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Chapter 4

RISK AND PROTECTIVE FACTORS ASSOCIATED WITH MOTORCYCLE INJURY SEVERITY IN THE UNITED STATES

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ABSTRACT

According to the Centers for Disease Control and Prevention, road crashes are one of the major causes of morbidity and mortality in the United States. The Healthy People 2020 has indicated that accidents are a major public health issue. Most motor-vehicle related events resulting in injury, disability, or death are predictable and preventable. Injuries are the leading cause of death for Americans aged 1 to 44 years and a leading cause of disability for all ages, regardless of sex, race/ethnicity, or socioeconomic status. Although motorcycles represent approximately 3% of all registered vehicles in the United States, motorcycling accounts for more than 13% of highway traffic fatalities. While fatalities normally represent a small percent of other motor vehicle occupants, fatalities can be as high as 40%

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for the motorcyclists when involved in accidents (or traffic crashes as typically referred to by transportation safety professionals). Motorcyclists are more vulnerable in crashes due to their lack of protection like enclosed vehicles do to motor vehicle occupants, so they are more likely to be severely injured or killed. Therefore, there is a motivation among stakeholders to decrease the injury severity of motorcyclists. A clear understanding of the factors influencing injury severity levels due to motorcycle crashes and the related evidence prevention strategies is of paramount importance. When examining a topic of motorcycle injury severity, it is important to keep into consideration of different issues that include the definition and concept of injury severity, trends in motorcycle crashes, motorcycle-related policies and laws, knowledge of risk and protective factors. The main purpose of this chapter is to discuss the risk factors and protective factors related to injury severity of motorcycle crashes in the US. Important aspects related to motorcycle crashes' injury severity such as methodological challenges related to conceptual clarity and measurement are discussed. In addition, implications for education, research, practice and policy including laws and enforcement are highlighted so that the overall motorcycle safety situation could be improved.

Keywords: motorcycle, motorcycle rider, motorcyclist, crash severity

INTRODUCTION

Motorcycle crashes tend to lead into more severe injuries and fatalities than crashes that involve other types of motor vehicles. Although motorcycles represent approximately 3% of all registered vehicles in the United States, motorcycling accounts for more than 13% of highway traffic fatalities. While fatalities normally represent a small percent of other motor vehicle occupants, fatalities can be as high as 40% for the motorcyclists when involved in traffic crashes. Motorcyclists are more vulnerable in crashes due to their lack of protection like enclosed vehicles do to motor vehicle occupants, so they are more likely to be severely injured or killed. Therefore, there is a motivation among stakeholders to decrease the injury severity of motorcyclists. A clear understanding of the factors influencing injury severity levels due to motorcycle crashes and the related evidence prevention strategies is of paramount importance. This chapter discusses the risk factors and protective factors related to injury severity of motorcycle crashes in the United States. Important aspects related to motorcycle crashes' injury severity such as methodological challenges related to conceptual clarity and measurement are discussed.

According to Pickrell and Starnes (2008), the following definitions of the terminologies pertaining to motorcycle users, based on definitions used by the National Highway Traffic Safety Administration (NHTSA) need to be clarified:

- *A motorcycle rider* is the person operating or in control of the motorcycle.
- *A motorcycle passenger* is the person seated behind the rider and not in control of the motorcycle.
- *A motorcyclist* is a collective term used for any combined reference to the rider and passenger of the motorcycle.

DEFINITION AND CONCEPT OF INJURY SEVERITY

In addition to reducing the number of crashes involving motorcycles, reducing injury severities associated with those crashes is one of the most important aspects of promoting motor cycle safety. Progress in promoting safety could be evaluated by considering reductions in injury severity levels experienced by those involved in motorcycle crashes. It is therefore important to properly define injury severities so that the evaluations could be done in a meaningful manner.

Typically, injury severity is recorded discretely using a five point scale, which is often referred to as the KABCO scale. The categories include:

- Fatal injury or killed (K),
- Incapacitating injury (A),
- Non-incapacitating injury (B),
- Possible injury (C), and
- Property damage only (O).

In safety studies related to transportation engineering literature this five point scale is commonly used. However there are other types of injury severity data that include detailed information on trauma location and extent of injury which may be a combination of discrete and continuous variables. Abbreviated Injury Scale (AIS) which was originally developed by the American Association for Automotive Medicine, the Organ Injury Scales (OIS) proposed by the

American Association for the Surgery of Trauma and the Injury Severity Score (ISS) used by hospitals are some of the examples of methods of accounting for injury severity.

