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Belted Female Occupants in Frontal Car Crashes are More Likely to Sustain Moderate Concussions than Male Occupants

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ABSTRACT NASS-CDS data from years 2005-2015 was analyzed to estimate the frequency and risk of moderate and serious concussion injuries sustained by belted occupants in car crashes in the US. The concussion data was compared to all other brain injuries of higher severity and analyzed considering crash severity, crash year, car model year, and the victim's age and sex. The results showed that an annual average estimation of 18,359 ±4,721 belted occupants sustained a concussion in the US, which comprises 84.7% of all occupants with $MAIS_{brain}2+$ injury. After controlling for crash severity, female occupants in frontal crashes were estimated to be 1.4 times more likely to sustain a concussion than male occupants. As new strategies for the prevention of brain injuries are developed, this study suggests the need to incorporate moderate concussion injuries, with particular attention to female occupants.

INTRODUCTION

Occupant injury prevention strategies that aim at the reduction of life-threatening head injuries have proven insufficient to achieve significant reductions of severe Traumatic Brain Injuries (TBIs) (Takhounts et al., 2013). Less severe TBIs, which are mainly concussions, have gained less attention in the development of these strategies. However, concussion may lead to persistent cognitive, physical or psychosocial impairment (Carroll et al., 2014). Updated injury prevention strategies that reduce both life-threatening TBIs and concussions are needed. For the development of these strategies, understanding real-world crash scenarios is required.

Several studies analyzed NASS-CDS data to clarify scenarios relevant for TBI. The risk of severe head and brain injuries increases with crash severity and with occupant's age (Mallory et al., 2011; Ridella et al., 2012). The use of seatbelt and airbags is associated with reduced frequency of AIS2+ skull and brain injuries (Pintar et al., 2000). Seatbelt use reduces the risk of concussions in frontal crashes by 73.6% (Viano & Parenteau, 2015). The NASS-CDS studies that incorporated concussions did not provide statistical analysis of how crash, vehicle and occupant demographics affect concussion risk.

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The aim of this study is two-fold: 1) To provide an overview of the frequency and risk of concussions sustained by belted occupants in car crashes, in comparison to brain injuries of higher severity. 2) To analyze the concussion data considering crash year, crash severity, car model year, and the victim's age and sex.

METHODS

NASS-CDS data from years 2005 to 2015 was analyzed using SAS. First, a descriptive analysis was conducted to estimate the frequency and risk of nine TBI categories. Second, odds ratio analysis was applied to model the effects of car model year, crash year, crash severity, occupant's sex and age on concussion risk.

Inclusion criteria

- Crash year 2005-2015
- Vehicle model year 2001-2015
- Passenger cars, pick-ups and mini-vans
- Non-ejected occupants
- Occupant age 15 or higher
- Occupants with known injury status or fatality
- 3-point belted

Injury categories

TBI categories were defined based on AIS90/98 codes: AIS2-3 *Concussion* (All AIS codes 16****2 or 16****3) reported as Cerebral Concussion, as

Level of Consciousness (LOC), as Length of Unconsciousness (LOU), or as Lethargic, Stuporous, Obtunded post resuscitation; AIS4-5 *Diffuse Axonal Injury* (DAI) reported as white matter shearing in the cerebrum or cerebellum, as LOC or as LOU; AIS4-5 *Intracranial Hemorrhage* (ICH) including intracerebral, intracerebellar and intraventricular locations; AIS3-5 *Contusion*, AIS4-5 *Epidural Hemorrhage* (EDH), AIS4-5 *Subdural Hemorrhage* (SDH) or AIS3 *Subarachnoid Hemorrhage* (SAH) in the cerebrum or cerebellum but not in the brainstem; AIS5-6 *Brainstem* reported as injury to the brainstem regardless of injury type; AIS3-5 *Others* with all brain injuries not included in any of the above categories.

Descriptive Analysis

Frequency of a particular brain injury was defined as the number of occupants who sustained that particular injury as their highest severity brain injury ($MAIS_{brain}$). The risk for an occupant to sustain a particular brain injury was obtained by dividing the number of occupants with that particular $MAIS_{brain}$ injury by the number of occupants with known injury status. National weighted estimates and the standard errors (±SE) of these estimates were obtained by applying the SAS SURVEYFREQ function that accounts for stratification, clustering, and sampling weights.

Odds Ratio Analysis

The odds ratio analysis was limited to frontal cases with available crash severity (delta-V). The SAS SURVEYLOGISTIC function was applied to model the effects of car, crash and occupant factors on the odds to sustain concussion. Concussion injury was considered as a dichotomous variable equal to one for occupants with the injury and zero otherwise. Delta-V was modeled as a continuous variable. Sex and Age were considered as dichotomous variables. Three car model year groups were defined. 2001-04 group incorporated depowered airbags. 2005-10 group complied with FMVSS301 updates and contained the first generations of IIHS top safety awards. 2011-15 group were subjected to the enhanced US-NCAP tests. A variable for crashes that occurred before or after 2010 was also included to control for the possible effect that the adoption of the AIS05/08 version into NASS-CDS may have had on the likelihood of concussion injuries to be reported in the AIS90/98 codes.

RESULTS

In total, 31,449 raw number of occupants met the inclusion criteria. Applying the weighting factors 14,093,453 occupants were obtained. 51.9% of these occupants were females. Young age (15-34) accounted for 51.7% of the total sample, followed by middle age (35-64) with 37.8% and old age (65+).

