Epidemiology of ~~Injuries Sustained~~injuries sustained by ~~Rear-seat Passengers~~rear-seat passengers in ~~Frontal Motor Vehicle Crashes~~frontal motor vehicle crashes

~~givenname~~Dipan ~~Bose~~~~surname~~^{a, *✉}
dbose@worldbank.org

~~givenname~~Jeff ~~Crandall~~~~surname~~^a

~~givenname~~Jason ~~Forman~~~~surname~~^a

~~givenname~~Douglas ~~Longhitano~~~~surname~~^b

~~givenname~~Carlos ~~Arregui-Dalmases~~~~surname~~^{a, c}

^aCenter for Applied Biomechanics, University of ~~Virginia~~Virginia, USA

^bHonda R&D ~~Americas~~Americas, USA

^cUniversitat Politècnica de Catalunya, ~~Barcelona-Tech~~Barcelona-Tech, Spain

*Correspondence to: The World Bank Group, MSN MC6-615, 1818 H Street NW, Washington, DC 20433, USA.

Abstract

Objective

Advanced occupant protection systems in motor-vehicles (e.g., seat belts and airbags), while widely adopted for front-seat passengers, are either absent or offer disproportionally lower safety to rear-seat passengers in similar crashes. Optimization of advanced restraint systems for the rear-seat environment will require a detailed understanding of epidemiology and associated risk factors for injuries sustained by rear-seat passengers. Thus, the objective of the study is to use national level motor-vehicle travel and crash data to quantify rear-seat travel exposure, and determine the descriptive characteristics and the injury outcomes for rear-seat passengers involved in frontal collisions.

Methods

While U.S. travel data from the 2009 National Household Travel Survey was used to determine rear-seat travel estimates, crash data from 2001 to 2010 National Automotive Sampling System Crash Worthiness Data System was used to enroll rear-seat passengers injured in a frontal crash. The descriptive epidemiology of rear-seat crash victims was separately done for the three age-groups: children (~~4-15~~8-15 years old), adults (~~16 to 59~~16-59 years old), and senior adults (60+).

Results

The study indicated that senior adults in rear-seats were associated with a significantly higher rate of sustaining fatal (6%) and severe injuries (16% for MAIS 3+ injuries) in comparison to the younger cohorts. The distribution of severe injuries further indicated that the thorax was the most frequently injured region across all age groups irrespective of the belt-use status.

Conclusions

Findings of the study conclude that while rear-seat travel in the U.S. is still very low and improving belt usage is a primary concern among rear-seat passengers; however, the epidemiology supports the need for adapting rear-seat restraint performance for effective protection for all groups of rear-seat passengers.

Keywords: Rear seat passenger; ~~seat~~Seat belt; ~~motor~~Motor vehicle crash; ~~airbag~~Airbag; ~~frontal~~Frontal crash; ~~optimized~~Optimized restrain systems

1 ~~INTRODUCTION~~Introduction

As traffic data suggests, rear-seat travel among motor vehicle passengers in the U.S. continues to be relatively low, compared with Europe or other developed countries: less than 13% of total annual person-

trips in a motor-vehicle involve a rear-seat passenger (Trowbridge and Kent, 2009), and rear seat occupants are present in approximately 13-17% of all tow-away collisions (Parenteau and Viano, 2003). As a result of low-exposure, rear-seat passengers are responsible for less than 10% of overall fatalities and injured victims (USDOT, 1997-2009). Consequently, this cohort of vehicle passengers has traditionally received less attention than front seat occupants in terms of targeted injury countermeasures and understanding of the relative risk factors applicable to the rear-seat environment (Trowbridge and Kent, 2009).

Various studies indicate that for children, a car's rear seat is safer than the front seat (Smith and Cummings, 2004; Kuppa et al., 2005). Moreover, recent research indicate that the fatality and injury-reducing efficacy of the rear seat highly depends on the passenger's age since the rear seat has been reported to be less safe than the front seat for older persons. Kuppa et al. (2005) reported a greater fatality risk for rear seat passengers than front seat passengers over the age of 50. Similarly, Bilston et al. (2010) found that the rear seat carried a higher risk of AIS 3+ injuries compared to the front seat for restrained passengers over the age of 50.

In newer automobile models - from 1997 until 2007 - improvements were made resulting in an even lower injury risk for all restrained passengers in the front seat over the age of 16 compared to rear seat passengers. Similar tendencies have been mentioned by other researchers (Esfahani and Digges, 2009; Kent et al., 2007). Nevertheless, Sahraei et al. (2010) observed that in models from 1990-1999, 1990 to 1999, the rear seat was safer than the front seat for all fastened passengers over the age of 25. However, this trend changed for models from 2000 until 2009, where the risk of fatality for all fastened passengers over the age of 25 was greater for rear seat than front seat passengers. These field observations are consistent with several recent frontal crash test studies where greater thoracic injury risks were observed with adult dummies seated in the rear seat compared to dummies seated in the front (Mizuno et al., 2011; Tylko and Dalmotas, 2005; Sahraei et al., 2010).

The growing disparity between rear seat and front seat safety for adults suggests a reexamination of the rear seat environment to identify potential areas for improvement. While for the front-seat occupants, upper-body (head, neck and chest) and knee excursion in the event of a frontal collision can be effectively controlled for safety using supplementary restraint devices like the air bags, such provisions are almost unavailable in the rear-seat. Even widely adopted advanced belt systems which control the belt payout in the event of a crash (e.g., pre-tensioners and force-limiting retractors) are not standard features in the rear-seats (Kent et al., 2007). As occupant age increases, the distribution of AIS2+ and 3+ injuries in restrained rear seat occupants tends to shift from predominantly head injuries (in young occupants) to thoracic injuries resulting from interaction with the seatbelt (in older occupants; Kuppa et al., 2005). Recent computational (Kent et al., 2007) and experimental (Forman et al., 2008, 2009) studies have indicated that thoracic injury risk in adult rear seat occupants may be reduced through the use of pre-tensioning, force-limiting seatbelt prototypes designed for use in the rear seat environment.

