Characterizing the distribution of injury and injury severity for belted front-seat occupants involved in frontal crashes

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ABSTRACT

Probability distribution curves at each AIS level within each body region were developed for front seat occupants in frontal crashes as a function of crash severity. Multivariate regression models used data on passenger vehicles 15 years old or newer with no rollover or fire as documented in USA NASS CDS 1998-2007. The 7268 subjects, representing 2.8 million occupants, had a 6% (95%CI 5-7) probability of sustaining MAIS2+ and 2% (95%CI 1-2) probability of sustaining MAIS3+ in at least one body region, demonstrating the limited risk of sustaining serious injuries for belted occupants in frontal crashes during the last decade. Models accounted for occupant's age, gender and height, vehicle's wheelbase, curb weight, age and model year, deployment of frontal airbags and specific direction of impact. The severity of crash resulted in statistically significant and positive relationships with the severity of injuries across all body regions but neck. Older occupant's age also resulted in statistically significant and positive relationships with more severe injuries in most body regions, particularly when evaluating MAIS3+.

Keywords: Epidemiology, Injury Probability, Velocity

ASSESSMENT AND DEVELOPMENT OF INJURY COUNTERMEASURES is typically based on probability distribution curves created using a limited number of experimental tests (Mertz (2002)) and scarce real world data (Huelke (1979), Laituri et al (2003b), Koh et al (2005),). The use of population-based data sets for the development of probability-based estimates of injury is far less common. As priorities for future research, policies, and countermeasures are developed, it is necessary to assess the current distribution of injuries and their severity in motor vehicle crashes as they relate to various occupant, vehicle, restraint and crash characteristics. In this paper, we focus on developing contemporary probability distribution curves for belted front seat occupants in frontal crashes using advanced statistical models that allow to simultaneously controlling for all these parameters.

METHODS

DATA SOURCE

Data from USA National Highway Traffic Safety Administration National Automotive Sampling System Crashworthiness Data System 1998-2007 were used. The NASS CDS is a stratified sample representative of police-reported crashes in the USA involving passenger vehicles in which at least one of the vehicles is towed away from the scene because of the damage from the crash (NHTSA (1998)). Trained investigators complete an extensive questionnaire of data elements to describe the crash, vehicles involved, the occupants and their injuries. During this time period, injury severity was assessed using the 1998 update of the AIS Scale (AAAM (1998)). About 5000 crashes per year are investigated and the selection for investigation follows an inverse relationship with the severity of the crash. Thus, each case is assigned a sampling weight to indicate how representative it is from other crashes in the USA. While data are publicly available at ftp://ftp.nhtsa.dot.gov/NASS/, a research-oriented version of the publicly available data available at http://www.unav.es/ecip/NASS/asistente/ was used for the analyses due to the relational nature of the files; the addition and removal of variables over the years; and, most importantly, code changes in the variable values over time,

DATA MANAGEMENT

Using data from calendar years 1998-2007, a flat file with one occupant per row and the relevant, vehicle, crash, and injury information was created. Inclusion criteria restricted the file to drivers and front seat passengers who were at least 18 years old at the time of the crash and who were belted and not ejected from the vehicle; the vehicle had to be a passenger vehicle 15 years old or newer at the time of the crash; and the crash had to be a frontal collision (defined as 11-1 o'clock) with no rollover or fire. Cases whose sampling weights were in excess of 1 million were excluded from analysis based on their rarity.

New variables were created to facilitate analyses of covariates such as gender, vehicle age, longitudinal delta V, and deployment of frontal airbags. Most notably, variables to summarize the most severe injury by body region were developed since the original data allowed for the description of up to ten possible injuries per person. These injury summary variables included ordinal variables reflecting the full range of AIS 0-6 values for each of the eight body regions, dichotomous variables representing the Maximum AIS (MAIS) for each body region as 2+ or 3+, and two additional dichotomous variables summarizing whether the MAIS for any body region was 2+ or 3+.

DATA ANALYSIS

A descriptive analysis was performed to determine the distribution of variables. This was done with the data as originally collected (usually referred to as "raw data") as well as with the data weighted to produce US-based estimates of the distribution of these variables.

Univariate analyses using ordinal logistic regressions were performed with the weighted data to evaluate the relationship between selected occupant, vehicle and crash characteristics and the occurrence of injuries of varying severity. Those variables that showed statistically significant relationships ($p<0.1$) with injury severity within most body regions were selected for inclusion as covariates in the multivariate models. These were gender, age, height of the subject, drivers or front seat passenger seating position; curb weight, wheelbase distance, age and model year of the vehicle; longitudinal delta V of the crash, presence of frontal crash direction of forces of 11, 12 or 1, and whether the frontal airbag deployed.

A random 80% sample of the weighted data was selected to run multivariate logistic regression models in order to assess the likelihood of overall AIS injury and region-specific injury at the AIS 2+ and 3+ severity levels. (The remaining 20% will be used for validation purposes in a separate paper.) Ordinal multivariate regression models were then developed for a more comprehensive examination of the causal factors at each AIS severity level (0-6). To ease comparison between models, all of them included the same list of covariates (as listed in the previous paragraph), regardless of the actual effect and its significance in that model. After each model was developed, predictions of adjusted probabilities of AIS 1 through 6 were computed for each body region.