Many electronic databases used by various states or very popular databases at national level such as the Fatality Analysis Reporting System (FARS) or General Estimates System (GES), use traditional discrete data forms, mainly based on police-reported data. These data provide crash detail information. The crash related records include crash severity, vehicle in error, date of crash, time of crash, crash location, type of road, alcohol-related, drug related, speed related, etc.; records for each unit involved in the crash include unit type (e.g., motor vehicle, motorcycle, bicycle, pedestrian, etc.), point of impact, number of occupants, etc.; and records for each person involved in the crash such as type of person (e.g., driver, occupant, pedestrian), injury severity, age, gender, safety equipment used, etc.).

MOTORCYCLE CRASH TYPES AND TRENDS

There are more than 8 million motorcycles registered in the United States over the last several years and the number and rate of motorcycle crashes are fluctuating even though slight improvements could be seen in the overall trend. Still, in 2013, there were 4,668 motorcyclists killed in motor vehicle traffic crashes and there were an estimated 88,000 motorcyclists injured during 2013 (NCSA, 2015). Table 1 shows the variation of Motorcycle crash numbers and rates in the recent years.

Data shows that in 2013 the most harmful event for 2,448 (51%) of the 4,774 motorcycles involved in fatal crashes was a collision with a motor vehicle in transport. (NCSA, 2015) In two-vehicle crashes, 74% of the motorcycles involved in motor vehicle traffic crashes were frontal collisions. Only 6% were struck in the rear.

Motorcycles are more frequently involved in fatal collisions with fixed objects than other vehicles. In 2013, 22% of the motorcycles involved in fatal crashes collided with fixed objects, compared to 18% for passenger cars, 14% for light trucks, and 4% for large trucks.

Table 1. Motorcyclists Killed and Injured, and Fatality and Injury Rates, 2005–2013 (Source: NCSA, 2015)

Year	Killed	Registered Vehicles	Fatality Rate*	Vehicle Miles Traveled (millions)	Fatality Rate**
2005	4,576	6,227,146	73.48	10,454	43.77
2006	4,837	6,678,958	72.42	12,049	40.14
2007	5,174	7,138,476	72.48	21,396	24.18
2008	5,312	7,752,926	68.52	20,811	25.52
2009	4,469	7,929,724	56.36	20,822	21.46
2010	4,518	8,009,503	56.41	18,513	24.40
2011	4,630	8,437,502	54.87	18,542	24.97
2012	4,986	8,454,939	58.97	21,385	23.32
2013	4,668	8,404,687	55.54	20,366	22.92
Year	**Injured**	**Registered Vehicles**	**Injury Rate***	**Vehicle Miles Traveled (millions)**	**Injury Rate****
2005	87,000	6,227,146	1,402	10,454	835
2006	88,000	6,678,958	1,312	12,049	727
2007	103,000	7,138,476	1,443	21,396	481
2008	96,000	7,752,926	1,238	20,811	461
2009	90,000	7,929,724	1,130	20,822	430
2010	82,000	8,009,503	1,024	18,513	443
2011	81,000	8,437,502	965	18,542	439
2012	93,000	8,454,939	1,099	21,385	434
2013	88,000	8,404,687	1,052	20,366	434

* Rate per 100,000 registered vehicles **Rate per 100 million vehicle miles traveled.

In 2013, there were 2,182 two-vehicle fatal crashes involving a motorcycle and another type of vehicle. In 42% (922) of these crashes, the other vehicles were turning left while the motorcycles were going straight, passing, or overtaking other vehicles. Both vehicles were going straight in 456 crashes (21%) (NCSA, 2015).

MOTORCYCLE HELMET LAWS AND THEIR EFFECTIVENESS

One area in need of immediate attention in terms of motorcycle safety is the use of helmets. Motorcycle helmet laws in the United States vary significantly among the states. As of 2016, there are 19 states and District of Colombia with universal (mandatory) helmet laws, 27 states with partial helmet laws and three states with no helmet laws at all, as shown in Figure 1 (IIHS, 2016).