The studies above indicate a disparity between front seat and rear seat safety, and a “proof of concept” regarding the incorporation of advanced and customized belt restraint technologies into the rear seat environment. To refine and implement these countermeasures, it is necessary to understand the epidemiology, demographics, and causal risk factors affecting the severity of injury outcome to identify targets for intervention. With belt usage rates among U.S. rear-seat passengers steadily improving (currently at 76%, IIHS, 2012, HHS, 2012), additional risk factors such as passenger characteristics (e.g., body type, sex, age), seating posture, use of special restraints (e.g., child seats), vehicle characteristics (e.g., interaction with front-seat back), and crash attributes (e.g., crash pulse, vehicle deformation) must be analyzed. With the goal of describing the characteristics of passenger, vehicle, crash and injury severities applicable to rear-seat passengers and subsequently identifying the associated risk factors, the objectives of this research are outlined as:

1. Compare overall vehicle-travel exposure and crash characteristics among rear-seat passengers involved in moderate to severe frontal crashes at all injury severities.
2. Perform stratified descriptive analyses applicable to three distinct age groups among rear-seat passengers (children, 8 to 15, 8-15 years old; adults, 16 to 59, 16-59 years old; and senior adults 60 years and older). Further, investigate the characteristics of the three age groups as a function of the injury severity rates sustained by the victim in frontal crashes.
3. Evaluate the distribution of moderate and serious injuries to the different body regions for all three age groups of rear-seat passengers.

2 DATA AND METHODSData and methods

2.1 Dataset

Sampled cases of rear-seat passengers involved in a motor vehicle frontal crash in the US were obtained from the National Highway Traffic Safety Administration's (NHTSA) 2001-2010 National Automotive Sampling System Crashworthiness Data System (NASS CDS). NASS CDS provides nationally representative data regarding motor vehicle crashes based on a weighted annual sample of approximately 5,000 5000 police reported tow-away crashes (NHTSA, 2008-2009, NHTSA, 2008-2009). The dataset includes detailed information about the occupant, vehicle, crash kinematics, restraint usage and injury outcome including incidence of fatality and injury severity codes for each individual injury based on the 1998 Abbreviated Injury Scale (AIS) (AAAM, 1990-1990). Sampled cases were screened from the NASS-CDS 2001 to 2010 database where the case occupant was seated in either the second or the third seating

row of the vehicle (defined as rear-seat passengers in this study). Rear-seat passengers represented 13% of all crash victims recorded in the database. The orientation of the crash in the selected cases was defined by the location of the maximum vehicle damage plane during the most severe crash event. The study focused on the frontal crash orientation since this crash mode represented 53% of the total cases involving rear-seat passengers. The rear-seat passengers were grouped into three age groups: age ~~8 to 15~~ **8-15** years, age ~~16 to 60~~ **16-60** years and age 60 years and older. The criteria for selecting the age of 8 years as the lower limit was based on the applicable age appropriate for using the adult seat belt and separate categories were created for adult and senior passengers. The age groups ~~8 to 15~~ **8-15** years old and ~~16 to 59~~ **16-59** years old represented 25% and 30%, respectively, of all rear-seat passengers included in the database. Senior rear-seat passengers represented 2% of all occupants while the remaining 43% comprised of rear-seat passengers less than 8 years old who were not included in this study. Occupants with all levels of injury severity, excluding cases with no injury which represented 28% of all rear-seat passengers, were included in the study.

Vehicles body types included passenger cars, sports utility vehicles (SUV), light trucks and minivans (curb weight less than 5000 kg). Vehicles models older than 1998 were excluded to maintain certain uniformity in occupant safety standards related to airbag regulations. Crashes involving rollover, fire or water submersion were excluded. As the NASS-CDS is a survey sample dataset, individual cases with disproportionately high weighting factors (greater than a million) were excluded. The survey selection criteria yielded ~~1,964~~ **1064** samples representing a weighted population of approximately 169,000 rear-seat passengers at the national level available for a retrospective descriptive analysis.

In addition to data on rear-seat crash victims, U.S.-based exposure data on rear-seat passengers and their travel characteristics were obtained from the National Household Travel Survey (NHTS) ~~(NHTS, 2009-2009)~~ **(NHTS, 2009)**. The NHTS is a periodic nationally representative survey of travel behavior. The 2009 NHTS collected information from 150,147 U.S. households through telephone surveys and trip diaries used to document travel during an assigned travel day. The dataset includes household, person, vehicle and daily (travel day) trip level data, however, specific data on rear-seat travel and restraint usage is not available. Weights are included in the data set to adjust for sampling error and bias when calculating national estimates.

2.2 Methods

Exposure data on rear-seat motor vehicle travel was estimated using a combination of NHTS travel survey data and vehicle occupancy characteristics as implied by the crash-involved NASS-CDS dataset. The weighted estimates from the NHTS survey data was compiled to calculate vehicle travel miles (on trip day) and total vehicle miles travelled as a function of total occupancy in the vehicle and category of vehicle used (e.g., passenger car, sports utility vehicle, light truck or mini-van). Rear-seat travel proportion was approximated for each vehicle category using all relevant samples where the vehicle occupancy was greater than two. The estimated rear-seat travel proportion ignored instances of two vehicle passengers while one of them was seated in the rear-seat row. To adjust for this, estimates for rear-seat travel in instances of double occupancy for each vehicle category was calculated from NASS-CDS which includes detailed information on seating location. It should be noted, however, that NASS-CDS data only applies to crash victims and may not accurately represent the overall exposure trends for all vehicle passengers. Applying the above proportion derived from NASS-CDS to the double occupancy data in NHTS, the percentage of rear-seat travel characteristics (both vehicle trips and miles travelled) were estimated for each vehicle category.

A descriptive analysis of all crash-related characteristics including vehicle information, crash kinematics, occupant information, seat-belt usage and injury outcome measures was performed for all rear-seat passengers selected from the NASS-CDS dataset. The severity of injury outcome was estimated by the incidence of fatality, whole-body AIS score of 2 and higher (MAIS 2+) and MAIS 3+. Additionally, for all MAIS 2+ and MAIS 3+ rear-seat victims, the distribution of incidence rate for the following six regions was evaluated: head/neck/face, thorax, spine, abdomen/pelvis, lower extremity and upper extremity. The descriptive analyses of the weighted survey sample data were developed using the SAS software, Version 9.2 of the SAS System for Windows. Copyright © [2002-2008].