Cumulative probability distribution curves by body region were computed for longitudinal delta Vs ranging from 0-64 km/h (i.e., the crash severity used in several NCAP frontal tests (EuroNCAP, 2004)). Each curve was developed by rescaling from 0 to 1 the cumulative probabilities derived from multiplying the predicted probability of sustaining an injury of any given level to the probability of a crash of that severity level occurring in the general population and leading to an injury in that body region.

Analyses were performed in STATA v. 10 (Stata Corp LP (2007)) and Excel (Microsoft Corporation, (2003)).

RESULTS

7268 occupants met the inclusion criteria but sampling weights were not available for 1895 of them (26%) and 39 of the cases (0.5%) had weights of 0 –implying that they do not belong to the original sampling frame of the NASS CDS system. Thus, 5334 occupants were included in the weighted calculations with weights ranging between 1 and 57872, and an average value of 544. These cases represent 2.864 million occupants in crashes during 1998-2007 in the USA.

Table 1 presents the distribution of selected occupant, vehicle and crash characteristics for both the raw and the weighted data. The comparison between both distributions demonstrates the fact that crashes selected for investigation tend to be more severe than those typically occurring on the roads in the US. Most notably, 3% of the occupants in the raw cases died as a consequence of the crash, whereas this percent was less than 1% when applied to the weighted population during that time period.

When focusing on the weighted data, the average age of all drivers and front-seat passengers in our selected crashes was 37 years old (95% CI 36-39); they are as likely to be male as female; more likely to be drivers than front seat passengers (85%, 95%CI 81-88); and they are, on average 170 cm tall (95% CI 169-171). Injury data were missing in 9% of raw cases, and 59% of occupants resulted in no injury at all while 6% of subjects presented an overall Maximum AIS (MAIS) of 2+ (95%CI 5-7) and 2% present an overall MAIS of 3+ (95% CI 1-2). Some 2% of the injuries were in undetermined body regions. Less than 1% of front seat occupants presented with AIS2+ in the chest, abdomen, spine and lower extremity and less than 1% experienced AIS 3+ injuries to the head or upper extremity. None presented AIS2+ injuries in neck, which in this body region categorization excludes cervical spine injuries. Information on the severity of the crash was missing in 50% of raw cases; yet among those with information available, the weighted average crash severity was 18 km/h (95% 17-19).

Table 1. Distribution of selected person, vehicle, crash and outcomes of cases meeting study inclusion criteria: Belted 18 years old or older drivers or front seat passengers in passenger vehicles no older than 15 years-old involved in single vehicle or two-vehicle only frontal crashes with no rollover or fire, USA NASS CDS 1998-2007.

			Raw cases (N=7268)		Weighted cases (N=2864188)	
			N (or Mean)	% (or SD)	N (or Mean)	95 % CI
Person	Age	(years –mean)	38	19	37	36-39
	Height	(cm –mean)	171	10	170	169-171
	Gender	(male)	3777	52	49	44-54
	Driver	(yes)	5969	82	85	81-88
Vehicle	Vehicle weight	(kg -mean)	1390	240	1363	1346-1382
	Wheelbase	(cm -mean)	269	14	268	267-269
	Vehicle age at time of crash	(years -mean)	5	4	6	5-6
	Model Year	Range 1983-2008	1998	5	1996	1995-1996
Crash	Longitudinal delta V	(km/h -mean)	24	15	18	17-19
	Direction of principal impact	11	1163	16	9	7-11
		12	5088	70	79	75-83
		1	1017	14	12	10-14
	Frontal airbag deployed	(yes)	4490	62	46	41-51
Outcomes	Treatment	None	2161	30	64	59-68
		Fatal	265	3	<1	<1*
MAIS	Head	0	6009	83	95	94-96
		1	556	8	3	2-3
		2	389	5	2	1-2
		3	100	1	<1	<1
		4	102	1	<1	<1
		5	85	1	<1	<1
		6	27	<1	<1	<1

	Face	0	5396	74	87	85-89
		1	1735	24	12	11-15
		2	98	1	<1	<1
		3	39	1	<1	<1
		4 or higher	0	0	0	0
	Neck	0	6966	96	98	98-99
		1	297	4	2	0-2
		2	3	<1	0	0
		3	2	<1	0	0
		4 or higher	0	0	0	0
	Chest	0	5334	73	88	86-90
		1	1343	18	11	9-13
		2	158	2	<1	<1
		3	255	4	<1	<1
		4	122	2	<1	<1
		5	49	1	<1	<1
		6	7	<1	<1	<1
	Abdomen	0	6440	89	96	95-97
		1	610	8	3	2-5
		2	114	2	<1	<1
		3	62	1	<1	<1
		4	31	<1	<1	<1
		5	11	<1	<1	<1
		6	0	0	0	0
	Spine	0	5995	82	93	91-94
		1	969	13	7	6-8
		2	196	3	<1	<1
		3	84	1	<1	<1
		4	8	<1	<1	<1
		5	5	<1	<1	<1
		6	11	<1	0	0
	Upper Ext	0	4703	65	78	73-82
		1	2069	28	20	17-25
		2	329	5	1	0-2
		3	167	2	<1	<1
		4 or higher	0	0	0	0
	Lower Ext	0	4776	65	81	76-83
		1	1715	24	18	15-21
		2	397	5	1	0-1
		3	376	5	<1	<1
		4	4	<1	0	0
		5 or higher	0	0	0	0
	Overall	1+	4244	58	41	36-46
		2+	1942	27	6	5-7
		3+	1082	15	2	1.5-2.4

* Value is 0.02% with a 95% CI 0.02-0.03.

