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Crash characteristics and injury patterns of restrained front seat occupants in far-side impacts

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STRUCTURED ABSTRACT

Objective—The study was conducted to determine the association between vehicle-, crash- and demographic-related factors and injuries to front seat far-side occupants in modern environments.

Methods—Field data were obtained from the United States (US) National Automotive Sampling System – Crashworthiness Data System (NASS-CDS) database, for the years 2009–2012.

Inclusion factors: adult restrained front outboard seated occupants, no ejection or rollovers, and vehicle model years less than 10 years old at the time of crash. Far-side crashes were determined by using collision deformation classification. Injuries were scored using the Abbreviated Injury Scale (AIS). Injuries (MAIS2+, MAIS3+, M denotes maximum score) were examined based on demographics, change in velocity, vehicle type, direction of force, extent zone, collision partner and presence of another occupant in the front seat. Only weighted data were used in the analysis. Injuries to the head and face, thorax, abdomen, pelvis, upper extremity and lower extremity regions were studied. Odds ratios and upper and lower confidence intervals were estimated from multivariate analysis.

Results—Out of 519,195 far-side occupants, 17,715 were MAIS2+ and 4,387 were MAIS3+ level injured occupants. The mean age, stature, total body mass, and BMI were 40.7 years, 1.7 m, 77.2 kg, and 26.8 kg/m², respectively. Of occupants with MAIS2+ injuries, 51% had head and 19% had thorax injuries. Of occupants with MAIS 3+ injuries, 50% had head and 69% had thorax injuries. The cumulative distribution of changes in velocities at the 50th percent level for the struck vehicle for all occupants and, MAIS2+ and MAIS3+ occupants were 19, 34 and 42 km/h, respectively. Furthermore, 73% of MAIS2+ injuries and 86% of MAIS3+ injuries occurred at a change in velocity of 24 km/h or greater. Odds of sustaining MAIS2+ and MAIS3+ injuries increased with unit increase in change in velocity, stature and age, with one exception. Odds of sustaining injuries were higher with the presence of an occupant in the front seat at the MAIS3+ level, although it was reversed at the lower level. The extent zone of 3+ increased the odds compared to the extent zones of 1 to 2 at both MAIS2+ and MAIS3+ injuries. Odds ratios and confidence interval are given.

Conclusions—Findings that head and thorax are more frequently injured body regions, prevalence of cranium injuries are similar at both injury severities; thoracic injuries are more prevalent at the MAIS3+ level; presence of another front seat occupant plays a role in MAIS3+ trauma; injuries continue to occur at change in velocities representative of side impact environments; mean demographic factors are close to mid-size automotive anthropometry, indicate the need to pursue this line of study. Because data were gathered from only four years, it would be important to include additional NASS-CDS database years, rescore injuries from previous years and/or analyze other international databases to reinforce these findings for advancing safety for far-side occupants.

Keywords

far-side crashes; NASS-CDS; change in velocity; motor vehicle injuries; restrained occupant

INTRODUCTION

Side impacts can be classified based on the position of the occupant with respect to the impacting vector as nearside and far-side occupants (Fildes et al., 1991, 1994; Frampton et al., 1998; Gabler et al., 2005a; Yoganandan et al., 2007a). Current United States Federal Motor Vehicle Safety Standards (FMVSS) are focused primarily on injuries and safety to the nearside occupant. Fundamental field data used during the development of the original FMVSS and its recent update are based on nearside occupants (FMVSS-214, 1990; Kuppa et al., 2003; Yoganandan and Pintar, 2005a). Studies to analyze injuries to nearside occupants were conducted using US databases such as the National Automotive Sampling System - Crashworthiness Data System (NASS-CDS) and Crash Injury Research Engineering Network (Augenstein et al., 2000; FMVSS-214, 1990, 2008; Gabler et al., 2005a; Yoganandan et al., 2007b). Research simulating these impacts in a laboratory setting has been based on subjecting intact Post Mortem Human Surrogates (PMHS) to contact monolithic or segmented load walls with varying initial/end conditions and impact velocities, from which biomechanical response corridors of different regions of the torso have been derived using forces, accelerations and deformations (Maltese et al., 2002; Pintar et al., 1997; Yoganandan and Pintar, 2005a, 2005b; Yoganandan et al., 2008; Yoganandan et

al., 2007a). Some of these studies have assisted in developing injury criteria for modern side impact dummies such as the ES-2re which is in the current US regulations (Kuppa et al., 2003). Nearside impact research with different angulations of the vector continue to be an area of study as recent field data has suggested increasing incidence and injuries from oblique crashes (Yoganandan et al., 2012, 2013a).