3 RESULTSResults

The NHTS survey results indicated that for all vehicle categories, vehicle trips and miles travelled involving rear-seat occupancy constituted approximately 15% and 18%, respectively, of all occupancy cases, [Table 1](#).

Table 1 Exposure data on rear-seat passengers obtained from the National Household Travel Survey [\(NHTS, 2009\)](#)~~(NHTS, 2009)~~. Figures in parenthesis indicate the proportion of vehicle trips or miles travelled which involved rear-seat occupancy compared to all occupancy cases for that vehicle ~~category-~~**category**.

alt-text: Table 1		
	Vehicle trips/year in billions	Vehicle miles/year in billions
Passenger car	13.9 (11%)	144 (13%)
Sports utility vehicle (SUV)	9.7 (19%)	127 (25%)

Light truck	3.1 (10%)	33 (11%)
Mini vans	6.7 (29%)	71 (37%)
Overall	34.5 (15%)	399 (18%)

The highest share of rear-seat travel involved passenger cars followed by Sports Utility Vehicles (SUVs), mini-vans and light trucks. Compared to the proportion of rear-seat vehicle trips, the proportion of rear-seat vehicle miles travelled was higher for SUV and mini-vans, indicating more miles travelled per trip when involving rear-seat passengers compared to the other vehicle categories.

The weighted estimate from the survey-sampled NASS-CDS dataset provided age-group specific descriptive statistics on rear-seat crash victims involved in frontal crashes, [Table 2](#).

Table 2 Descriptive statistics summary for all rear-seat passengers of different age groups sustaining an injury (AIS 1+) in a frontal ~~crash~~:[crash](#).

alt-text: Table ~~2-2~~

			8 to 15 8-15 year old	16 to 59 16-59 year old	60+ year 60+year old
Sample size [raw n, weighted sample size]			371, 82k	602, 75k	91, 12k
		Units *	Mean or % *** (95% CI)	Mean or % *** (95% CI)	Mean or % *** (95% CI)
<u>Occupant</u>	Age	Years	11 (9, 12)	26 (25, 27)	74 (72, 77)
	Sex	%	53 (30, 75)	45 (37, 53)	33 (9, 57)
	Stature	cm	141 (126, 157)	170 (168, 173)	158 (150, 166)
	Mass	kg	45 (38, 52)	73 (67, 79)	71 (67, 75)
	BMI (underweight) *** <18.5 kg/m ²	%	38 (21, 55)	18 (11, 25)	11 (2, 20)
	BMI (Normal body type)≥18.5; <25 kg/m ²	%	31 (13, 49)	45 (35, 55)	38 (21, 55)
	BMI (overweight)≥25; <30 kg/m ²	%	22 (0, 51)	24 (15, 33)	28 (20, 35)
	BMI (Obese)≥30 kg/m ²	%	8 (5, 12)	13 (6, 20)	23 (13, 24)
	Belt usage	%	79 (70, 88)	53 (44, 63)	71 (49, 92)
<u>Vehicle</u>	Passenger car	%	44 (26, 63)	62 (53, 72)	73 (64, 83)
	SUV	%	18 (5, 31)	19 (12, 27)	10 (7, 14)
	Van (including minivans)	%	15 (3, 26)	13 (6, 20)	13 (5, 21)
	Light truck	%	23 (0, 53)	5 (<0.5, 9)	3 (1, 6)
	Vehicle age at crash	Years	3 (2, 4)	4 (4, 5)	3 (3, 4)
	Mean occupancy	No. of occupants	4 (3, 4)	4 (4,4)	4 (3, 4)
<u>Crash</u>	Delta-V (total)	km/h	23 (18, 28)	24 (22, 26)	21 (17, 25)
	PDOF (rank 1)=0°	%	44 (18, 70)	41 (31, 52)	35 (15, 55)
	PDOF (rank 1) in 0°–30°	%	15 (9, 22)	24 (15, 32)	23 (11, 35)
	PDOF (rank 1) in 330°–0°	%	40 (17, 63)	35 (27, 44)	42 (30, 54)
	No. of events in crash	%	2 (2, 2)	2 (2, 2)	2 (1, 2)

	Frontal as first event	%	83 (75, 92)	81 (76, 87)	85 (78, 93)
	Max. AIS in vehicle	%	2 (1, 2)	2 (2, 2)	2 (1, 2)
	Posted speed limit>35 mi/h	%	69 (45, 88)	56 (45, 67)	66 (43, 89)
	Single vehicle crashes	%	27 (0, 57)	20 (15, 26)	9 (0, 18)

* For categorical variables, the estimates are % of cases corresponding to the value indicated in this ~~column~~column.

** Estimates are reported as mean and percentage values for continuous and categorical variables, ~~respectively~~respectively.

*** The BMI classification is based on the NIH ~~guidelines~~guidelines.

The passengers analyzed in the study represented 82,000, 75,000, and 12,000, rear-seat passengers from the ~~8-to-15~~8-15 years old, ~~16-to-59~~16-59 years old, and 60 years and older, age groups, respectively. In the ~~8-to-15~~8-15 years old age group, 53% of the passengers were male, the average age was 11 years old with mean stature and mass of 141 cm and 45 kg, respectively. While 31% under this age group had a normal BMI (~~18.6~~(18.6-25 kg/m²), 38% were underweight (BMI less than 18.5 kg/m²), and the remaining were overweight or obese. While seatbelt usage was 79%, the use of child booster seat was very low in this population (2 out of 371 sampled passengers). In the ~~16-to-59~~16-59 year old age group, 45% of the passengers were male, the average age was 26 years old with mean stature and mass of 170 cm and 73 kg, respectively. While 45% under this age group had a normal BMI (~~18.6~~(18.6-25 kg/m²), 37% were overweight or obese (BMI greater than 25 kg/m²). The seatbelt usage for ~~16-to-59~~16-59 years old group was 53%, which was lower than the usage rates in the other two age groups. In the 60 years and older age group, 33% of the passengers were male, the average age was 74 years old with mean stature and mass of 158 cm and 71 kg, respectively. While 38% under this age group had a normal BMI (~~18.6~~(18.6-25 kg/m²), 51% were overweight or obese (BMI greater than 25 kg/m²). The seatbelt usage for ~~16-to-59~~16-59 years old group was 71%.