Missing data points in different variables and the use of an 80% sample of the original data permitted multivariate logistic regression models to be developed from 1585 raw cases representing 738,313 individuals. The effect of each covariate on the probability of sustaining an AIS 2+ or 3+ overall and by body region is summarized in tables 2 and 3, respectively. In the tables, adjusted Odds Ratios (ORs) and whether they reached statistical significance ($p<0.05$) or borderline significance ($0.1\geq p\geq 0.05$) are presented for each of 16 regression models with 12 covariates. (There should have been 2 more models for neck injuries, but since no one sustained neck injuries of AIS2 or higher, this body region could not be evaluated in this manner.)

The body-region specific models confirmed statistically significant relationships for 12 covariates in between 4 and 9 of the models. In addition, 1 to 3 other covariates had borderline significance in every model. Last, overall and body region-specific analyses demonstrated relationships in between 2 and 7 of the 16 models.

Regarding the overall likelihood of sustaining more severe AIS injuries, longitudinal delta V showed the most stable effect. In 15 of all 16 models a unit increase in crash severity was statistically significantly related to an increase in the probability of sustaining both AIS 2+ and 3+, the only exception being the modeling evaluating spinal AIS2+ injuries. A one-year increase in age (of the occupant) increased the probability of both injury outcomes whereas deployment of the frontal airbag was related to a decrease in sustaining either severity of injuries in 10 models. Older vehicles (both in model year and age at the time of the crash) increased the likelihood of sustaining overall 2+ and 3+, although the body regions for which this was true were head, spine for both outcomes, lower extremity for AIS2+ and face and upper extremity for AIS3+. Being male decreased the likelihood of sustaining AIS3+ overall and across all body regions.

All covariates had significant impacts on at least one body region's maximum AIS level, including increases in the chances of sustaining more severe injuries with height and directions of force other than 12 o'clock or decreases in relation to being front seat passengers as opposed to drivers or being in vehicles with longer wheelbases.

Table 2. Multivariate logistic regression models on sustaining AIS 2+ injuries overall and by body regions among belted 18 years old or older front occupants in passenger vehicles no older than 15 years old in single vehicle or two-vehicle only frontal crashes with no rollover or fire. USA NASS CDS 1998-2007 weighted data (N=738.313)

	Overall		By body region^{+}													
			Head		Face		Chest		Abdomen		Spine		Lower E		Upper E	
	OR	p	OR	p	OR	P	OR	p	OR	p	OR	p	OR	p	OR	p
Age	1.0		1.0	#	1.1	*	1.1	*	1.1	*	1.1	*	1.1	*	1.0	
Height	1.0		1.0		1.1	*	1.0		1.1	*	1.1	#	1.1	*	1.1	
Gender (Male)	0.6	#	0.6		1.1		0.8		0.1	*	0.1	#	0.3	*	0.5	
Front seat passenger	0.7		1.0		0.6		0.8		4.1	*	0.1	*	1.0		0.4	*
Vehicle weight	1.0	*	1.0	*	1.0		1.0		1.0		1.0	*	1.0	*	1.0	
Wheelbase	0.9	*	0.9	*	1.0		1.0		0.9	*	1.1		0.9	*	1.0	
Vehicle age	0.9		1.0		1.7	*	0.8	#	1.2		1.2		1.1		0.9	*
Model year	1.1		1.1	#	1.2	#	1.0		0.9		1.2		1.2	*	1.0	
Longitudinal Delta V	1.1	*	1.1	*	1.1	*	1.1	*	1.1	*	1.0		1.1	*	1.1	*
DoF 11	1.3		2.4	*	0.4		0.3	*	16	*	1.3		0.8		0.9	
DoF 1	0.6		1.7		1.0		0.1	*	0.3		0.3		0.2	*	0.1	*
Airbag (deployed)	0.7	*	0.8	*	0.8	#	0.8	*	1.1		0.7		0.7	*	0.6	*

DoF = Direction of Force (Impact); * $p<0.05$; # $0.1 \geq p \geq 0.05$; $^{+}$ Neck could not be analyzed because there was no AIS 2+ in this body region; Models use as the reference case an 18 year old female driver 150 cm tall, driving a 1983 vehicle purchased the year of the crash with a weight of 1000 kg and a wheelbase of 220 cm involved in a 12 o'clock crash with a longitudinal delta V of 0 and for which the airbag did not deploy

The eight multivariate ordinal regression models (one for each body region) confirmed the above findings demonstrating a statistically significant and positive relationship between the severity of the crash and the head, chest, abdomen, spine, lower and upper extremity injury severity but led to no significant findings for neck and only borderline significant ones for face.