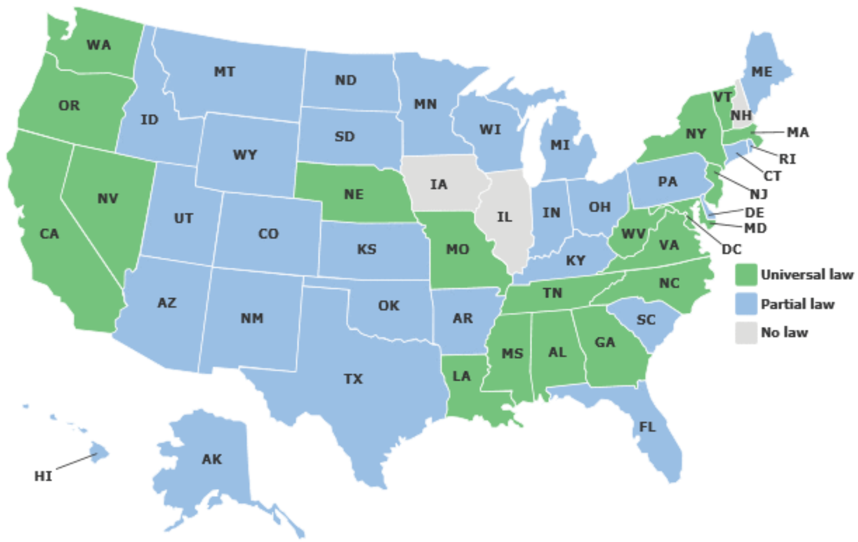

Figure 1. Motorcycle Laws in the United States (Source: IIHS, 2016).

Motorcycle safety-related studies in the past have addressed helmet use, helmet-use laws in different states, effects of helmet use on motorcycle crash outcomes, factors related to motorcycle fatalities, and injuries, using a variety of databases, some of which are summarized here.

Branas and Knudson (2001) investigated motorcycle rider fatality rates between states with mandatory motorcycle helmet laws and those without the laws. Competing influences of variables such as population density, weather conditions, alcohol consumption, maximum speed limit, urban vs. rural roads, motorcycle engine size, and age of the motorcycle riders were analyzed on the fatality rates of motorcyclists. Bivariate analyses demonstrated that states with motorcycle helmet laws have significantly higher fatality rates per 10,000 registered motorcycles compared to states without helmet laws. After simultaneously adjusting for other factors using multivariate regression models, fatality rates in states with mandatory motorcycle helmet laws were shown to be lower than those of states without helmet laws.

Peek-Asa et al. (1999) examined the prevalence of non-standard helmet use among motorcycle riders following introduction of a mandatory helmet law and the prevalence of head injuries among a sample of non-standard helmet users involved in motorcycle crashes. Among the injured riders examined in 1992, exactly one-third, whose crash reports indicated non-standard helmet use, had 15.5% fatalities of non-helmeted riders compared to 13.6% of helmeted riders.

Among the riders wearing non-standard helmets, 75% sustained head injuries of any severity which was significantly greater than riders not wearing a helmet, of which 51.9% had any injuries. Average head injury severity for riders identified as wearing non-standard helmets was 82.65, which was significantly higher than 1.56 for riders not wearing helmets and 0.96 for riders wearing standard helmets.

Results of surveys conducted by Williams et al. (1979) indicate that when helmet use is legally required of all motorcyclists, nearly 100% wear helmets. Helmet-use rates were substantially lower when use is not required of any motorcyclists, or when helmet-use laws covering all motorcyclists are amended so that only those under age of 18 years are covered. Amending helmet-use laws so that only young motorcyclists are required to wear helmets appears to have little impact on user rates. Based on the study completed in 1979, overall helmet use rate in New Orleans, Louisiana; Phoenix, Arizona; and Texas, where such laws existed, was 48%, similar to the use rate in Los Angeles, California (46%), where such helmet use was not required of any motorcyclists at the time.

An analysis by Mayrose (2008) show that from 1995–2003, mandatory helmet law states had a 22.3% rise in total fatalities, with a 3% increase in helmet use among fatally injured riders in these states. Partial-law states had a 32.9% increase in total motorcycle fatalities with a 1.2% increase in helmet use, while the three other states with no helmet law at all had a 21.78% increase in total motorcycle fatalities with only a 2% increase in helmet use. The increase in fatalities can be attributed to an increased number of motorcyclists on the road over this time period. It was found that motorcyclists are more likely to wear helmets in states with mandatory helmet laws than their counterparts in states with only partial helmet laws or no laws at all.

Rutledge et al. (1993) studied the association of helmet use with the outcome of motorcycle crashes, controlling for severity of the crash as measured by a modified injury severity score that excluded head injury. Risk of head injuries was found to be nearly twice as high in unhelmeted riders. This study illustrated the increased likelihood of head injury when a helmet is not worn, but also showed helmet use is not a significant factor determining morbidity rates, hospital charges, and length of stay. There were, however, some unanticipated findings in the study. There were no significant differences in overall mortality, mean trauma scores, mean hospital stays, mean hospital charges, or percentage of cases discharged to rehabilitation facilities between helmeted and unhelmeted patients.