The distribution of vehicle categories was similar across the three age-groups with passenger cars involving highest number of rear-seat passenger victims (~~44%-to-73%~~-(44-73%). Of note was the fact that when ~~8-to-15~~8-15 year old rear-seat victim was involved, light trucks constituted 23% of all vehicles. This proportion was significantly higher than the two other age groups where light trucks were involved in only ~~3%-to-5%~~3-5% of all vehicle cases. The 60 years and older group involved the highest percentage of passenger car vehicles compared to the remaining groups. The model year of the vehicle involved in all three age groups was very similar: ~~19%-to-23%~~19-23% of the vehicles were newer than 2005 models. The average vehicle age at the time of crash was ~~3-to-4~~3-4 years old. The mean occupancy in the vehicle was approximately 4 for all age groups.

In terms of crash characteristics, the mean delta-v (differential velocity of the vehicle before and after the crash impact) estimates for the frontal crash across all ages of rear-seat passengers were between 21 km/h ~~to~~and 24 km/h. Approximately, ~~35%-to-44%~~35-44% of these frontal crashes were of head-on with the principal direction of force aligned with the direction of vehicle movement. Of the remainder frontal crashes, oblique crashes to the left of the travel direction were more frequently observed than those to the right (~~35%-to-42%~~-(35-42% were left-sided while ~~15%-to-24%~~15-24% were right-sided). The mean number of events (described in NASS as an impact to the vehicle causing considerable vehicle damage or occupant injury) was two across all age groups. While the frontal impact event was the most severe in terms of vehicle damage, it was also the first event in the crash sequence for ~~81%-to-85%~~81-85% of the crashes. Roads with posted speed limit of 35 miles/h or higher were responsible for ~~56%-to-69%~~56-69% of all the crashes included in the study. While describing the nature of the crash it was observed that for age groups ~~8-to-15~~8-15 and ~~16-to-59~~16-59, ~~20%-to-27%~~20-27% were single-vehicle crashes whereas the 60 years and older group was involved in single-vehicle crashes in only 9% of the cases. This was further explained by identifying the object contacted during the most severe event as recorded in NASS-CDS. Across all age groups, the most frequently contacted objects included the other vehicle (~~71%-to-91%~~-(71-91%)), trees and poles (~~2%-to-9%~~-(2-9%)), ditch or culvert (17%), and traffic barriers (~~3%-to-4%~~-(3-4%)). The other vehicle (or multiple vehicle crashes) accounted for the largest proportion of cases as suggested by the proportion of single-vehicle crashes described before.

A summary of descriptive statistics was also evaluated and compared for rear-seat passengers of different age groups who sustained serious injuries (AIS 3+) during the crash, [Table 3](#).

Table 3 Descriptive statistics summary for all rear-seat passengers of different age groups sustaining a severe injury (AIS 3+) in a frontal ~~crash-~~crash.

alt-text: Table 3

			8-to-15 8-15 year old	16-to-59 16-59 year old	60+ year 60+year old
Sample size [raw n, weighted sample size]			29 (1.7k)	98 (6.7k)	28 (1.9k)
		Units**	Mean or %** (95% CI)	Mean or %** (95% CI)	Mean or %** (95% CI)

<u>Occupant</u>	Age	Years	12 (12, 13)	24 (20, 28)	80 (77, 83)
	Sex (=male)	%	59 (45, 73)	46 (26, 65)	16 (9, 24)
	Stature	cm	149 (139, 160)	167 (161, 173)	158 (156, 162)
	Mass	kg	46 (39, 53)	79 (70, 88)	64 (61, 68)
	BMI (underweight)***<18.5 kg/m ²	%	59 (49, 70)	17 (5, 30)	34 (19, 48)
	BMI (Normal body type)≥18.5; <25 kg/m ²	%	29 (4, 54)	23 (13, 34)	27 (14, 39)
	BMI (overweight)≥25; < 30 kg/m ²	%	10 (4, 27)	29 (11, 46)	37 (29, 45)
	BMI (Obese)≥30 kg/m ²	%	1 (0, 6)	30 (17, 44)	3 (0, 8)
	Belted during crash	%	37 (21, 52)	12 (3, 22)	54 (41, 66)
<u>Vehicle</u>	Passenger car	%	47 (23, 71)	67 (43, 90)	61 (47, 75)
	SUV	%	36 (2, 71)	13 (0, 26)	33 (19, 48)
	Van (including minivans)	%	12 (0, 26)	11 (0, 25)	4 (0, 7)
	Light truck	%	5 (0, 14)	9 (0, 27)	2 (0, 6)
	Vehicle age at crash	Years	4 (3, 5)	5 (4, 6)	5 (4, 6)
	Mean occupancy	No. of occupants	4 (3, 4)	4 (4, 5)	3 (3, 4)
<u>Crash</u>	Delta-V (total)	km/h	42 (32, 51)	34 (28, 40)	34 (32, 36)
	PDOF (rank 1)=0°	%	28 (0, 70)	49 (26, 72)	17 (6, 28)
	PDOF (rank 1) in 0°–30°	%	18 (5, 31)	25 (2, 48)	19 (5, 33)
	PDOF (rank 1) in 330°–0°	%	55 (23, 86)	26 (14, 38)	64 (56, 73)
	No. of events in crash	%	2 (1, 2)	2 (1, 2)	1 (1, 1)
	Frontal as first event	%	94 (80, 100)	80 (69, 90)	93 (89, 98)
	Max. AIS in vehicle	%	4 (3, 4)	4 (3, 4)	4 (4, 4)
	Posted speed limit>35 mi/h	%	55 (27, 84)	54 (35, 73)	57 (38, 76)
	Single vehicle crashes	%	27 (0, 73)	46 (21, 70)	13 (6, 21)

* For categorical variables, the estimates are % of cases corresponding to the value indicated in this ~~column~~column.

** Estimates are reported as mean and percentage values for continuous and categorical variables, ~~respectively~~respectively.

