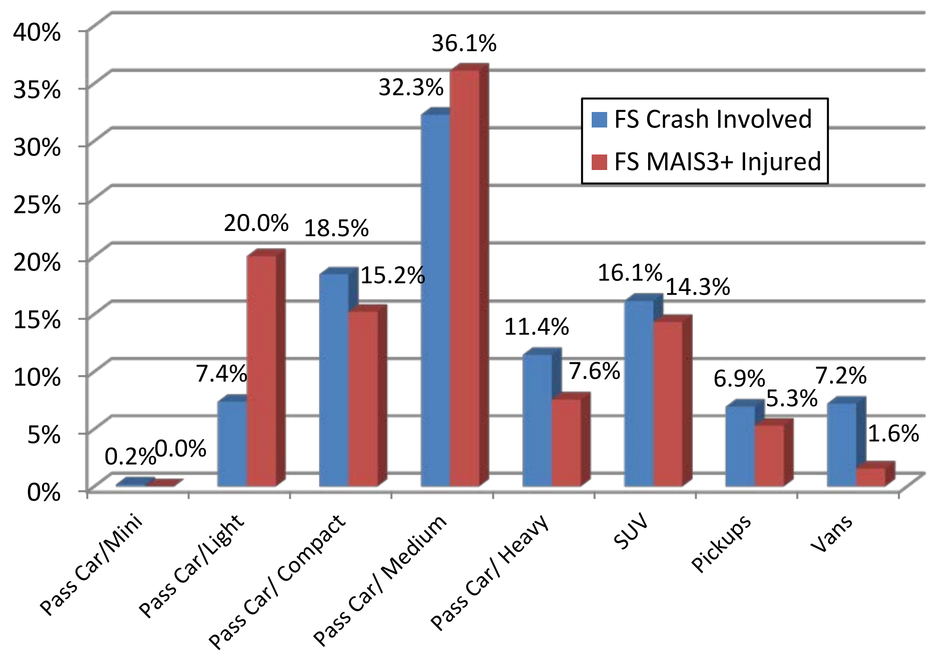

Figure 14. Far-side involved versus MAIS 3+ injuries by NCAP Vehicle Class NASS CDS 2004 to 2013

DISCUSSION

The use of the AIS 1998 coding for the MAIS 3+ injuries in NASS years 2004 to 2013 permitted a comparison of the analyses conducted under this study with the earlier comprehensive analysis that used 1993 to 2002 data [Gabler 2005]. As shown in Figure 1, the use of different AIS coding introduces confounding factors that obfuscate the influence of vehicle safety changes. The use of AIS 2008 coding tended to reduce the exposed delta V for MAIS 3+ injured in far side crashes by about 2 kph over the crash severity range of 25 to 50 kph lateral delta V.

The NASS 2004 to 2013 data shows that 75% of far-side involved occupants are drivers, and drivers make up 79% of MAIS3+ injured occupants. This data indicates that drivers are over represented among the MAIS 3+ injured occupants.

The recent decade of data (Figure 5) shows that the most frequent impact angle is 60 degrees and the most frequently damaged area of the vehicle side is the forward 2/3, known as the Y damage pattern. These results are consistent with the earlier findings of Gabler. However, the frequency of MAIS 3+ injured in vehicles with distributed damage increased from 10% in the 1993-2002 data to 20% in the 2004-2013 data.

Figure 7 shows a difference in far-side crash characteristics that has occurred in recent data years. In earlier data years passenger cars were the most frequent crash partner for both exposure and MAIS 3+ injuries. In the recent years, passenger cars have been replaced by light trucks and vans (LTV) as the most frequent crash partner for MAIS 3+ injuries. Since LTV's are generally heavier than passenger cars, the crash severity of the struck vehicle would be expected to increase, all other factors being equal. This was found to be the case. In the Gabler study, the median delta V lateral velocity for MAIS 3+ injured was 28 kph. In contrast, the present study found the median velocity to be 36 kph. The higher distributed damage frequency in recent vehicles with MAIS 3+ injured occupants may also be influenced by the increased frequency of LTV's as the striking vehicle.

Both the present and the earlier studies found that the chest was the body region most frequently injured at the MAIS 3+ level. The chest/abdomen AIS 3+ constituted 41% of the injuries in the Gabler study and 43% in this study. The head/face accounted for 32% of AIS 3+ in Gabler and 23% in this study.

Gabler found that occupant to occupant contact was attributed to 4.8 % of the AIS 2+ head injuries compared with 11.8% in this study as shown in Figure 9. Of note is the fact that the current study aggregates driver and right front passenger injury contact data while previous studies report driver experience alone. For AIS 2+ chest injuries, occupant to occupant contact was associated with 3.7% of the chest injuries compared with 4.3% in this paper as shown in Figure 10. In both data sets the AIS 2+ injuries from occupant to occupant contact is small.