Wilson (1990) found that although effectiveness of helmet use depends on many factors (e.g. driver age, speed, crash direction), but in assessing effectiveness, motorcycle helmets are estimated to be 29% effective in preventing motorcycle rider fatalities. Further, although motorcycle helmets saved an estimated 670 lives in 1987, they could have prevented an additional 693 fatalities if 100% of motorcycle riders wore helmets. In examining the data, it was evident there is a consistency in helmet usage patterns between the rider and the passenger, such that when the rider is helmeted so tends to be the passenger. This is also true when the rider is unhelmeted.

In a recent study by Dissanayake and Shaheed (2012) state-level motorcycle rider fatality rates were investigated while considering various factors, including helmet laws, using the generalized least-squares (GLS) regression modeling of statewide rider fatality rates utilizing data from all 50 states and the District of Columbia.. The intention was to develop statistical models to predict state-level motorcycle safety parameters while taking various factors into account. From the GLS modeling carried out in that study, a statistically significant relationship was found between helmet laws and motorcyclist fatalities per 10,000 registered motorcycles and per 100,000 populations in a state. Specifically, that study showed that states with mandatory helmet laws had 5.6% fewer motorcycle fatalities per 10,000 registrations and 7.85% fewer motorcycle fatalities per 100,000 population.

RISK AND PROTECTIVE FACTORS RELATED TO INJURY SEVERITY OF MOTORCYCLE CRASHES

Numerous studies have been conducted over the years and several factors have been consistently identified as contributing to motorcycle injury severity in the United States. Therefore, this section discusses some of the risk and protective factors that have been widely acknowledged. Based on the published literature and annual crash records in the United States, motorcycle riding continues being a risky endeavor, for example in 2013 motorcyclists were estimated to be 26 times more likely to to be killed and 5 times more likely to be injured when compared to passenger car occupants per mile traveled (NCSA, 2015; IIHS, 2016).

Alcohol use is one of the most highly cited risk factors for drivers of all types of vehicles but more worse for motorcycle riders. In the United States alcohol-impaired is defined as a motor vehicle driver or motorcycle rider with blood alcohol concentration (BACs) of 0.08 grams per deciliter (g/dL) or higher (NCSA, 2015). The percentage of motorcycle riders involved in fatal crashes with BACs of at least 0.08 grams per deciliter (legally alcohol-impaired) is typically higher than any other type of motor vehicle drivers (Peek-Asa et al. 1999; NCSA, 2008; Soderstorm et al. 1993, NCSA, 2015). For example in 2013, 27% of motorcycle operators who were involved in fatal crashes had a BAC above 0.08, 23% for passenger car drivers, 21% for light-truck drivers and only 2% for large truck drivers (NCSA, 2015).

Helmet use is another important factor in relation to injury severity of motorcyclists. An extensive study by Branas and Knudson (2001) found that motorcycle rider death rates in states with universal (mandatory) helmet use laws were lower on average than death rates in states with non-universal helmet use laws. Pickrell and Starnes (2008) comment that in the same crash event, an un-helmeted motorcyclist is about 40% more likely to suffer a fatal head injury and 15% more likely to suffer a nonfatal injury when compared with a helmeted motorcyclist. The National Center for Statistics and Analysis estimates that helmets are effective in preventing the likelihood of fatality by 37% for motorcycle riders and 41% for motorcycle passengers (NCSA, 2015). The Insurance Institute for Highway Safety (IIHS) argues that a helmet is the most important piece of motorcycle safety equipment (IIHS, 2016). Helmets decrease the severity of head injuries and the likelihood of death and NHTSA estimates that motorcycle riders who don't wear helmet are 3 times more likely than those who wear helmet to sustain traumatic brain injuries in the event of a crash (IIHS, 2016). Gielen and Samuels (2012) report that helmets are estimated to reduce the risk of head injury by 69%, death by 42%, and therefore associated with reductions in overall injury severity and likelihood of needing of hospitalization. Additional studies whose findings agree that non-helmet use increases odds of higher injury severity levels include Lardelli-Claret et al. (2005), Chang and Yeh (2006), Lin and Kraus (2009), Eustace et al., (2010), Shaheed and Dissanayake, (2011), Fagnant and Kockelman, (2015), etc.