*** The BMI classification is based on the NIH ~~guidelines~~guidelines.

For seriously injured rear-seat passengers in the 60 years and older group, proportion of male passengers was 16%, significantly lower (at 95% CI) than the two other age groups (~~46% to 59%~~–(46-59%). In terms of passenger body type, obese AIS 3+ victims (~~BMI > 30~~(BMI>30 kg/m²) dominated the ~~16 to 59~~16-59 years old group (30%) while the same proportions in the ~~8 to 15~~8-15 years old and 60 years and older group were 1% and 3%, respectively. While remaining vehicle and crash characteristics for seriously injured passengers were similar to the results described for all injured passengers, differences worthy of note included the orientation and number of vehicles involved in the crash. Head-on crashes were represented in 49%, 28% and 17% of ~~16 to 59~~16-59 years old group, ~~8 to 15~~8-15 years old group, and the 60 years and older group,

respectively. Similar to the statistic observed for all injured passengers, seriously injured 60 years and older passengers had the lowest rate of single vehicle crashes (13% compared to ~~27% to 46%~~ ~~27-46%~~ for other age groups).

The injury outcome analyzed for the rear-seat passengers indicated increasing incidence for moderate to severe injury with the increase in the age, [Table 4](#).

Table 4 Distribution of injuries for all rear-seat passengers sustaining AIS 1+ injury in a frontal crash.

alt-text: Table 4-4			8 to 15 8-15 year old	16 to 59 16-59 year old	60+ year 60+year old
Sample size [raw n, weighted sample size]			371, 82k	602, 75k	91, 12k
	Units* Units*		Mean or %**% %** (95% CI)	Mean or %**% %** (95% CI)	Mean or %**% %** (95% CI)
MAIS 2+		%	8 (4, 12)	18 (13, 23)	24 (11, 38)
MAIS 3+		%	2 (1, 3)	9 (6, 11)	16 (10, 21)
Mean ISS		–	2 (1, 2)	3 (2, 4)	6 (4, 7)
Fatality rate		%	<0.5 (0, 1)	1 (<0.5, 1)	6 (3, 10)
Mean max. AIS in vehicle		%	2 (1, 2)	2 (2, 2)	2 (1, 2)
Distribution of AIS 2+ injuries by region	Head/neck/face	%	4 (1, 6)	7 (4, 10)	8 (0, 16)
	Thorax	%	1 (<0.5, 1)	3 (1, 5)	10 (6, 14)
	Abdomen/Pelvis	%	2 (<0.5, 3)	1 (<0.5, 1)	7 (3, 11)
	Spine	%	<0.5 (0, 1)	2 (<0.5, 4)	4 (0, 8)
	Upper extremity	%	3 (0, 6)	7 (5, 10)	4 (2, 7)
	Lower extremity	%	1 (<0.5, 3)	5 (2, 8)	11 (7, 15)
Distribution of AIS 3+ injuries by region	Head/neck/face	%	1 (0, 1)	2 (1, 3)	3 (<0.5, 5)
	Thorax	%	1 (<0.5, 1)	3 (1, 5)	9 (5, 14)
	Abdomen/Pelvis	%	<0.5 (0, 1)	<0.5 (<0.5, 1)	1 (0, 3)
	Spine	%	<0.5 (0, 1)	1 (<0.5, 2)	3 (0, 7)
	Upper extremity	%	<0.5 (0, 1)	3 (2, 4)	2 (<0.5, 4)
	Lower extremity	%	<0.5 (<0.5, 1)	2 (<0.5, 4)	5 (1, 8)

The incidence rate of MAIS 2+ and MAIS 3+ injury for the ~~8 to 15~~ ~~8-15~~ years old age group was 8% and 2%, respectively, significantly lower (at 95% CI) than the two older groups. The 60 years and older group has the highest rate of injury with 24% and 16% incidence for MAIS 2+ and MAIS 3+ outcomes, respectively. The mean Integrated Severity Score (ISS) defined by the sum of the square of three highest AIS levels recorded in distinct body regions, was 2 and 3 for the ~~8 to 15~~ ~~8-15~~ years old and ~~16 to 59~~ ~~16-59~~ years old groups, respectively. However, the mean ISS score for the 60 years and older was 6 and was significantly higher (95% CI) than the two younger groups. Similar trends were seen for the fatality rate as well where the rate for the 60 years and older group was significantly higher (95% CI) than the other two groups. The distribution of injuries to the different body regions also exhibited differences as a function of age group. For moderate to severe injuries (AIS 2+), the incidence rate for the ~~8 to 15~~ ~~8-15~~ years old group was below 5% for all body regions. For the ~~16 to 59~~ ~~16-59~~ years old group the head/neck/face and both extremities were associated with an AIS 2+ incidence rates in the range of ~~5% to 7%~~, ~~5-7%~~, while the rate was below 5% for the remaining regions. In the 60 years and older group, upper extremity, head, thorax and abdomen/pelvis was associated with AIS 2+ injury rates higher than 7%. Similar trends was also observed for serious injuries

(AIS 3+), where the 60 years and older group had a thoracic injury rate (AIS 3+) of 9%, significantly higher than any other rate including all body regions and age groups at this threshold.

4 ~~DISCUSSION~~Discussion

The findings from this descriptive analysis highlight exposure and epidemiology trends for rear-seat travel in motor vehicles. The current exposure data obtained on vehicle travel trends confirms the relatively low incidence of rear-seat travel based on the U.S.-based traffic data (18% of total vehicle miles travelled in all seating positions). The percentage of vehicle trips with a rear seat passenger observed here (15%) is consistent with that observed in previous studies (13%, [Trowbridge and Kent, 2009](#)). Combining the travel data with crash incidence rates indicates that vehicle travel involving rear-seat passengers is not necessarily at a higher or lower risk of being involved in a crash compared to vehicle travel without rear-seat passengers, if the rear-seat passengers are properly belted (~~Dipan~~[\(Bose et al., 2013-~~et al. 2013~~\)-](#)). [Parenteau and Viano \(2003\)](#) found that rear seat occupants were present in approximately 17% of all collisions in NASS-CDS (1991-1998), and 13% of all collisions in NASS-GES (1992-1998). Although not studied here, that study found that rear seat occupants were over-represented in fatal collisions, with a rear seat occupant present in approximately 23% of fatal collisions (FARS 1988-1996). Those data suggest that although rear seat occupants account for a relatively small portion of vehicle travel, those that are present encounter a disproportionately high exposure to higher-severity collisions that result in fatality. Future work should include investigating whether or not rear seat occupants continue to be over-represented in higher-severity, fatal collisions in newer model year vehicles, and identifying the risk factors that contribute to this disparity.