Table 1 shows the annual average frequency of weighted occupants with $MAIS_{brain}2+$ injuries by injury category and injury severity. A total of 18,359 ±4,721 occupants sustained a moderate concussion, which comprises 84.7% of the 21,669 ±5,767 occupants with $MAIS_{brain}2+$ injuries. Excluding concussions, the most frequent injury categories were SDH (935 ±169), SAH (566 ±130), Contusion (519 ±348), ICH (463 ±119), and Brainstem (323 ±105).

Table 1. Annual Frequency of $MAIS_{brain}2+$ injuries

No. of Occupants	$MAIS_{brain}$ 2	3	4	5	6	Total
Concussion	18,359	60	-	-	-	18,419
Contusion	-	515	-	4	-	519
DAI	-	-	49	110	-	159
Brainstem	-	-	-	164	160	323
SDH	-	-	726	209	-	935
SAH	-	566	-	-	-	566
EDH	-	-	112	5	-	117
ICH	-	-	323	139	-	463
Others	-	98	42	28	-	169
Total	18,359	1,239	1,253	659	160	21,669

Fig. 1 shows raw and weighted risks for concussions by crash year. Sliding three year average risk values are used to mitigate year-by-year fluctuations typical in NASS-CDS data (Takhounts et al., 2013). Weighted risk 95th percent confidence corridors are also shown. A steady increase of weighted injury risk initiates from 2006 and intensifies from 2010.

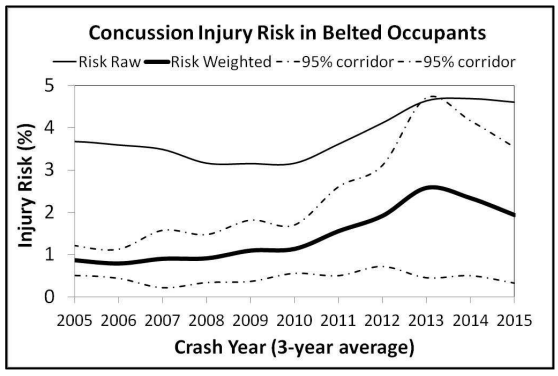

Fig. 1. Concussion injury risk by crash year

Odds Ratio Analysis

Limiting the sample to frontal crashes with available delta-V resulted in a dataset containing a total of

4,175,093 weighted occupants, 50,548 of which sustained a concussion. Table 2 summarizes the results from applying the odds ratio analysis for concussions to this dataset. The p-values show that delta-V (0.0007), sex (0.0389), age (0.0046), and crash year 2010+ (0.0175) significantly contributed to predict the probability of concussion. Car model year groups did not. The point estimates indicate that, after adjusting for the effects of age, crash year and delta-V, a belted female occupant involved in a frontal crash with a vehicle model year 2001 or later is estimated to be 1.4 times more likely to sustain a concussion than a belted male occupant. In addition, for a given vehicle model year group, comparable cases were 1.6 times more likely to be reported a concussion for crashes occurring 2010 or later.

Table 2. Odds ratio estimates for Concussion

Effect	Point estim	95% Conf. limits		p-value
delta-V	1.05	1.02	1.07	0.0007
Sex Female vs Male	1.46	1.02	2.08	0.0389
Age 65+ vs 15-64	0.49	0.31	0.78	0.0046
CYear 10/15 vs 05/09	1.63	1.10	2.42	0.0175
MYear 01/04 vs 11/15	1.08	0.43	2.72	0.8023
MYear 05/10 vs 11/15	1.32	0.46	3.76	0.4530

DISCUSSION

The apparent increase of concussion risk by crash year observed in Fig. 1 can be attributed to the evolving nature of concussion diagnosis, rather than vehicle or occupant related factors. In the current study we used the AIS90/98 version to consistently analyze data from years 2005 to 2015. In 2006, the AIS05 version was released and updated in 2008. This version replaced the entire section on concussive injuries in AIS90/98 with injury descriptors that reflect updated neurotrauma diagnostic terminology (Gennarelli & Wodzin, 2006). The AIS05/08 version was incorporated into NASS-CDS from 2010. Prior to this incorporation, crash investigators and physicians were trained on the new codes, which likely affected their tendency to report concussions. In the odds ratio analysis in the current study (Table 2), we found this change to be significant and quantified it as 1.6 fold increase in the likelihood of a case to be reported a concussion in crash years 2010 and later as compared to years 2005-2009.

The results in Table 2 show that, after controlling for crash severity, crash year 2010, sex and age, belted female occupants were estimated to be 1.4 times more likely to sustain a concussion than belted male occupants. These results align with sports medicine studies that found female athletes to be more likely to sustain a concussion than their male counterpart, although the reasons for this difference are under debate (Rowson et al., 2016). Future work on the effect of sex on concussion risk in car crashes is needed to clarify if the difference we found in injury risk relates to how restraint systems in cars perform with different body sizes between females and males, or if relates to more detailed anatomical or physiological differences between sexes. Test methods that assess concussion risk and that prioritize females over males should be developed and implemented.

CONCLUSION

An annual average estimation of 18,359 ±4,721 belted occupants sustained a moderate concussion in a car crash in the US, which comprises 84.7% of all occupants with $MAIS_{brain}2+$ injury. After controlling for crash severity, crash year and age, belted female occupants were found to be at 1.4 times higher risks than males in similar conditions. As new strategies for the prevention of brain injuries are developed, this study suggests the need to incorporate moderate concussion injuries, with particular attention to female occupants.

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