Table 3. Multivariate logistic regressions on sustaining AIS 3+ injuries overall and by body regions among belted 18 years old or older front occupants in passenger vehicles no older than 15 years old in single vehicle or two-vehicle only frontal crashes with no rollover or fire. USA NASS CDS 1998-2007 weighted data (N=738.313)

	Overall		By Body Region+													
			Head		Face		Chest		Abdomen		Spine		Lower E		Upper E	
	OR	p	OR	p	OR	p	OR	p	OR	p	OR	p	OR	p	OR	p
Age	1.1	*	1.1	*	1.2	*	1.1	*	1.1	*	1.1	*	1.1	*	1.1	*
Height	1.0		1.1	#	1.5	*	1.1		1.1	*	1.0		1.0		1.1	
Gender (Male)	0.3	*	0.1	*	0	*	0.1	*	0.1	*	1.1		0.2	*	0.1	*
Front seat passenger	0.8		1.5		--		0.9		11	*	0.2		2.3	*	1.2	
Vehicle weight	1.0	*	1.0		1.0		1.1	*	1.0		1.0		1.0		1.0	
Wheelbase	0.9	*	1.0		1.0		0.9	*	0.9		1.0		1.0		1.0	
Vehicle age	1.1		1.2	#	7.1	*	0.8		1.2		1.6	*	1.0		1.6	*
Model year	1.2	*	1.2	*	6.0	*	1.1		0.9		2.1	*	1.0		1.6	*
Longitudinal Delta V	1.1	*	1.1	*	1.2	*	1.1	*	1.2	*	1.1	*	1.1	*	1.1	*
DoF 11	1.3		0.1	*	2945	*	0.3	#	102	*	67	*	0.6		4.7	#
DoF 1	0.5		3.2	#	--		0.1	*	0.5		--		0.5		0.1	*
Airbag (deployed)	0.7	*	0.8		0	*	0.7	*	0.6		1.5	*	0.8		0.6	*

DoF = Direction of Force (impact); * $p<0.05$; # $0.1 \geq p \geq 0.05$; + Neck could not be analyzed because there was practically no AIS 3+ in this body region; Models use as the reference case an 18 year old female driver 150 cm tall, driving a 1983 vehicle purchased the year of the crash with a weight of 1000 kg and a wheelbase of 220 cm involved in a 12 o'clock crash with a longitudinal delta V of 0 and for which the airbag did not deploy

These findings are summarized in Table 4 where the ORs and p values are shown for each independent variable. Vehicle model year was significant for all regression models and demonstrated the benefit of advances in vehicle crashworthiness and restraint design. Being male, younger, shorter, and a front seat passenger, being in a vehicle with a longer wheelbase and a newer vehicle at the time of the crash, and having a frontal airbag deployed in the crash significantly decreased the probabilities of having more severe injuries in a number of body regions. These ordinal regression models were used to develop predictions of the severity of injury (i.e., AIS level) as a function of longitudinal delta-V. Figure 1 presents the predicted probabilities of sustaining no injury. Whereas at low longitudinal delta V such probabilities are practically 1, these probabilities do not reach 0 at higher speed crashes. As an example, at 64 km/h these range from a low 27% for lower extremities to a high 99% for neck injuries, with 52% of sustaining no chest and upper extremity injuries, 67% of not having head injuries, 71% of not having face injuries, 76% of not having spinal injuries and 79% of not having abdominal injuries. Conversely, the adjusted predicted probabilities of sustaining AIS 1+, 2+, 3+, 4+, 5+ or 6 increased with severity of crash (data not shown).

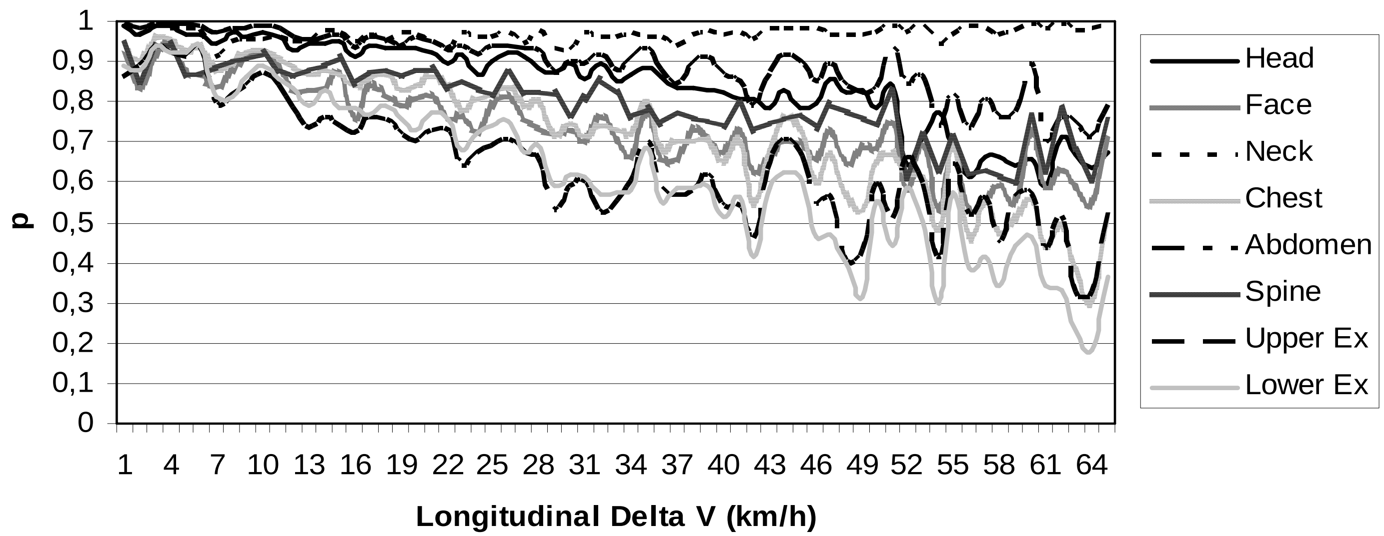
We could predict P(AIS6) for head and chest, P(AIS5+) for abdomen and spine, P(AIS3+) for face, upper and lower extremities, and P(AIS1+) for the neck region. Since the numbers were very small for AIS 4+, we present cumulative distributions only for AIS1+ to 3+ (Figures 2-8). These figures show monotonically increasing probabilities of injury by injury severity and longitudinal delta V. They relate to subjects sustaining at least one injury in the pertinent body region. The longitudinal delta V at which 50% of the injured individuals sustain such injury (AIS1+) is 19 km/h for the upper extremity injuries, 21 km/h for the lower extremity injuries, 24 km/h for the facial injuries, 25 km/h for the neck injuries, 27 km/h for the chest injuries, 28 km/h for the spinal injuries, 29 km/h for the head injuries, and 32 km/h for the abdominal injuries. Across body regions, the delta Vs at which different AIS levels were reached varied. For example, in the lower legs it was 21 km/h for AIS1+, 26 for AIS2+ and 28 for AIS3+. Yet, for most other body regions the shifts were of small magnitude.