In terms of vehicle type involved in frontal crashes with rear-seat occupancy, the rear-seat travel exposure, consistent with results for all vehicle travel data, was highest for passenger cars (144 billion miles travelled per year). Among the rear-seat travels, while passenger cars contributed to 36% of the exposure (vehicle travel miles), their involved in injurious frontal crashes was relatively higher (~~43%-to 73%~~[\(43-73%](#) across all age groups). Therefore, it is more likely to find a rear-seat passenger travelling in a mini-van than other vehicles (a third of all mini-van trips involve a rear-seat passenger); however, rear-seat occupants in passenger cars are most likely to be involved in an injurious crash. The above correlation may most likely be attributed to the high exposure of passenger cars in general, further attributes related to driver age distribution, behavior, crash characteristics are yet to be determined.

While comparing occupant characteristics, an important distinction lies in the age distribution while comparing front-seat passengers with rear-seat ones involved in a crash. Among rear-seat passengers involved in frontal crashes, more than two-third passengers (68%) are 15 years and below. With the age distribution of rear-seat victims biased towards infants and children, who already avail more adaptive protection using child restraining systems, the true injury risk to the vulnerable older passengers in the rear-seat is likely to be under-appreciated. For a given collision the cohort of 60 years and older rear-seat passengers has a significantly higher risk of fatality compared to their younger counterpart ([Kent et al., 2005, 2009](#); [Morris et al., 2002, 2003](#)). As a result, although this age-cohort represents only 2% of the total rear-seat population involved in a frontal crash, the cohort accounts for over 38% of the fatally injured rear seat occupants in this study (based on weighted figures; over 40% when based on raw counts). For the above reason the study focused on a stratified analysis of three different age cohorts to clearly distinguish their descriptive characteristics and the risk of injury severity.

One of the primary factors for high incidence of injuries among the rear-seat passengers is the relatively lower rate of seat-belt usage. This was further corroborated as the severity of injury incidence exhibited a positive correlation with decrease in belt usage rates. While the rate of usage has increased compared to previous studies (e.g., [Parenteau and Viano, 2003](#)), the current rate of 76% is not yet at par with the front-seat belt usage rate of 85%. Looking further into the belt-usage rates for victims involved in crashes, the cohort of ~~16 to 59~~[16-59](#) years old indicated a belt-usage rate of 53%, significantly lower than the rates for older passengers (71%) as well as child passengers (79%). The belt usage rate among ~~16 to 59~~[16-59](#) years old rear-seat passengers is substantially lower (12%) among those who sustain serious injuries (MAIS 3+). Interpreted differently, among all ~~16 to 59~~[16-59](#) years old injured (AIS 1+) rear-seat victims not wearing the seat belt increases the odds of sustaining a serious injury (AIS 3+) by eight times. It was however interesting to note that the same increased odds of sustaining serious injuries relative to all injured victims reduced to only two folds while considering 60 years and older passengers. This result suggests that not only improving belt usage rates is critical for reducing serious injuries among rear-seat passengers, in agreement with the findings from the literature, there is also potential for improving belt effectiveness in the rear seat environment by adapting to individual characteristics of the passenger.

While the crash severity was fairly uniform across different age groups, the injury severity clearly identified the 60 years and older age cohort as vulnerable rear-seat passengers. The fatality rate (6%), and the associated mean ISS score, for the 60 years and older group was significantly higher (at 95% CI) compared to the younger groups. In terms of injury rates, both at MAIS 2+ and MAIS 3+, no significant distinction could be made between the 16 ~~to~~[and](#) 59 years old group and the older one; however, the injury rates among the children were significantly lower. These trends are consistent with the general body of knowledge on the role of aging in injury and fatality susceptibility. Due to a number of physiological changes (such as osteoporosis and the thinning of cortical bone), older people tend to exhibit a greater injury risk for a given crash exposure compared to younger people ([Morris et al., 2002, 2003](#); [Kent et al., 2005, 2009](#)). Older people are also frailer than younger - they tend to exhibit greater morbidity and fatality risk for a given injury compared to younger people ([Bulger et al., 2000](#); [Evans, 2001](#); [Martinez et al., 1994](#); [Miller et al., 1998](#); [Miltner and Salwender, 1995](#); [Peek-Asa et al., 1998](#)). As a result, older people tend to be injured (even fatally) in lower-severity collisions that may be normally survivable for younger persons ([Kent et al., 2005](#)).

The distribution of injuries indicated that while the head and the upper extremities were most frequently injured among children and 16 to 59 16-59 years old group, the highest incidence rate of AIS 2+ among 60 years and older were observed in the thorax and the abdomen region. Further focusing on only serious injuries (AIS 3+), 60 years and older had an incidence rate of 9% to the thorax while the rates for all other body regions across age groups were less than 5%. This observation of a shift to thoracic injury with advanced age is consistent in the literature across belted occupants for both front and rear seating positions (Kent et al., 2005, 2007; Morris et al., 2002, 2003). Comparing with previous studies, however, it appears that the likelihood of thoracic injuries among rear-seat passengers is considerably higher than the front row counterparts. In a NASS-CDS study (1998-2008) involving belted drivers (age 16 years and older) injured in frontal crashes indicated a thoracic AIS 2+ incidence rate of 1.2% (Bose et al., 2011), while this study reported that among rear-seat passengers the thoracic AIS 2+ rate was 3% for 16 to 59 16-59 years old and 9% for 60 years and older. This is consistent with previous frontal crash test studies which have indicated a greater predicted chest injury risk for adult dummies seated in the rear seat compared to the front seat (Mizuno et al., 2011; Tylko and Dalmotas, 2005; Sahraei et al., 2010). This is also consistent with previous field data studies, which have indicated a greater injury or fatality risk in general for rear seat occupants (compared to front seat occupants) for persons of advanced age (Kent et al., 2007; Kuppa et al., 2005; Sahraei, 2010; Sahraei 2010; Esfahani and Digges, 2009). These data together indicate that while the seat-belt is the primary safety device available for rear-seat passengers, it may also be a likely source of injury for the adult passengers. This supports previous efforts which have indicated that rear seat passengers may benefit from advanced seat belt technologies (similar to those employed in the front seat) that are designed to manage occupant motion while limiting the forces applied to the chest to a sub-injurious level (Kent et al., 2007; Forman et al., 2008, 2009).

