Accident Analysis and Prevention 117 (2018) 98–105

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Accident analysis to support the development of strategies for the prevention of brain injuries in car crashes

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ARTICLE INFO

Keywords:
NASS-CDS
Traumatic brain injuries
Concussion
Subdural haemorrhage
Sex
Age

ABSTRACT

This study estimated the frequency and risk of *Moderate*-to-*Maximal* traumatic brain injuries sustained by occupants in motor vehicle crashes in the US. National Automotive Sampling System - Crashworthiness Data System crashes that occurred in years 2001–2015 with light vehicles produced 2001 or later were incorporated in the study. Crash type, crash severity, car model year, belt usage and occupant age and sex were controlled for in the analysis. The results showed that *Moderate* concussions account for 79% of all $MAIS_{brain}2+$ injuries. Belted occupants were at lower risks than unbelted occupants for most brain injury categories, including concussions. After controlling for the effects of age and crash severity, belted female occupants involved in frontal crashes were estimated to be 1.5 times more likely to sustain a concussion than male occupants in similar conditions. Belted elderly occupants were found to be at 10.5 and 8 times higher risks for sub-dural haemorrhages than non-elderly belted occupants in frontal and side crashes, respectively. Adopted occupant protection strategies appear to be insufficient to achieve significant decreases in risk of both life-threatening brain injuries and concussions for all car occupants. Further effort to develop occupant and injury specific strategies for the prevention of brain injuries are needed. This study suggests that these strategies may consider prioritization of life-threatening brain vasculature injuries, particularly in elderly occupants, and concussion injuries, particularly in female occupants.

1. Introduction

Traumatic Brain Injuries (TBIs) account for about half of the 1.3 million annual traffic related deaths and the 50 million traffic related injuries worldwide (World Health Organization, 2013). Vehicle occupants comprise the largest group of road traffic deaths by road user type in most high-income countries (World Health Organization, 2013). TBIs are the main cause of death and severe injuries amongst most vehicle crash types and population groups; young adults and the elderly are at higher risks than mature adults (Bruns and Hauser, 2003; Bener et al., 2010) and females are at higher risks than males (Bose et al., 2011). Comprehensive estimations of costs per body region injured in vehicle crashes in the US, including medical costs, emergency services, lost work wages and loss of quality of life, among others, point at TBIs as the second most costly after spinal cord injuries (Zaloshnja et al., 2004). Fatal TBIs in Motor Vehicle Crashes (MVCs) produce a total estimated annual comprehensive societal cost in the US of US$ 62.8 billion (Eigen and Martin, 2005). Despite the ever-improving vehicle occupant protection, TBI prevention strategies must still be assigned top priority.

Occupant injury prevention strategies target at the reduction of the risk of fatal and severe head injuries in high severity crash tests. Unfortunately, these strategies have proven insufficient to achieve significant reductions of these TBIs risks (Eigen and Martin, 2005; Takhounts et al., 2013). Non-life threatening TBIs, which are mainly concussions, have gained less attention in the development of the prevention strategies. Still, recent traffic data analysis has shown that *Moderate*-to-*Serious* concussions account for 60% of all head injuries in MVCs (Viano and Parenteau, 2015) and several studies have shown that the consequences of a concussion often cause fatigue, sleep disorders, sequelae, long term pain, vertigo, mood disorders and depression (Carroll et al., 2014). As many as 30% of concussion victims may suffer persistent cognitive, physical or psychosocial impairment (Carroll et al., 2014). Hence recent studies call for updated head injury prevention strategies that reduce concussion injuries, in addition to fatal and severe head injuries. For the development of these strategies, understanding the real-world crash scenarios and the occupant factors of

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https://doi.org/10.1016/j.aap.2018.04.009
Received 30 June 2017; Received in revised form 7 March 2018; Accepted 7 April 2018
0001-4575/

relevance for specific TBIs is required.

The National Automotive Sampling System - Crashworthiness Data System (NASS-CDS) is a publicly available US nationwide MVC data collection program developed and maintained by the National Highway Traffic Safety Administration (NHTSA) (Zhang and Chen, 2013). NASS-CDS is a probability sample survey of towed-away and police-reported MVCs with a complex sample design that allows for national estimates on crash, vehicle, and occupant characteristics (Pintar et al., 2000; Zhang and Chen, 2013). The main purpose of the NASS-CDS is to support the development of traffic safety countermeasures. A number of studies have used the NASS-CDS to analyze head and brain injuries in MVCs. The risk of *Severe* head injuries has been shown to increase with crash severity (Talmor et al., 2006) and with occupant's age (Ridella et al., 2012). The rate of extra-axial bleeding injuries has been shown to increase with age in 1993–2007 crashes (Mallory, 2010). A former study analyzed 1991 to 1998 crashes to conclude that the use of seatbelts and airbags was associated with reduced frequencies of skull and brain injuries of moderate or worse severity in front row occupants (Pintar et al., 2000). More recently, an analysis of crashes from years 1994 to 2011 has estimated the frequency and risks of concussion injuries (Viano and Parenteau, 2015). The study showed that the risk of concussions is reduced with belt use and that the majority of these injuries occur at crash severity speed changes of less than 40 km/h (Viano and Parenteau, 2015). None of the previous studies that incorporated *Moderate* brain injuries (Pintar et al., 2000; Viano and Parenteau, 2015) provided an analysis of the demographics of concussion victims or a statistical analysis of how different crash, vehicle and occupant factors affect risks for concussion injuries.