However, far-side impacts have begun to receive more attention, although research efforts examining injury patterns and associated crash characteristics are relatively sparse (Bostrom et al., 2008; Digges and Gabler, 2006). Studies were initiated in the United Kingdom and Australia. In an early study using data gathered in Birmingham, England, from 1983–1989, 193 far-side crashes to belted occupants were examined (Mackay et al., 1991). The authors reported that contacts with the belt systems were the most frequent source of thorax and abdominal injuries, and among head injured occupants, approximately one-third came out of the belt. Another study conducted using the Australian field data gathered between 1989 and 1992, examined 198 side impact crashes to 234 occupants (Fildes et al. 1994). These authors reported that 38% of the injured occupants were on the far-side and furthermore, these occupants had different types of contact loadings within the vehicle. In another international study, field data from the United Kingdom Midlands between 1992 and 1996 were gathered from 295 lateral crashes to restrained far-side occupants (Thomas and Frampton, 1999). Approximately one-third of all AIS3+ injuries and fatalities occurred to these occupants. In addition, the head and thorax were found to be the most commonly injured body regions although the authors ignored physical interactions with other occupants.

In a lateral impact study using the US NASS-CDS database from 1988 to 1996 and the William Lehman Injury Research Center (WLIC) data from 1995 to 1998, far-side occupant exposure was found to be approximately one-third of all crashes regardless of the database (Augenstein et al., 1999). A later study focused on far-side crashes and used the NASS-CDS and WLIC data for the years 1988 to 1998 and 1994 to 1998 (Augenstein et al., 2000). It was found that the head and chest were the two most frequently injured body regions to restrained front outboard occupants. The seat was the most frequent source of MAIS3+ injuries for weighted data and “the seat belt contact” was identified as a frequent source for raw data. A study envisaged by an international consortium has been a primary driver of recent research in the far-side impact area. During an analysis of NASS-CDS data for the years 1993 to 2002, it was found that far-side impacts accounted for 43% of seriously injured occupants (Gabler et al., 2005a). A parallel study used NASS-CDS for the years 1993 to 2003 to determine the role of variables such as velocity and extent zone (Digges et al., 2005). While these studies have examined early data on far-side impacts, injury patterns and crash characteristics associated with recent model year vehicles should be examined. In other words, association between vehicle-, crash- and demographic-related factors and injuries to far-side occupants in modern environments should be examined. The aim of this research is to conduct a descriptive study of far-side impacts. Specifically, using a more recent database and injury coding, the outcome variables of interest were vehicle-, crash- and occupant-related factors and injuries. The motivation for choosing these variables in the descriptive study is to provide fundamental data to advance crashworthiness for this type of impact which has received relatively less attention compared to nearside impacts.

METHODS

Case Selection

The US NASS-CDS database for the years 2009 to 2012 was used in the study (USDOT). Appendix A includes a description of the database and weighting factors. The study limited the analysis to vehicles of model year less than or equal to 10 years old at the time of the collision. This is because beginning in the year 2009 NHTSA implemented a new sampling procedure in NASS in which injury information was not collected on occupants in vehicles more than 10 years old at the time of the collision. Far-side occupants were defined as outboard occupants seated on the contralateral side of the impact. For example, impact vectors corresponding to 260- to 310-degrees used the right front passenger and likewise, 50- to 100-degrees used the driver seating position, representative of US driving conditions. Far-side crashes were determined by using the third character of the Collision Deformation Classification (CDC). Drivers were selected if the General Area of Damage (GAD) was right and the right front passenger was selected for injury analysis if GAD code was left. All data were analyzed at the occupant level and all occupants were in the front outboard seat, restrained with a three-point belt. Occupants were not ejected. In addition, rollovers were excluded. AIS codes were used in the study.