It should be noted that the injury rates for the youngest age group were low despite the very low usage (<1%) (<1%) of child-specific safety devices such as the booster seat. Additional factors such as safe driving behavior, high belt usage rate (83% among all crash victims), and marginal higher association with heavier vehicle types (other than passenger cars), may be attributed to the lower injury rates among children.

The study while provided descriptive statistical data on injury rates and characteristics of vehicle, crash and passengers involving rear-seat travel, further case-analysis studies would be required to understand the causation mechanism and contributing factors for injuries sustained among rear-seat passengers. The primary strength of this study is to provide nationally representative statistics on rear-seat motor vehicle travel and crash characteristics including injury epidemiology. Additionally, the study is able to characterize the injury epidemiology for three distinct age cohorts and therefore providing insight into the passenger-related factors contributing to the vulnerability in rear-seat travel. It should however be understood that the estimated are drawn from a survey sampled data with associated bias in characterizing the population-level data on rear-seat passengers.

5 CONCLUSIONS

U.S. traffic data suggests that while rear-seat passengers have considerably low travel exposure, however, factors such as low rate of belt usage and unavailability of advanced safety features compromise the overall protections to victims involved in a crash. The findings of the study also indicated that the senior adults (60 years and older) in spite of their relatively higher belt usage rate are significantly more vulnerable to serious injuries and fatalities in comparison to the younger age cohorts. The highest incidence of serious injuries observed in the thorax region may be attributed to the general lack of supplementary restraint features (e.g., belt load limiters, airbags, pre-tensioners) in the rear-seat configurations. An assessment of the individual injury patterns and associated mechanisms among rear-seat crash victims is necessary to explore additional risk factors including but not limited to influence of seating posture, body habitus, and belt fit as factors contributing to the high incidence of thoracic, abdominal and pelvic injuries. With increasing rear-seat travel, which includes a substantial portion of children (8 to 15 (8-15 years old) and the vulnerable senior occupants, it is necessary to adapt the existing restraint features to accommodate the priorities for the rear-seat environment. Uncited references(Association for the Advancement of Automotive Medicine (AAAM) (1990); Bose et al., (2013); Insurance Institute for Highway Safety (IIHS) (2012); National Household Travel Survey (2009); National Highway Traffic Safety Administration (NHTSA) (2008); U.S. Department of Transportation, National Highway Traffic Safety Administration (USDOT) (1997))

References

- Association for the Advancement of Automotive Medicine (AAAM)-, 1990. The abbreviated injury scale, Abbreviated Injury Scale. Association for the Advancement of Automotive Medicine, Des Plaines, IL.
- Bilston L.E., Du W. and Brown J., A matched-cohort analysis of belted front and rear seat occupants in newer and older model vehicles shows that gains in front occupant safety have outpaced gains for rear seat occupants, *Accid. Anal. Prev. Accid. Anal. Prev.* **42**, 2010, 1974-1977.
- Bose D., Segui-Gomez M. and Crandall J.R., Vulnerability of Female Drivers Involved female drivers involved in Motor Vehicle Crashes: An Analysis motor vehicle crashes: an analysis of US population at Risk risk, *American Journal of Am. J. Public Health* **101** (12), 2011, 2368-2373.
- Bose D (The reference style should be changed to: Bose D., Arregui-Dalmases C., Sanchez-Molina D., Velazquez-Ameijide J., and Crandall J., ipan, Arregui-Dalmases Carlos, Sanchez-Molina David, Velazquez-Ameijide Juan and