As shown in Figure 9 and Figure 10, the percentage of AIS 3+ head and chest injuries from occupant to occupant contact was 13.6% and 4.9% respectively. Protection opportunities limited to head to head contact would address about 2.25% of the far-side AIS 3+ head and chest injuries for belted front outboard seated far side occupants.

The occupant to occupant protection opportunities are extremely modest when compared to the 65.3% of AIS 3+ head injuries caused by contact with the seat back and far side interior. For the driver AIS 3+ chest injury contacts, 53.3% could be addressed by mitigating occupant contacts with the seat back and center stack and another 21.0% are associated with far side interior contacts. Finally, 16.9% are attributed to safety belt contacts.

Countermeasures that reduce the excursion of the upper body and mitigate the severity of contacts with the seat back, center stack, and far-side interior offer the possibility of addressing at least 65.3% of the head injuries and 74.3% of the chest injuries at the AIS 3+ level.

Belt loading was associated with 16.9% of the MAIS 3+ chest injuries. Earlier studies of occupant kinematics in far-side crashes indicate that the occupant frequently comes out of the shoulder restraint and the upper body translates across the vehicle [Digges 2001, Alonzo 1999, Pintar 2006, 2007]. In a study of post mortem human specimens in far-side sled tests at 16 and 34 kph, Kent found that increased engagement of the shoulder belt decreased the lateral head excursion but increased the risk of chest injury (Kent 2013). The authors observed that in the tests a substantial portion of the belt loading passed through the lower portion of the contralateral rib cage; a region with lower injury resistance to the oblique loading when compared to loading of the superior ribs and shoulder in frontal crashes by the belt. A related type of belt loading in low severity real world crashes has been shown to produce severe liver injuries to drivers restrained by 2 point belts (Augenstein 2000). The tests conducted by Kent also demonstrated that effective restraint engagement of the chest can generate lateral bending of the cervical spine sufficient to generate injury from head inertia. These research results suggest the need for carefully monitoring the risk of chest and abdominal injuries from belt loading when evaluating far-side countermeasures.

Figure 11 and Figure 12 show crash severity comparisons of populations exposed to near-side and far-side crashes. For the far-side crashes, the median crash severity is 17 kph; about 2 kph higher than for the near-side population. For the MAIS 3+ injured population the median far-side crash severity is 36 kph; 4.5 kph higher than for the near-side MAIS 3+ population.

Figure 13 suggests that there is a statistically measurable decrease in the odds of MAIS3+ injury during nearside crashes for the model year 2005-2013 group. A non-significant and reduced improvement is observed for 2005-2013 model year far-side involved vehicles. This suggests that countermeasures and design changes have been introduced and have impacted nearside occupant protection while greater opportunities remain to improve far-side protection.

As shown in Figure 14, light passenger vehicles are overrepresented in the MAIS3+ injury category per crash involvement. This observation follows logically from the fact that occupant compartment sizes are smaller as vehicle mass decreases increasing the risk for far-side compartment contact by the head during far-side crashes and through interaction with intruding structures in some cases.

CONCLUSIONS

One major change in the far-side crashes in newer vs. older NASS CDS data years has been an increase in the frequency of pickups, SUV's and vans as the collision partner. In the recent NASS CDS years reported in this paper, the median crash severity for MAIS 3+ belted front seat outboard occupants has increased by 4.5 kph. For the MAIS 3+ population, the frequency of distributed damage (damage to the entire side of the struck vehicle) has increased from 10% to 20%.

The following characteristics are the most representative NASS CDS 2004-2013 the crash conditions associated with MAIS 3+ injured belted front seat outboard occupants exposed to far-side crashes:

MAIS 3+ injury exposure: 79% driver; 21% right front passenger

Median crash severity – lateral delta V; 36 kph.

Most frequent crash directions -

- 54% of MAIS 3+ at 60 degrees
- 21% of MAIS 3+ at 90 degrees

Most frequent vehicle horizontal damage areas for AIS3+ injured occupants-

- Front 2/3 (Y) - 34%
- Distributed (D) - 20%
- Center passenger compartment - 17%

Body region injured (belted outboard front seat occupants):

- 43% of AIS 3+ is to the Chest/Abdomen
- 23% of AIS 3+ is to the Head

Most frequent head injuring contacts for 23% of MAIS 3+ (belted outboard front seat occupants,)

- Far-side structure - 61.7%
- Other occupant – 13.6%

Most frequent chest/abdomen injuring contacts for 43% of MAIS 3+ (belted outboard front seat occupants,)

- Front seat and center stack - 53.3%
- Far-side structure – 21.0%
- Safety belt - 16.9%
- Other occupant – 4.9%

As belt systems improve in upper body retention for far-side protection, excessive lateral loading of the lower ribs is undesirable due to the increased vulnerability of this body region to injury. Additional studies are recommended to assess suitable belt loading criteria for far-side crashes.