Variable definitions

Briefly, AIS is an anatomical-based coding system developed to provide researchers with a simple numerical method for ranking and comparing injuries by severity, and to standardize the terminology used to describe injuries. The coding ranges from one to six: one represents a minor injury and six represents maximal injury. Injured occupants were defined in this study as those with at least one AIS 2 or AIS 3 level injury to a body region. The 2009 data were coded based on AIS 2005 procedures while later years were coded based on the 2005–2008 update (AIS, 2005, 2008 update). Injured and uninjured occupants were examined based on the following variables: demographics (stature, age, BMI, sex); change in velocity; Principal Direction of Force (PDOF), with 80 to 100 and 260 to 280 degrees representing 3 and 9 o'clock, 50 to 70 and 290 to 310 degrees representing the 2 and 10 o'clock positions corresponding to passengers and drivers as far-side occupants in passenger cars, light trucks, vans and SUVs; collision deformation classification scheme, termed as extent zones, ranging from the least zone of 1 to the most extensive zone of 9, with the boundary between the fifth and sixth zone corresponding to the centerline of the vehicle (Figure 1); collision partner (passenger car; light trucks, vans and sports utility vehicles, large trucks and objects such as pole and tree); and the presence of another occupant (front seat) in the vehicle. Extent zone serves as another indicator of crash severity and it represents the extent of damage to the struck side of the vehicle. Injuries were evaluated at the selected AIS levels to the head and face, thorax, abdomen, pelvis, upper extremity and lower extremity body regions. Only weighted data counts were used in the analysis.

Statistical analysis

Velocity and extent zones were described using cumulative percentage distributions to compare with previous studies (Yoganandan et al., 2011a). A multivariate analysis including (controlling for) occupant age, stature, change in velocity, BMI, vehicle type, presence of a

contra-lateral occupant in the front seat, and extent zone was conducted. The research question was as follows. Do vehicle-, occupant-, and crash-related factors predict injury to far-side occupants? Selection of these variables is in-line with previous automotive studies (Yoganandan et al., 2011a). Odds ratios and 95% confidence intervals were obtained using logistic regression techniques to determine factors associated with AIS 2+ and AIS 3+ injuries, and the significance was set at the $p < 0.05$ level.

RESULTS

Overall Data Counts and Occupant Demographics

The database consisted of 519,195 total weighted far-side occupants, out of which there were 17,715 MAIS2+ and 4,387 MAIS3+ cases. The mean age, stature, total body mass, and BMI were 40.7 years, 1.7 m, 77.2 kg, and 26.8 kg/m², respectively. These data for the MAIS2+ and MAIS3+ cases were: 41.8 and 40.4 years, 1.7 m and 1.7 m, 78.3 and 79.5 kg, and 26.9 and 27.0 kg/m², respectively. These demographic data were close to the mid-size automotive anthropometry (discussed later). Table 1 shows data based on weighted counts as a function of vehicle type which includes passenger cars and light trucks, vans and Sports Utility Vehicles (SUV); seating position; sex; collision deformation extent based on the Society of Automotive Engineers (SAE) classifications (Figure 1); and principal direction of force.

Changes in Velocities and Extent Zones

Figure 2 describes the cumulative frequency distributions of the change in velocities for all, MAIS2+ and MAIS3+ occupants. At the 50% level, changes in velocities for the struck vehicle for all, MAIS2+ and MAIS3+ occupants were 19, 34 and 42 km/h, respectively. Furthermore, 73% of MAIS2+ and 86% of MAIS3+ occupant injuries occurred at a change in velocity of 24 km/h or greater. Figure 3 shows the distribution of injuries regardless of body region by extent zones, as a function of all occupants, and MAIS2+ and MAIS3+ occupants and using the same dataset. More than two-thirds of all far-side occupants were associated with extent zones of two or less. However, when the extent zone was limited to two or fewer zones, MAIS3+ injuries occurred in 11% and MAIS2+ injuries occurred in 34% of the cases.