Table 4. Multivariate ordinal regressions on AIS 0-6 by body region among belted, ≥18 years old, front occupants in passenger vehicles <16 years old in single vehicle or two-vehicle only frontal crashes with no rollover or fire. USA NASS CDS 1998-2007 weighted data (N=738.313)

	Head		Face		Neck		Chest		Abdomen		Spine		Lower E		Upper E	
	OR	p	OR	p	OR	p	OR	p	OR	p	OR	p	OR	p	OR	p
Age	1.0	0.2	1.0	0.9	1.0	0.9	1.0	0.4	1.01	0.027	1.0	0.1	1.02	0.01	1.03	<0.01
Height	1.0	0.8	1.0	0.7	1.0	0.9	1.0	0.4	1.1	0.001	1.0	0.8	1.0	0.6	1.0	0.8
Gender (Male)	0.5	0.03	0.4	<0.01	0.5	0.9	0.3	0.006	0.1	<0.01	0.4	0.005	0.3	<0.01	0.4	0.001
Front seat passenger	1.8	0.06	0.9	0.9	1.8	0.9	0.9	0.7	1.5	0.3	1.6	0.1	0.7	0.2	1.0	0.9
Vehicle weight	1.02	<0.01	1.02	0.01	1.0	0.9	1.0	0.8	1.0	0.2	1.0	0.2	1.0	0.9	1.0	0.9
Wheelbase	0.97	0.01	0.9	0.09	1.0	0.9	1.0	0.6	1.0	0.1	1.0	0.9	1.0	0.9	1.0	0.9
Vehicle age	1.0	0.7	1.1	0.3	1.3	0.9	0.9	0.4	1.0	0.5	1.1	0.04	0.8	0.01	0.8	0.003
Model year	1.1	0.06	1.1	0.1	1.2	0.9	0.9	0.8	1.1	0.5	1.1	0.02	0.9	0.04	0.9	0.08
Long. Delta V	1.1	<0.01	1.0	0.08	1.0	0.9	1.04	<0.01	1.1	<0.01	1.03	0.02	1.06	<0.01	1.04	0.006
DoF 11	2.1	0.02	1.2	0.5	3.0	0.9	0.6	0.3	2.3	0.04	0.6	0.1	0.9	0.9	1.3	0.4
DoF 1	1.5	0.4	0.4	0.01	7.1	0.02	0.9	0.8	2.3	0.1	1.0	0.9	1.2	0.7	2.0	0.1
Airbag deployed	0.8	<0.01	0.8	<0.01	1.1	0.9	0.9	0.3	0.8	0.001	0.9	0.09	1.0	0.5	0.8	<0.01

DoF = Direction of Force (Impact); Models use as the reference case an 18 year old female driver 150 cm tall, driving a 1983 vehicle purchased the year of the crash with a weight of 1000 kg and a wheelbase of 220 cm involved in a 12 o'clock crash with a longitudinal delta V of 0 and for which the airbag did not deploy.

Figure 1. Probability of sustaining no injury by longitudinal delta V. Predictions* from multivariate ordinal regressions for belted ≥18 years old front occupants in passenger vehicles <16 years old in single or two-vehicle only frontal crashes with no rollover or fire. USA NASS CDS 1998-2007 weighted data.



* Adjusted for age, gender, height, seating position (driver and front seat passenger), vehicle age, vehicle model year, direction of impact, and airbag deployment

Figures 2-9. Normalized Cumulative probability of AIS1+, 2+ and 3+ by severity by longitudinal delta V (0-64 km/h) by body regions conditional on sustaining an injury in that body region. Front seat passengers in frontal crashes USA NASS CDS 1998-2007.