According to the IIHS some kinds of motorcycles are riskier than others (IIHS, 2016). *Supersport bikes are* another factor that has been associated with high motorcycle fatalities. These motorcycles are built on a racing platform and typically have more horsepower per pound (powerful) and very fast but they are cheap and affordable and thus attractive and popular with young riders who are looking for fun (speeding) and daring and hence prone to higher risk driving behaviors (IIHS, 2007; III, 2016). Driver death for supersport motorcycles are estimated to be four times higher than those of cruiser/standard motorcycles (Teoh and Campbell, 2010; III, 2016; IIHS, 2016). In addition, among fatally injured motorcycle riders, the riders of supersport motorcycles happen to be the youngest, with an average age of 27 while touring motorcycle riders tend to be the oldest at 51 years old (IIHS, 2016; III, 2016).

The other risk factor that has been linked with severe injury and fatalities for motorcycle riders involves *unlicensed or improperly licensed riders and riders with previous driving convictions*. According to NHTSA (NCSA, 2015) a valid motorcycle license comprises a rider having a valid driver license (non-CDL license status) with a motorcycle endorsement or motorcycle-only license. Before riding on public highways in all fifty states and the District of Columbia motorcycle riders are required to obtain a motorcycle operator license or endorsement. However, many motorcycle riders are not properly licensed (III, 2016). In 2013, while 25% of motorcycle riders involved in fatal crashes did not have a valid motorcycle license but only 13% of drivers of passenger vehicles involved in fatal crashes did not have valid licenses (NCSA, 2015). Furthermore, motorcycle riders tend to have the highest percentage of drivers with previous driving convictions such as driving impaired, speeding and revocation when compared with drivers of other vehicle types (NCSA, 2015). For example, in 2013 riders involved in fatal crashes were 1.2 more likely to have received previous license suspensions or revocations when compared with passenger vehicle drivers (NCSA, 2015).

Speeding is another major perennial risk factor normally related to severe traffic injury severity levels. Once again, motorcycle riders are typically more likely to be involved in speeding-related fatal crashes than other drivers. For instance, NHTSA reports that in 2013 the percent of motorcycle riders involved in fatal crashes that were speeding-related was 34% compared to 21% for drivers of passenger cars, 18% for light truck drivers and 8% for large truck drivers (NCSA, 2015). Accordingly, a number of previous research studies agree on the association of motorcycle speeding with increased injury and crash severity levels (e.g. Shankar and Mannering 1996; Clarke et al. 2004; Lardelli-Claret et al. 2005; Shankar and Varghese 2006, Chimba and Sando 2010, Eustace et al., 2010), etc.

Some research studies have shown that *population density* generally affects highway mortality rates but specifically correlates more with motorcycle rider fatalities. Usually, when the population density increases, it leads into frequent stops on the highways and streets as compared to lower population density areas where drivers can drive with fewer interruptions (Keeler 1994; Calkins and Zlatoper 2001; Cohen and Einav 2003; Farmer and Williams 2005). A study by Branas and Knudson (2001) reports a significant positive relationship between state-level population densities and motorcycle rider death rates.

Weather condition has also been found to correlate with motorcycle fatal crashes. Weather as measured in terms of annual daily mean temperature and annual precipitation, is correlated with motorcycle riders' fatality rates. While the association of temperature to motorcycle fatality rates is highly positive, precipitation's association with motorcycle riders' fatality rates is negatively related (Branas and Knudson, 2001; Houston and Richardson, 2008). Based on their findings, Branas and Knudson (2001) argue that these two factors likely affect the length of the riding season (and hence exposure to crashes) in each state in the United States. For example, states with higher annual daily temperatures and lower annual precipitation (e.g., southwestern states) have relatively longer riding seasons and therefore greater chances for motorcycle fatalities to occur whereas states with lower annual daily temperatures and higher annual precipitation (e.g., northeastern states) have relatively shorter riding seasons and fewer motorcycle fatalities (Branas and Knudson, 2001).

In addition, a study by Morris (2006) reports that the largest percentages of motorcyclist fatalities and injuries occur during warm months associated with the smallest percentages of normalized heating degree days and the largest percentages of precipitation inches. On the other hand, the smallest percentages of fatalities and injuries occur during cold months associated with the largest percentages of normalized heating degree days and the smallest percentages of precipitation inches.