Odds Ratios and Confidence Interval Estimates

Table 2 shows the odds ratios and upper and lower 95% confidence intervals based on the multivariate analysis after adjusting for covariates. The odds of sustaining the MAIS2+ and MAIS3+ injuries increased with unit increase in stature and age, with one exception (age at MAIS2+ level). The odds of sustaining injuries were higher with the presence of an occupant in the front seat at the MAIS3+ level, although the trend was reversed at the lower level. Compared to far-side occupants in a passenger car with passenger car as collision partner, the odds of sustaining MAIS2+ and MAIS3+ injuries increased when the far-side occupant was in light trucks, vans and SUV or stationary objects as partners. The odds of sustaining MAIS2+ and MAIS3+ injuries decreased when the far-side occupant was seated in a light truck, van or SUV with object or light truck, van or SUV as the collision partner. The extent zone of 3+ increased the odds compared to the extent zones of 1 to 2 for both

MAIS2+ and MAIS3+ injuries. The odds of sustaining injuries were greater in oblique than lateral impacts at MAIS2+ level and the odds of sustaining injuries were greater in lateral than oblique impacts at the higher injury level. The odds of sustaining MAIS3+ injuries increased for both injured overweight (BMI ranging from 25 to 29.9 kg/m²) and obese (BMI greater than 30 kg/m², in accordance with the definition of the US Centers for Disease Control and Prevention) occupants at the MAIS3+ level than the normal BMI (BMI less than 25 kg/m²) occupants. The odds of sustaining MAIS3+ injuries for obese occupants increased compared to overweight occupants. The odds decreased for these group combinations at the lower injury level. Likewise, the odds of sustaining injuries at both severity levels increased when the change in velocity was greater than 40 km/h, compared to the 24 to 40 km/h change in velocity. The odds of sustaining injuries at both severity levels decreased when the change in velocity was less than 24 km/h compared to the other two velocity groups. All numerical data of odds ratios and confidence intervals are shown (Table 2).

Injuries by Body Region

Of weighted occupants with MAIS2+ injuries, 51% had AIS2+ head, 19% thorax, 7% abdomen, 12% pelvis, 11% spine, 27% upper extremity and 16% lower extremity injuries. Of weighted occupants with MAIS3+ injuries, 50% had AIS3+ head, 69% thorax, 12% abdomen, 11% pelvis, 14% spine, 7% upper extremity and 8% lower extremity injuries (Figure 4). Implications of these results are discussed in the next section.

DISCUSSION

The study identified the subset of NASS-CDS occupants meeting the inclusion criteria stated in the Methods section. Among this analytic sample of 519,915 far-side occupants, the aim was to describe injury patterns and further determine the association between relevant occupant-, vehicle-, and crash-level factors and the odds of MAIS2+ and MAIS3+ injury. Variables used in the analysis consisted of: (a) from crash perspectives the change in velocity, extent zone, angulation of the impact vector as defined by the principal direction of force and collision partner, and (b) from occupant perspectives the demographics, BMI, the presence or absence of another front seat occupant, and injury assessments based on body regions following the latest scoring scheme (AIS, 2005). The analysis included collection of these variables at two injury levels: MAIS2+ and MAIS3+, generally used in the analysis of NASS-CDS files (Digges and Dalmaotas, 2001). Although NASS-CDS continues to gather data from unbelted occupants, only belted far-side occupants were considered in the study because of their relevance to current and future automotive environments. This is in-line with recognition that the US nationwide seat belt use (average) has risen to 86% in 2012 (Chen, 2012). Because of similarities in outcomes from databases from other countries such as Australia, as a first step, the present analysis may be used to advance far-side occupant safety in the western world (Fildes et al., 2007; Yoganandan et al., 2011a). It should be noted that NASS-CDS data prior to 2009 were not used because of differences in injury coding in AIS. NASS changed the coding scheme from AIS1990–98 update to AIS 2005 starting year 2009.