Figure 2. Head

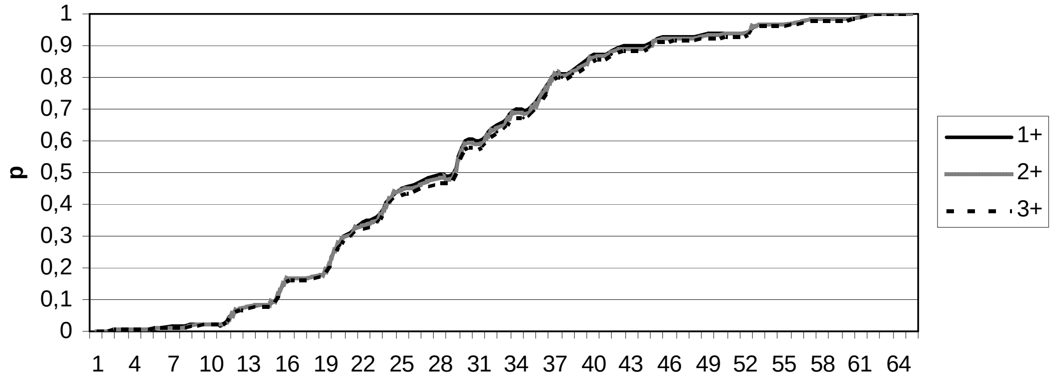


Figure 3. Face*

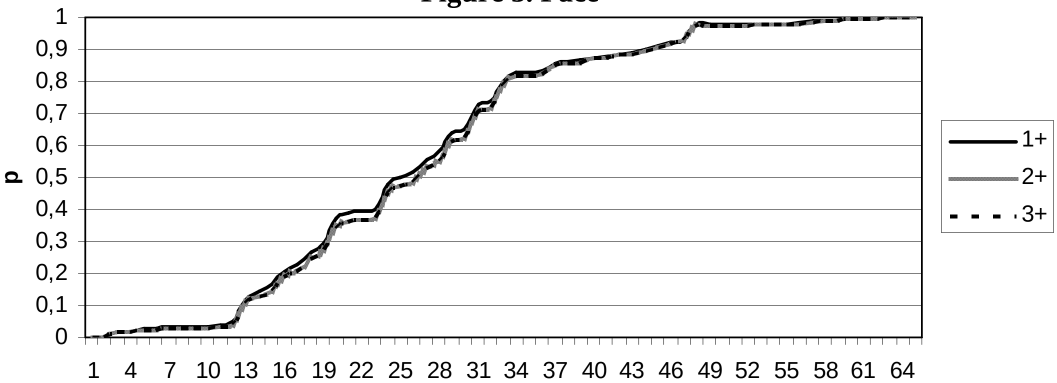


Figure 4. Neck*

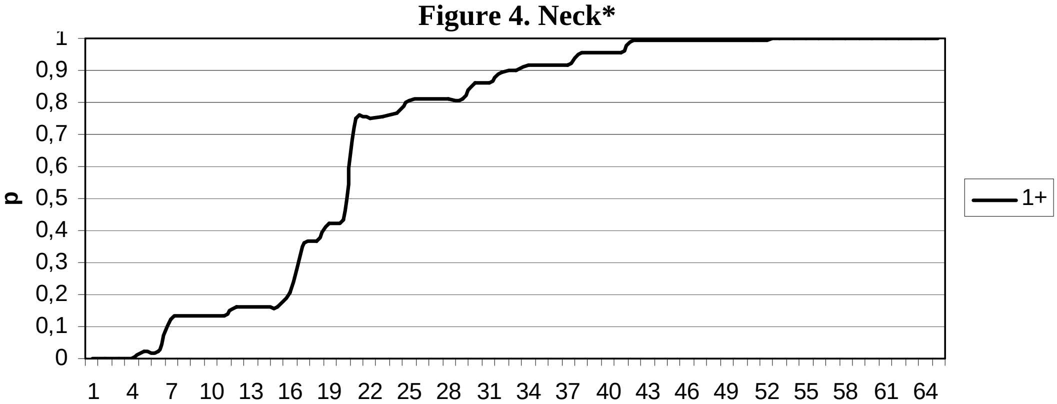


Figure 5. Chest

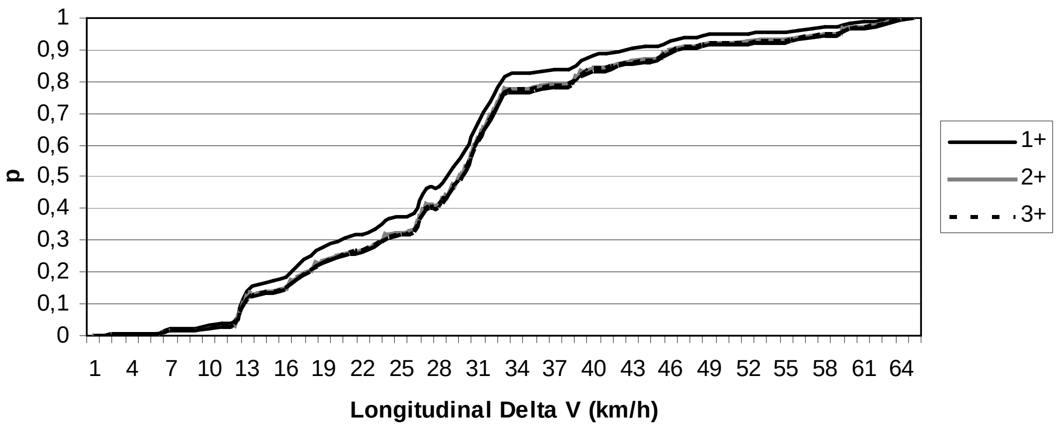


Figure 6. Abdomen

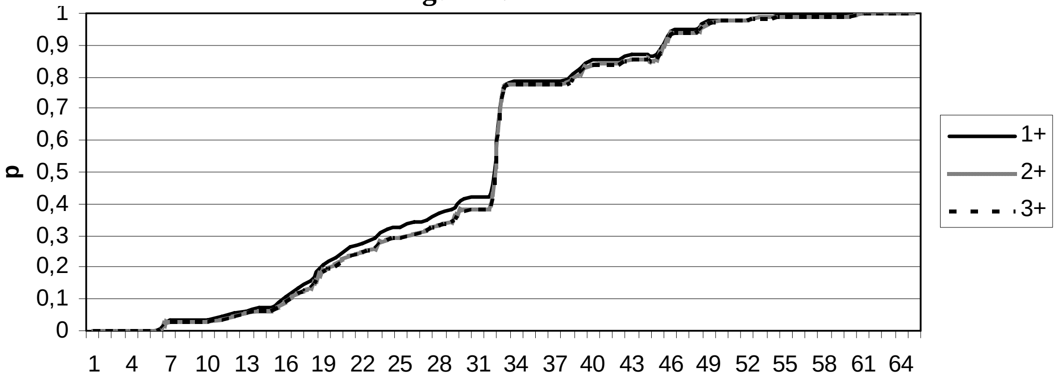


Figure 7. Spine

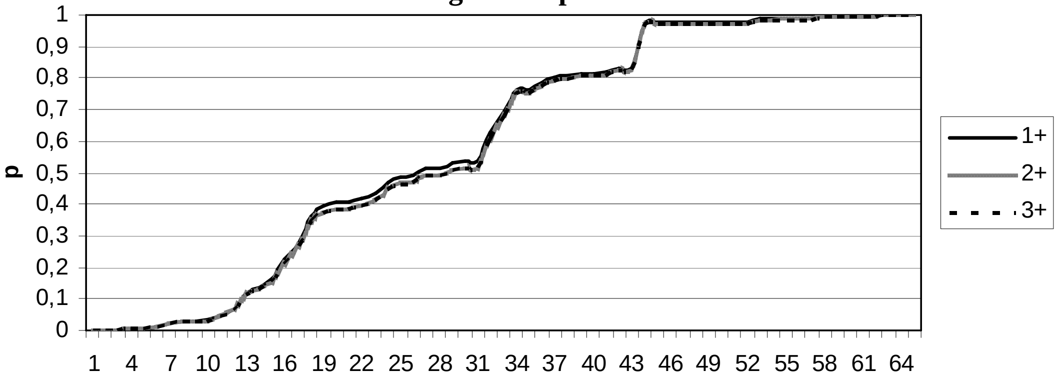


Figure 8. Upper Extremities

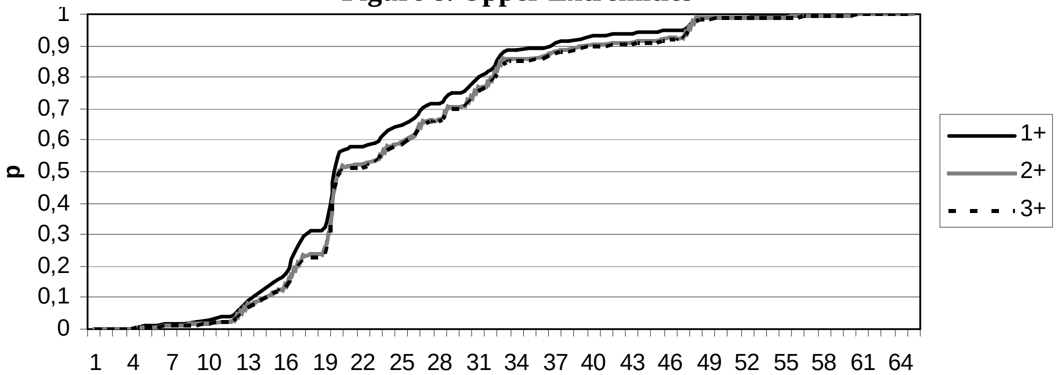
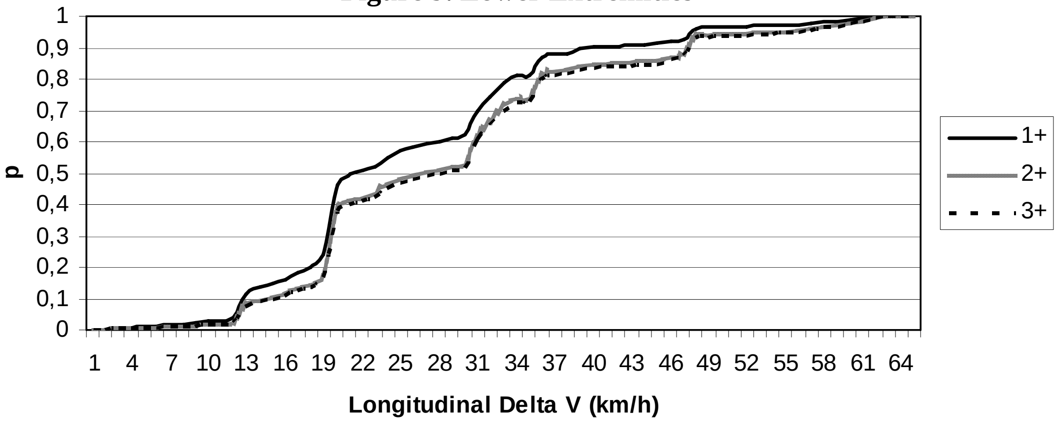


Figure 9. Lower Extremities



Predictions adjusted for age, gender, height, seating position (driver and front seat passenger), vehicle age, vehicle model year, direction of impact, and airbag deployment among 18 years belted occupants of passenger vehicles no older than 15 years old in single vehicle or two-vehicle only frontal crashes with no rollover or fire. * Regression coefficients were either marginally or non statistically significant.