The aim of this study is to estimate the frequency and risk of all *Moderate*-to-*Maximal* (AIS2+) brain injuries sustained by occupants in reported MVCs, and to analyze the data considering crash year, crash type, crash severity, car model year, belt usage and the victim's age and sex.

2. Methods

NASS-CDS data from years 2001–2015 were analyzed to estimate the frequency and risk of TBIs sustained by occupants in MVCs. First, a descriptive analysis was conducted to estimate the frequency and risks for different TBI categories by crash type, crash year and belt use. Second, logistic regression was applied to model the effects of car model year, crash severity, occupant's sex and age on the odds of sustaining the most relevant injuries identified.

Injuries in NASS-CDS are documented by NASS investigators according to the Abbreviated Injury Scale (AIS)© for which they are previously trained and certified. The AIS is an anatomically based and consensus derived scoring system. Every seven digit AIS code consists of a six digit injury descriptor and an AIS severity code that classifies an individual injury by body region according to its relative severity on a six point ordinal scale (Gennarelli and Wodzin, 2006). In this scale, AIS1 stands for *Minor* injuries, AIS2 for *Moderate*, AIS3 for *Serious*, AIS4 for *Severe*, AIS5 for *Critical*, and AIS6 for *Maximal* (currently untreatable) injuries. The NASS investigators follow up their on-site investigations by interviewing crash victims to preliminary determine the nature and severity of injuries. Thereafter, the investigators get access to hospital records that are provided by the medical community. These records are contrasted with the preliminary investigator observations and become the primary source of data to judge the nature and severity of injuries.

NASS-CDS utilizes several parallel versions of AIS. In this study, NASS-CDS cases from years 2001 to 2015 with injury codes according to AIS-90/98 were downloaded from the NHTSA resources and merged into a single database of occupants. Crash, vehicle and injury data relevant for this study were assigned to their corresponding occupants. To build the occupants database, SPSS Statistics version 24 (IBM Corporation, New York, USA) software was utilized. To analyze the database, SAS Enterprise Guide version 7.1 (SAS Institute Inc., North Carolina, USA) software was utilized.

Detailed descriptions of the inclusion criteria, the injury classification and the statistical methods applied follow.

2.1. Inclusion criteria

The following inclusion criteria were applied:

- Crash year 2001–2015
- Vehicle model year 2001–2015
- Light vehicles (passenger cars, pick-ups and mini-vans)
- Non-ejected occupants
- Occupant age 15 or higher
- Occupants with known injury status or fatality

Light vehicles was defined with the NASS variable VEHICLE MODEL (Light vehicles when variable was between 0–490). Occupant ejection was defined with the NASS variable EJECTION (Non-Ejected when variable was 0). Occupants with reported injury status are those assigned a MAIS between 0 and 6 or Fatality. Crash types were defined in five categories with the NASS variables GAD1 (highest area of vehicle damage) and ROLLOVER (Frontal if GAD1 = F and ROLLOVER < = 0; Side if GAD1 = L or R and ROLLOVER < = 0; Rear if GAD1 = B and ROLLOVER < = 0; Rollover if ROLLOVER > 0; and Other for occupants in crash types not included in any of the previous categories).

Belted occupants were defined as those in which the investigator found evidence of belt use and that the used belt was of 3-point belt type (shoulder belt and a lap belt in combination) (Belted when variable MANUSE = 4). All other occupants, including those not using any belt, those with an inoperative belt, those only using a shoulder belt, those only using a lap belt, or those using a belt which type could not be confirmed, were grouped in a category and denoted as Unbelted. Occupant's sex was defined using the variable SEX (Male if SEX = 1 and Female if SEX = 2–6). Change in velocity (DVTOTAL) of the occupant's vehicle was used to estimate the crash severity.

2.2. Injury categories

All *AIS2+* brain injuries were categorized based on seven-digit AIS codes. A broad description of the brain injury categories that comprised the main focus of this study is provided below. A table with the injury category assigned to each seven-digit AIS code is provided in the appendix (Table A8)

- Concussions: AIS2-3 injuries documented as Cerebral Concussion, as Length of Unconsciousness, as Level of Consciousness, or as Lethargic, Stuporous, or Obtunded post resuscitation.
- Contusions: AIS3-5 injuries documented as contusions in the cerebrum or the cerebellum.
- Diffuse Axonal Injuries: AIS4-5 injuries documented as white matter shearing in the cerebrum or the cerebellum (but not in the brainstem), as Length of Unconsciousness, or as Level of Consciousness.
- Epidural Haemorrhages: AIS4-5 injuries reported as epidural or extradural haematoma/haemorrhage in the cerebrum or the cerebellum.
- Subdural Haemorrhages: AIS4-5 injuries reported as subdural haematoma/haemorrhage in the cerebrum or the cerebellum.
- Sub-Arachnoid Haemorrhages: AIS3 injuries reported as subarachnoid or subpial haemorrhage in the cerebrum or the cerebellum.
- Intracranial Haemorrhages: AIS4-5 injuries reported as intracerebral, intracerebellar or intraventricular haematoma/haemorrhage.
- Brainstem Injuries: AIS5-6 injuries reported as injuries to the brainstem, including compression, contusion, DAI, infarction,