- Crandall Jeff, Increased risk of driver fatality due to unrestrained rear-seat passengers in severe frontal crashes ~~1 April~~, *Accident Analysis & Prevention**Accid. Anal. Prev.* **53**, 2013, 100-104.
- Bulger E.M., Arneson M.A., Mock C.N. and Jurkovich G.J., Rib fractures in the elderly, *J.Trauma**J. Trauma* **48**, 2000, 1040-1046.
- Esfahani E. and Digges K., Trend of rear occupant protection in frontal crashes over model years of ~~vehicles. SAE~~*vehicles*, *SAE Technical**Tech. Pap.* 2009, 2009-01-0377.
- Evans L., Age and fatality risk from similar severity impacts, *Journal of traffic medicine 25**J. Traffic Med.* **29**, 2001, 10-19.
- Forman J., Michaelson J., Kent R., Kuppa S. and Bostrom O., Occupant ~~Restraint~~*restraint* in the ~~Rear Seat.ATD Responses~~*rear seat: ATD responses* to ~~Standard~~*standard* and ~~Pre-tensioning, Force-Limiting Belt Restraints~~*pre-tensioning, force-limiting belt restraints*, *Annu.Proc.Assoc.Adv.Automot.Med**Annu. Proc. Assoc. Adv. Automot. Med.* **52**, 2008, 141-154.
- Forman J., Lopez-Valdes F., Lessley D., Kindig M., Kent R., Ridella S. and Bostrom O., Rear seat occupant safety: an investigation of a progressive force-limiting, pretensioning 3-point belt system using adult PMHS in frontal sled ~~tests. Stapp Car Crash~~*tests*, *Journal**Stapp Car Crash J.* **53**, 2009, 49-74.
- Insurance Institute for Highway Safety (IIHS)~~(IIHS)~~, ~~2012~~. Safety ~~belt~~*Belt* and ~~child restraint laws, June~~*Child Restraint Laws*. Available at ~~(http://www.iihs.org/laws/SafetyBeltUse.aspx)~~*http://www.iihs.org/laws/SafetyBeltUse.aspx*.
- Kent, R., Henary, B., Matsuka, F., 2005~~7~~. On the fatal crash experience of older drivers. In: Proceedings of the 49th Association for the Advancement of Automotive ~~Medicine, Ann Adv Automot~~*Medicine*. *Ann. Adv. Automot. Med.*
- Kent, R., Forman, J., Parent, D., Kuppa, S., 2007~~7~~. Rear seat occupant protection in frontal crashes and its feasibility. ~~20th~~*In*. Proceedings of the 20th International Technical Conference on the Enhances Safety of Vehicles (ESV).
- Kent R., Trowbridge M., Lopez-Valdes F.J., Ordoyo R.H. and Segui-Gomez M., How many people are injured and killed as a result of aging? Frailty, fragility, and the elderly risk-exposure tradeoff assessed via a risk saturation model, *Ann Adv Automot Med**Ann. Adv. Automot. Med.* **53**, 2009, 41-50.
- Kuppa, S., Saunders, J., Fessahaie, O., 2005~~7~~. Rear seat occupant protection in frontal crashes. ~~19th~~*In*. Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicles.
- Martinez R., Sharieff G. and Hooper J., Three-point restraints as a risk factor for chest injury in the elderly, *J.Trauma**J. Trauma* **37**, 1994, 980-984.
- Miller T.R., Lestina D.C. and Spicer R.S., Highway crash costs in the United States by driver age, blood alcohol level, victim age, and restraint use, *Accid Anal Prev**Accid. Anal. Prev.* **30**, 1998, 137-150.
- Miltner E. and Salvender H.J., Influencing factors on the injury severity of restrained front seat occupants in car-to-car head-on collisions, *Accid Anal Prev**Accid. Anal. Prev.* **27**, 1995, 143-150.
- Mizuno K., Matsui Y., Ikari T. and Toritsuka T., Seatbelt effectiveness for rear seat occupants in full and offset frontal crash tests, *International Journal of Crashworthiness, Vol**Int. J. Crashworthiness* **16** (1), 2011, 63-74.
- Morris, A., Welsh, R., Frampton, R., Charlton, J., Fildes, B., 2002~~7~~. An overview of requirements for the crash protection of older drivers. In: Proceedings of the 46th Association for the Advancement of Automotive Medicine, ~~141-156~~*141-156*.
- Morris, A., Welsh, R., Hassan, A., 2003~~7~~. Requirements for the crash protection of older vehicle passengers. In: Proceedings of the 47th Association for the Advancement of Automotive ~~Medicine~~, ~~165-180~~*Medicine*. *165-180*.
- National Highway Traffic Safety Administration (NHTSA), 2008. National Automotive Sampling System Crashworthiness Data System - Analytical user's manual, 2008 File, U.S. Department of Transportation*
- National Household Travel Survey, 2009. U.S. Department of Transportation, Federal Highway ~~Administration~~*Administration*. ~~2009~~*URL: URL: (http://nhts.ornl.gov)**http://nhts.ornl.gov*. ~~National Highway Traffic Safety Administration (NHTSA), 2008~~*National Highway Traffic Safety Administration (NHTSA). National Automotive Sampling System Crashworthiness Data System - Analytical user's manual, 2008 File, U.S. Department of Transportation. URL: (http://www.nhtsa.gov/NASS)*
- Parenteau C. and Viano D.C., Field data analysis of rear occupant injuries part I: adults and teenagers, *Society of Automotive Engineers**Soc. Automot. Eng.* 2003.

Peek-Asa C., Dean B.B. and Halbert R.J., Traffic-related injury hospitalizations among California elderly, 1994, *Accid. Anal. Prev.* **30**, 1998, 389-395.

Sahraei E., Digges K. and Marzougui D., Reduced protection for belted occupants in rear seats relative to front seats of new model year vehicles, *Ann. Adv. Automot. Med.* **54**, 2010, 149-158.

Smith K. and Cummings P., Passenger seating position and the risk of passenger death or injury in traffic crashes, *Accident Analysis and Prevention* **36**, 2004, 257-260.

Trowbridge M.J. and Kent R.W., Rear-seat *Motor Vehicle Travel* in the *U.S. - Using National Data* to *Define* a *Population* at *Risk*, *Am. J. Prev. Medicine* **37** (4), 2009, 321-323.

Tylko, S., Dalmotas, D., 2005. Protection of rear occupants in frontal crashes. In: Proceedings of International Technical Conference on the Enhanced Safety of Vehicles.

U.S. Department of Transportation, National Highway Traffic Safety Administration (USDOT), 1997. Fatality Analysis Reporting System Coding and Validation Manual. USDOT, Washington DC. Available at <http://ftp.nhtsa.dot.gov/fars/>. Accessed on 25.04.12.

Highlights

- Thoracic injuries among rear-seat passengers is considerably higher than the front row counterparts.
- The senior adults in the rear-seat, in spite of their relatively higher belt usage rate, are significantly more vulnerable to serious injuries and fatalities in comparison to the younger age cohorts.
- It is necessary to adapt the existing restraint features to accommodate the priorities for the rear-seat occupant.

Queries and Answers

Query:

Please confirm that given names and surnames have been identified correctly and are presented in the desired order.

Answer: Yes

Query:

Your article is registered as a regular item and is being processed for inclusion in a regular issue of the journal. If this is NOT correct and your article belongs to a Special Issue/Collection please contact r.balan@elsevier.com immediately prior to returning your corrections.

Answer: Yes, my understanding is that this article will be registered as a regular item and published in a regular issue of the journal.

Query:

Please validate the country name in the affiliation "b".

Answer: The country name for affiliation "b" is USA.

Query:

Highlights should only consist of 85 characters per bullet point, including spaces. The highlights provided are too long and hence edited to meet the requirement. Kindly confirm that the changes made are okay.

Answer: I agree with the proposed highlights as edited and included here.

Query:

“USDOT, 2009” has been changed to “USDOT, 1997” as per the reference list. Please validate if the changes made are correct.

Answer: Incorrect, the citation should be USDOT, 2010. In the reference list for US DOT, 1997 should be replaed by 2010.