The cumulative distribution of change in velocities at the 50 percent level in this study (Figure 2) is somewhat greater than those from previous studies which used earlier NASS-CDS years. For example, in an analysis of NASS-CDS database for the years 1993 to 2002, crashes with serious or fatal injuries were associated with a change in velocity of 32 km/h and the corresponding metric for all occupants was 15 km/h at the 50 percent level (Digges et al., 2005; Gabler et al., 2005a). It is acknowledged that the cumulative distribution is an indicator of actual injuries; the risk of injury is a different calculation and varies from 1.8% to 33.5 % depending on velocity (Table 1). Vehicle model years were not restricted to FMSS-214 compliant vehicles in the cited previous studies while this criterion was included in the current analysis. All vehicle model years were 2000 or greater. The overall increase in the change in velocity distribution in the present dataset may be attributable to the more recent collection period of the data. However, the importance of injury coding differences should be underscored. NASS-CDS data were coded in the cited study using the AIS 1990–98 update. AIS has been revised since this period (AIS, 2005). Changes have been reported between the two versions. Three or more fractured ribs on the same side receive AIS=3 in the recent version while the 1990 version calls for more than three ribs or any of the fractures to be open, displaced/comminuted to receive this score. Pneumothorax is always a combined code with a rib fracture or a pleural laceration in the 1990 version and should be coded separately in the 2005 version. A recent study reported underscoring of chest injuries with the AIS 2005 revision compared to the AIS 1990–98 update (Yoganandan et al., 2013b). From these perspectives, caution should be exercised while interpreting data gathered from two different recent AIS scoring schemes.

Results from the present study indicated that the odds of sustaining MAIS3+ injuries increased with the presence of another occupant at the MAIS3+ level, regardless of seating position in the front seat. Fildes et al. also reported that other occupants are a frequent source of chest and abdominal injuries in far-side crashes (Fildes et al., 2007). This previous study used NASS-CDS data for the years 1995 to 2004. Taken together, these results suggest that the issue of occupant-to-occupant contact needs to be addressed in crashworthiness studies. Likewise, the finding that 50% of injuries at the MAIS2+ continue to occur at change in velocities less than 34 km/h also needs further research as current New Car Assessment Program (NCAP) change in velocities with moveable deformable barrier impacts, albeit for nearside impacts, are around this magnitude.

The increased odds of sustaining injuries in oblique versus pure lateral crashes at the MAIS2+ level appears to be supported by biomechanical literature. For example, both Pintar et al. and Forman et al. observed greater lateral excursions in oblique far-side tests than in pure-lateral tests performed under otherwise matching conditions, with human cadaver subjects (Forman et al., 2013; Pintar et al., 2007). This was attributed specifically to greater axial rotation of the torso in the oblique tests, causing sled-tested subjects to rotate around and out of the shoulder belt. The opposite finding of decreased odds ratios for MAIS3+ injuries is less than clear, and this topic needs additional biomechanical research.

The increased odds of sustaining injuries in the overweight and obese occupants compared to normal occupants and obese compared to overweight occupants at the higher injury severity indicate that increased BMI is not protective. However, increased BMI was

protective at the lower severity. Hospital-based studies have associated increased BMI with poorer outcomes from blunt trauma patients (Arbabi et al., 2003; Byrnes et al., 2005; Choban et al., 1991; Mock et al., 2002; Neville et al., 2004; Newell et al., 2007; Spaine and Bollen, 1996; Whitlock et al., 2003). Other clinical studies have reported contrasting results (Alban et al., 2006; Brown et al., 2005; Brown et al., 2006; Duane et al., 2006; Morris et al., 1990; Zein et al., 2005). Studies using the NASS and CIREN databases have reported similar conflicting associations between injuries and BMI (Arbabi et al., 2003; Mock et al., 2002; Tagliaferri et al., 2009; Viano et al., 2008; Wang et al., 2003; Yoganandan et al., 2011a; Yoganandan et al., 2009). Although longer kinematics of the far-side occupant may affect interactions within the vehicle and or other occupant, the inverse association between the two injury levels deserves further study (Pintar et al., 2007; Pintar et al., 2006).