Only 2.25% of belted AIS3+ head and chest injured occupants involved in far-side collisions sustained their injuries due to head to head contact with another front seat occupant. Overall, these findings suggests that greater opportunities to reduce injuries exist in limiting occupant lateral movement when compared to the benefits of preventing head to head contact alone when more than one front outboard occupant is present.

REFERENCES

[1] The Abbreviated Injury Scale. Des Plaines, IL: Association for the Advancement of Automotive Medicine; 1998

[2] The Abbreviated Injury Scale. Des Plaines, IL: Association for the Advancement of Automotive Medicine; 2005.

[3] The Abbreviated Injury Scale. Des Plaines, IL: Association for the Advancement of Automotive Medicine; 2008.

[4] Alonso, B, Digges, K, and Morgan, R, Far-side vehicle simulations with MADYMO", SAE 2007-01-0378, April 2007.

[5] Augenstein J, Perdeck E, Bowen J, et al. Injuries to restrained occupants in far-side crashes. Annu Proc Assoc Adv Automot Med 1999;43:139–158.

[6] Augenstein, J, Digges, K., and others, "Dummy Measurements of Chest Injuries Induced by Two-Point Belt Systems", 44th Annual Proceedings of the Association for the Advancement of Automotive Medicine, October, 2000.

[7] Digges KH, Dalmotas D. Injuries to restrained occupants in far-side crashes. In: Proceedings of the International Conference on Enhanced Safety of Vehicles, Amsterdam, The Netherlands; 2001.

[8] Digges, KH, Echemendia, C, Fildes, B, and Pintar, F, A safety rateing for far-side crashes, Paper Number 09-0217, Proceedings of the 21st ESV Conference, Washington DC, June 2009.

[9] Digges KH, Gabler HC. Opportunities for reducing casualties in far-side crashes. In: Proceedings of the SAE Conference, Warrendale, PA: SAE; 2006.

[10] Digges KH, Gabler HC, Mohan P, Alonso B. Characteristics of the injury environment in far-side crashes. Annu Proc Assoc Adv Automot Med. 2005;49:185–197.

[11] Fildes BH, Fitzharris M, Gabler CH, Digges K, Smith S. Chest and abdominal injuries in far-side crashes. In: Proceedings of the ESV Conference, 2007:43–56.

[12] Fildes, B, and Digges, K, (editors), Occupant protection in Far-side Crashes, Final Report on International Collaborative Research on Far-side Protection, GW University and Monash University Report, June 2009. http://autosafetyresearch.org/pdfs/Far-side%20final%20report%20Finalx.pdf

[13] FMVSS-214. Side Impact Protection. Washington, DC: US Government Printing Office; 1990. 49 CFR; Parts 571. FMVSS-214. Washington, DC: US Government Printing Office; 2008 49 CFR: 571.214.

[14] Frampton R, Brown R, Thomas P, Fay P. The Importance of non-struckside occupants in collisions. 42nd Annu Proc Assoc Adv Automot Med. 1998;303–320.

[15] Gabler HC, Digges K, Fildes BH, Sparke L. Side impact injury risk for belted far-side passenger vehicle occupants. Journal of Passenger Car - Mechanical Systems. 2005;114:1–9.

[16] Kent, R, Forman, J, Lessey, D, Arbogast, K, Higuchi, K, A parametric study of far-side mechanisms, Proceedings of the 23rd ESV Conference, Seoul, Korea, May 2013.

[17] Mackay M, Parkin S, Hill JR, Munns J. Restrained occupants on the nonstruck side in lateral collisions. 35th Annu Proc Assoc Adv Automot Med. 1991;35:119–131.

[18] Newland, C., Belcher, T., Bostrom, O., Gabler, H., Cha., J., Wong, H., Tylko, S., and Dal Nevo, R., “Occupant-to-Occupant Interaction and Impact Injury Risk in Side Impact Crashes”, Stapp Car Crash Journal, Vol 52, pp..327-347, 2008.

[19] Pintar FA, Yoganandan N, Stemper BD, et al. Comparison of PMHS, WorldSID, and THOR-NT responses in simulated far side impact. Stapp Car Crash J. 2007;51:313–360.

[20] Pintar FA, Yoganandan N, Stemper BD, et al. WorldSID assessment of far side impact countermeasures. Annu Proc Assoc Adv Automot Med. 2006;50:199–219.

[21] Thomas P, Frampton R. Injury patterns in side collisions—a new look with reference to current test methods and injury criteria. In: Proceedings of the 43rd Stapp Car Cash Conference, 1999:13–24.