DISCUSSION

This paper provides a comprehensive view on current motor vehicle injury distributions for US frontal crash occupants. Among belted adult front seat occupants, the likelihood of sustaining any MAIS 3+ while in frontal crashes meeting the inclusion criteria was 2%, and the likelihood of sustaining MAIS2+ injuries was 6%. Even though deaths were not recoded into AIS6, it is worth noting the small percent of death among these individuals (<1%). The number of deaths herewith identified matches the official estimates of the US over the period of the study, and provides an indirect measure of the validity of the sampling data procedure. To a certain extent, the low number of deaths reinforces the relatively limited risk of sustaining serious injuries for belted occupants in frontal crashes that and reflects progressive improvements in both vehicle and restraint designs, as proven in other time trend evaluations (Hecker & Trochelman (2005), Cummings et al (2006)). Yet, it is worth nothing that 1% of the data represent 28642 people affected with AIS3, 4, 5 or 6 in different body regions. Thus, additional injury prevention is still needed and challenges remain to be solved.

While the small data set for serious injuries prevented the identification of a direct relationship between severity of the crash and severity of injury at each AIS level in some body regions (i.e., neck and face), the models were able to demonstrate consistently the dependence of injury severity on occupant, vehicle and crash traits. Most notable is the positive association between crash severity and injury severity, even when holding all other covariates constant, which was one of the objectives of this paper. Simpler analysis had already suggested this association (Conroy et al (2008).

To reach sufficient sample size, several years of NASS CDS data were compiled which may have resulted in some of the more recent crash data being obscured by older crashes. To minimize this, control was exerted in two stages. Firstly, we established strict inclusion and exclusion criteria to define a precise study population, albeit limiting our evaluation of some issues such as the role of safety belts. Secondly, we used multivariate regression techniques that allow further control for variables such as the occupant's precise age, gender and height; the vehicle age (model year and age at time of crash) and size; the specific direction of force during impact and a number of other characteristics which may have changed over the years such as airbag inflation. While we would have liked to evaluate other covariates, such as bracing of occupants prior to crash, or occupant weight, missing data for those other variables prevented us from doing so.

Adding covariates in the models allowed us to evaluate their impact on injury outcome. Most of our findings are consistent with previous reports (Newgard and McConnell (2008), Bédat et al (2002)). For example, the increase in injury severity with age (Kent et al, 2005, Crandall et al 1998), being female (Hill (2006), Conroy et al (2008)), being taller (Dehner et al, 2008) or the decrease in injury severity related to being in a vehicle with longer wheelbase (Evans L (1992)), a newer vehicle (as measured both in terms of age of the vehicle at the time of crash and model year (Blows et al (2003)), and having the frontal airbag deploy (Welsh et al (2008), MacLennan et al (2008)). This consistency lessens the fear of possible selection bias related to the misclassification regarding safety belt use reported by some authors (Robertson (2002), Schiff and Cummings (2004)). Some other findings have not been reported in the literature in a way comparable to ours. For example, the relatively small impact of curb weight on injury severity when all other covariates are included (Evans (2004)). We have found no comparator for our finding on the increase in injury severity when the crash is at 11 or 1 as opposed to 12 o'clock.

The adjusted predicted probabilities by injury level resulted in density functions closely matching the original distributions. Once the analysis was conditioned on sustaining body-region specific injuries of any severity level, cumulative curves resulted in interesting findings related to the crash severities related to those injuries, albeit the small number of cases sustaining more severe injuries prevents a big distinction in curves when they relate to

AIS1+, 2+ or 3+ and may not be relevant in the neck and face regions. Yet, we present the graphs to be exhaustive.

CONCLUSIONS

This paper provides detailed probability distribution curves of injuries of varying severity at each body region as a function of crash severity controlling for possible confounders and using real world data for the whole US crash population. The results demonstrate the effectiveness of current restraints and vehicle design on the head, face abdomen, spine and upper and lower extremities when front occupants are involved in frontal crashes. Severity of the crash remains the single most consistent predictor of more and more severe injuries, with one unit increases in severity leading to increases of around 1% in the chance of sustaining more severe injuries across all body regions. Age of the occupant is the next most consistent risk factor across all regions and severity levels. Assessment of injury severities within each body region identified the contributions of occupant traits (i.e., age, gender, and height) and demonstrated the need for evaluating occupants other than a middle-aged 50th male and 5th female.

The probability curves should be useful to biomechanical researchers to evaluate the need for additional and optimal safety systems. Similar analyses should be conducted to develop probability distribution curves for other types of crashes.

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