The distribution of injuries (Figure 3) were such that the roles of the head and thorax were different between MAIS2+ and MAIS3+ severities, with the thorax sharing a larger proportion at the higher level. These data show that in higher severity crashes, the human thorax is more frequently injured than the head body region. A previous study reported dissimilar results wherein head injuries predominated in the higher severity crashes and chest injuries were more common in lower severity crashes (Augenstein et al., 2000). It is known from Crash Injury Research Engineering Network (CIREN) analysis that serious head injuries are often associated with head contact in non-ejected occupants in frontal and side crashes (Yoganandan et al., 2009). It is also known that the brain injuries can be produced at lower acceleration levels when the external insult is in the side impact mode (Gennarelli et al., 2002; Gennarelli et al., 1987). From these perspectives, the present results should be examined in more detail using more detailed medial information focused on far-side occupant injuries in modern vehicle environments to belted populations. From these perspectives, these results have opened new areas for improving vehicle crashworthiness and occupant safety in modern vehicles and environments.

Approximately 40% of the cases in the current NASS-CDS database had missing change in velocity data. This is lower than the percentage of missing cases in other studies. In an analysis of data from the same database, Pintar et al. found that 41% of the cases had missing information (Pintar et al., 2000). Far-side impact studies using NASS-CDS data have not reported missing cases with change in velocity (Digges et al., 2005; Gabler et al., 2005b). Ignoring missing information in the NASS-CDS database can affect the cumulative distribution of the change in velocity. Although imputation methods with averages or estimate of the covariance structure with multiple imputation have been used in other fields including sociology and clinical medicine, Stitzel et al. applied the weighting imputation method to NASS-CDS data (Stitzel et al., 2007). The authors of the cited study remarked that multiple imputation methods may be more advantageous than simple imputing with sample means process. Because a full consensus has not been reached in the automotive literature and many studies have not applied imputation to NASS-CDS data, the present study removed missing change in velocity information. From this perspective, the current results are considered as a first step in analyses of far-side impacts, with the acknowledgment that additional studies are needed.

CONCLUSIONS

Using the NASS-CDS data for the years 2009 to 2012 and limiting the analysis to vehicle model years less than 10 years old at the time of crash, injuries and crash characteristics were determined using multivariate analysis for restrained outboard front seat far-side occupants. Results showed that the head and thorax are more frequently injured body regions, with thorax injuries more prevalent at the MAIS3+ level and head injuries with similar prevalence at both severities; the presence of another front seat occupant play a role in trauma; injuries continue to occur at change in velocities representative of side impact testing environments, although Standards do not exist for far-side impacts; the mean demographic factors were close to the mid-size automotive anthropometry for injured and all occupants. Because data were gathered from only four years, it would be important to include additional NASS-CDS database years, rescore injuries from previous years and/or analyze other international databases to reinforce these findings for advancing safety for far-side occupants.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Appendix

Description of NASS-CDS database and weighting factors

The database is operated by the National Highway Traffic Safety Administration (NHTSA) which is part of the U.S. Department of Transportation. Established in 1979 as part of a nationwide effort to reduce motor vehicle crashes, injuries, and deaths on highways, this database has been used to gather data to advance knowledge about the nature of crash injuries, and the relationship between the type and seriousness of a crash and injuries. Field research teams located at Primary Sampling Units (PSUs) across the country study about 5,000 crashes a year involved in highway crashes reported by the police and involving passenger cars, light trucks, vans and utility vehicles. Motor vehicle crashes that qualify for inclusion in the database meet the following criteria. A crash incident must be reported on state or local crash forms, signed by a police officer and the report should be available through police agency files. The incident must be reported to the state crash statistics office and involve a harmful event, defined as property damage and/or personal injury and occur directly as a result of the crash. Other intervening circumstances such as disease, deliberate intent, legal intervention, or cataclysm are excluded. Finally, the incident must involve a motor vehicle in transport and on a traffic way. Crashes occurring at sites such as parking lots and driveways are excluded. At least one of the vehicles involved in the crash should be towed from the scene in order for the crash to be included in database.