[22] Yoganandan, N, Arun, M, Halloway, D, Pintar, F, Maiman, D, Szabo, A, Rudd, A, Crash characteristics and injury patterns of restrained front seat occupants in far-side impacts, . Annu Proc Assoc Adv Automot Med. 2014;58:27-34

APPENDIX

Table A.1

Injury_Source_Cat	Injury Source	Injury_Source_Category	Injury Source
Belt/Restraints	Belt Restraint Webb/Buckle	Left Side Struct (Far Side Structure)	Left Forward Upper Quadrant
	Belt B Pill Atch		Left Forward Lower Quadrant
	Oth Restr Sys Compon		Left Rear Upper Quadrant
Center Stack	Floor Or Console Transmiss Lever		Left Rear Lower Quadrant
Dr Side Bags_Any	Air Bag-Dr Side		Left Armrest/Hardware In Forward Upper Quadrant
	Bag-Dr Side+Eyew		Left Armrest/Hardware In Forward Lower Quadrant
	Bag-Dr Side+Jlry		Left Armrest/Hardware In Rear Upper Quadrant
	Bag-Dr Side+Obj		Left Armrest/Hardware In Rear Lower Quadrant
	Bag-Dr Side+Mout		Roof Left Rail
	Bagcover-Dr Side	Oth Vehicle_Ext Struc	Other Exterior Surface Or Tires
Front Seat Back	Seat, Back Support		Unk Exterior Obj
	Head Restraint Sys		Omv Front Bumper
Glass_Noncontact	Flying Glass		Omv Hood Edge
	Other Noncontact Inj Source		Omv Other Front Of Veh
Ground	Ground		Omv Hood
Instr Panel Ctr	Center Panel		Omv Windshield, Roof Rail, A-Pillar
	Center Ins Panel		Omv Side Surface
	Ce Low Instru Panel		Omv Side Mirrors
Instr Panel Left	Left Pane;		Omv Side Protrus
	Knee Bolster		Omv Rear Surface
	Left Instr Panel		Omv Und/Carriage
	Low Lt Instru Panel		Omv Tires/Wheels
Instr Panel Rt	Right Panel		Omv Oth Exterior
	Glove Compartment Door		Omv Unk Exterior
	Right Ins Panel		Oth Obj
	Rl Instru Panel	Other Occupants	Other Occupants
Left Side Struct (Far Side Structure)	Left Interior	Pass Side Bags_Any	Air Bag-Ps Side
	Left Hardware		Bag-Ps Side+Eyew
	Left A (A1/A2)Pillar		Bag-Ps Side+Jry
	Left B Pillar		Bag=Ps Side+Obj
	Oth Left Pillar		Bag=Ps Side+Mout
	Left Window Glas		Bagcover-Ps Side
	Left Window Fram		Bagcvr-Psside+Ey
	Left Window Sill		Bagcvr-Psside+Ob
	Left Window+Oth	Right Side Struct (Far Side Structure)	Right Interior
	Left Side Glass Reinforced By Ext Obj		Right Hardware
	Left Side Panel Forward Of A1/A2 Pillar		Right A (A1/A2) Pillar
	Left Side Panel Rear Of The B-Pillar		Right B Pillar

Table A.1, continued

Injury_Source_Cat	Injury Source	Injury_Source_Category	Injury Source
Right Side Struct (Far Side Structure)	Oth Right Pillar	Steer Assembly	Steering Wheel Combo Of Rim And Hub/Spoke
	Right Side Wind Glass		Steering Column, Transmission Selector Lever
	Right Side Wind Frame		Hand Ctrls For Braking/Accel
	Right Side Window Sill		Steering Ctrl Devices
	Right Side Window+Oth		Steering Knob Att To Steering Wheel
	Right Side Panel Forward Of A1/A2 Pillar		Repl Steer Whl
	Right Side Panel Rear Of The B-Pillar		Joy Stick Steering Ctrl
	Right Forward Upper Quadrant	Toe/Floorpan Pan	Floor (Includ Toe Pan)
	Right Forward Lower Quadrant		Foot Controls Includ Parking Brake
	Right Rear Upper Quadrant	Unknown	Inj, Unknown Source
	Right Rear Lower Quadrant	Windshield/Fr Header	Windshield
	Right Armrest/Hardware In Fwd Upper Quadrant		Mirror
	Right Armrest/Hardware In Fwd Lower Quadrant		Sunvisor
	Right Armrest/Hardware In Rear Upper Quadrant		Windshld Dr Side Only
	Right Armrest/Hardware In Rear Lower Quadrant		Windshld Ps Side Only
	Roof Right Rail		Reinforced Wndsh By Ext Obj
Roof	Roof/Convertible Top		Sunvisor Reinforced By Ext Obj
Steer Assembly	Steering Wheel Rim		Front Header
	Steering Wheel Hub/Spoke		