Because the sampling process is a representation of national data, weighting is done to obtain national estimates. The US was divided into 1,195 PSUs, out of which up to 27 were used in the sampling process. In addition, select number of crashes investigated in each selected unit. Weighting factors used to derive national estimates incorporate three factors: PSU, national and ratio inflation factors. Within each PSU there are several police jurisdictions. The PSU inflation factor is equal to the product of the inverse of the probability of selecting a particular crash from other crashes, and the inverse of the probability of selecting the police jurisdiction in which the crash occurred from all police jurisdictions within the PSU. The national inflation factor is defined as the product of the PSU inflation factor and inverse of the probability of selecting the specific PSU from all other units. The ratio inflation factor is defined as the product of the national inflation factor and rate which adjusts for differences between actual and estimated crashes. Ratios are obtained by dividing the total crash counts under a given scenario by estimated counts determined using the national inflation factors. The final weight assigned to each crash is the

product of the three inflation factors. The corresponding weights associated with each case in the database allow the determination of national estimates of crash injury outcomes.

Discussion about mid-size anthropometry

During the development of injury metrics and design of the crash test device for side impacts, the age and total body mass used to represent the mid-size occupant were 45 years and 76 kg, respectively (Kuppa et al., 2000; Kuppa et al., 2003; Yoganandan and Pintar, 2005b). The mass of the US regulated side impact dummy (ES-2re), currently under development/evaluation WorldSID dummy, the Hybrid III frontal impact dummy used around the world for crashworthiness evaluations, and the side impact dummy ES-2 used in Europe are very close to this magnitude (Yoganandan et al., 2011b). The mean age and total body mass for all occupants were close to the mid-size automotive anthropometry. Furthermore, the BMI of the crash test device is also close to the mean BMI obtained from the present results. Based on these and current results of mean demographic variables as stated in the results section, far-side occupants can be considered to be in the mid-size automotive anthropometry, and this is true for all occupants and both MAIS 2+ and MAIS 3+ occupants.

Discussion about side airbags

Side airbags have been used in modern vehicles as a part of safety equipment. However, their role in injury mitigation in far-side impacts was not analyzed in the present study because of the availability of different types of airbags (head curtains, torso bags, combo bags, seat-mounted versus door-mounted bags) and the reduction in the sample size based on bag type. Furthermore, the conditions for airbag deployment(s) have not been standardized and deployment criteria have changed over the years in the industry. Because different bags have different primary roles (head curtains for example mainly focused on head injury mitigation although kinematic changes may occur to the torso), it would not be accurate to group all bags into one category and examine their efficacy. An additional factor may involve the timing issue, i.e., the bag should stay deployed as occupants in far-side impacts have longer time than nearside occupants. These issues are considered as future research.

Figure 1.

Extent zones according to the SAE definition, from (Gabler et al., 2005b)

Figure 2.
Cumulative distribution of the change in velocity.

Figure 3.
Cumulative distribution of the extent zones.

Figure 4.
Comparison of injuries by body region for the two groups of occupants.

Table 1

Summary of data based on all cases

Description	All far-side collision occupants			MAIS2+ occupants			MAIS3+ occupants		
	Weighted data			Weighted data			Weighted data		
	Sample size 519,195			Sample size 17,715			Sample size 4,387		
	Estimated Count	Percent of total	Row percent	Estimated Count	Row percent	Estimated Count	Row percent	Estimated Count	Row percent
Vehicle type	Passenger car	355,002	68.4	12,180	3.4	3,376	1.0	3,376	1.0
	Light truck, SUV and van	164,193	31.6	5,535	3.4	1,011	0.6	1,011	0.6
Sex	Male	220,092	42.4	6,974	3.2	2,044	0.9	2,044	0.9
	Female	297,166	57.2	10,741	3.6	2,343	0.8	2,343	0.8
	Unknown	1,937	0.4	-	-	-	-	-	-
Seating position	Driver	403,684	77.8	15,159	3.8	3,152	0.8	3,152	0.8
	Passenger	115,511	22.2	2,556	2.2	1,235	1.1	1,235	1.1
Extent zone	1-2	300,005	57.8	5,755	1.9	468	0.2	468	0.2
	3+	115,628	22.3	11,154	9.6	3,658	3.2	3,658	3.2
	Unknown	103,562	19.9	806	0.8	261	0.3	261	0.3
	Lateral	94,282	18.2	4,578	4.9	1,840	2.0	1,840	2.0
Direction of force	Oblique	182,111	35.1	7,385	4.1	1,738	1.0	1,738	1.0
	non-horizontal	200,916	38.7	5,348	2.7	809	0.4	809	0.4
	Unknown	41,886	8.1	404	1.0	-	-	-	-
	Below 24	253,711	48.9	4,103	1.6	446	0.2	446	0.2
	24-40	53,143	10.2	4,656	8.8	910	1.7	910	1.7
Change in velocity (km/h)	Above 40	6,382	1.2	2,159	33.8	1,145	17.9	1,145	17.9
	Unknown	205,959	39.7	6,797	3.3	1,886	0.9	1,886	0.9
Body mass index (kg/sq m)	Normal	209,175	40.3	9,146	4.4	1,384	0.7	1,384	0.7
	Overweight	147,392	28.4	3,181	2.2	1,205	0.8	1,205	0.8
	Obese	78,112	15.0	2,307	3.0	1,017	1.3	1,017	1.3
	Unknown	84,516	16.3	3,081	3.6	781	0.9	781	0.9

Table 2

Odds ratios (OR) and 95% lower and upper confidence intervals (LCI and UCI) shown in parenthesis. Variables in the second column represent values or the reference group.

Injury levels and odds ratios	MAIS2+		MAIS3+	
	OR	(LCI UCI)	OR	(LCI UCI)
Age	0.9884	(0.9868 0.9900)	1.0281	(1.0249 1.0313)
Stature	1.0106	(1.0064 1.0147)	1.0485	(1.0396 1.0576)
Other front seat occupant (first variable refers to far-side occupant)				
Driver and passenger	0.4444	(0.4177 0.4726)	1.1702	(1.0312 1.3269)
Passenger and driver	0.3568	(0.3255 0.3905)	1.8268	(1.5626 2.1323)
Collision partner (first variable refers to the far-side occupant)				
Light truck, SUV and Van - passenger car	2.4655	(2.2895 2.6564)	1.8789	(1.6216 2.1811)
Passenger car - Object	4.6647	(4.1838 5.1992)	2.0063	(1.5673 2.5632)
Light truck, SUV and Van - Light truck, SUV and Van	0.4936	(0.4242 0.5720)	0.1009	(0.0676 0.1460)
Light truck, SUV and Van - Object	0.3650	(0.2782 0.4707)	0.3461	(0.2028 0.5569)
Extent zone				
3+	3.5304	(3.3191 3.7559)	24.9586	(20.8425 30.0727)
Direction of force				
Oblique	1.1392	(1.0617 1.2229)	0.3917	(0.3402 0.4509)
Body mass index				
Overweight	0.8513	(0.8039 0.9014)	1.7722	(1.5573 2.0171)
Obese	0.7531	(0.6978 0.8123)	1.9059	(1.6400 2.2137)

Injury levels and odds ratios		MAIS2+		MAIS3+	
		OR	(LCI UCI)	OR	(LCI UCI)
Obese	Overweight	0.8846	(0.8159 0.9586)	1.0755	(0.9190 1.2576)
Range in change in velocity parameter					
Greater than 40 km/h	24 to 40 km/h	4.3574	(4.0078 4.7369)	18.0901	(15.9399 20.5499)
Less than 24 km/h	24 to 40 km/h	0.1583	(0.1482 0.1691)	0.0534	(0.0439 0.0646)
Less than 24 km/h	Greater than 40 km/h	0.0363	(0.0331 0.0398)	0.0030	(0.0024 0.0036)