Higher *levels of education* have been considered as a factor in promoting personal healthy behaviors (Grossman, 1975). Generally, healthy behaviors have been associated with compliance with existing laws such as wearing motorcycle helmets, wearing seat belts, obeying traffic rules, etc. (Dissanayake and Shaheed, 2012) Several studies show that education is negatively associated with motor vehicle fatality rates (e.g., Calkins and Zlatoper, 2001; Braver, 2003; Muelleman et al., 1992). According to Paulozzi (2005), income is usually postulated to be negatively correlated with traffic fatalities because wealthy people are generally regarded as more aware and place a higher value on safety, and possess the means to enhance it. Nevertheless, in the case of motorcycle riders, income per capita has been found to be positively correlated with higher motorcycle fatalities (Houston and Richardson, 2008). Houston and Richardson (2008) argue that since motorcycles are expensive and luxurious, in the United States they are more often used as recreational vehicles rather than a primary mode of transportation and hence affluent people are the most likely to buy and ride motorcycles as extra luxurious recreational vehicles.

Motorcycle training is an important factor in reducing motorcycle-related crashes. Riding a motorcycle requires additional mental and physical skills than those needed in driving motor vehicles (IIHS, 2016) and motorcycle riders are more vulnerable road users when compared with drivers of other vehicle types due to their lack of protection when involved in a crash (Rifaat et al., 2012). A study by Fagnant and Kockelman (2015) suggests that motorcycle riders who have received motorcycle training are less likely to have been involved in a motorcycle crash at some point in their riding history. That is why motorcycle riders are always recommended to attend periodic training in order to increase their awareness of traffic safety, improve on their defensive motorcycle maneuvers and increase their odds of avoiding traffic crashes and severe injuries.

According to Fagnant and Kockelman (2015) top riders recommend to other motorcycle riders that protective factors of injury severity include wearing a helmet, avoiding riding under the influence (of alcohol or drugs), and to obtain motorcycle training. Additionally, riding a motorcycle equipped with antilock brakes and avoiding driving a motorcycle at excessive speed constitute additional protective factors of motorcycle injury severity. Furthermore, the results from the study by Fagnant and Kockeleman (2015) suggest that inexperienced riders on long-distance trips, students and riders with criminal convictions are at greater risk of being involved in motorcycle crashes than other riders.

According to IIHS (2016) an *antilock braking system (ABS)* reduces the risk of a motorcycle crash. ABS prevents wheels from locking up, which is an absolutely essential feature for a motorcycle. While for a motor vehicle a wheel lockup might simply result into a skid, for a motorcycle, it often results into a serious fall and hence severe injuries and the Insurance Institute for Highway Safety estimates that the rate of fatal crashes is 31% lower for motorcycles equipped with optional antilock brakes when compared with similar models without them (IIHS, 2016).

Motorcycle conspicuity is another important factor in motorcycle safety. Wells et al. (2004) show that low motorcycle rider conspicuity may increase the risk of motorcycle crash related injury. A study by Shaeed et al. (2012) shows that leading motorcycles with riders having bright yellow clothing and helmet were detected at the greatest distance, which may enhance the motorcyclists' safety. The US crash data for 2013 show that the most harmful event for 51% of motorcycles involved in fatal crashes was a collision with a motor vehicle in transport (NCSA, 2015); also in 42% of two-vehicle fatal crashes involving a motorcycle and another type of vehicle, the other vehicles were turning left while the motorcycles were going straight, passing, or overtaking other vehicles. These types of crashes can be partly contributed due to the inability of a motor vehicle driver to see the motorcycle or low motorcycle conspicuity (Shaheed et al., 2013). Protective factors for motorcyclists include the increased use of reflective or fluorescence clothing, white or light colored helmets, and daytime headlights (Wells et al., 2004; Shaheed et al., 2012).

Other risk factors as related to motorcycle injury severity include road *bends (curves)* and *grades*, which had been found to have substantial affects in the motorcyclist's fatality and incapacitating injury rates. Studies have shown that curved and graded segments have higher motorcyclist fatality rate when compared with level and straight road segments (e.g., Elliott et al., 2003; Chimba and Sando, 2010; Eustace et al., 2010). In addition, *nighttime* crashes and/or crashes in *dark lighting* conditions tend to result into a higher than average fatality rates (Eustace et al., 2010; Shaheed and Dissanayake, 2011; Dissanayake and Shaheed, 2012; NCSA, 2015).

METHODOLOGICAL CHALLENGES RELATED TO CONCEPTUAL CLARITY AND MEASUREMENT

Over the years, researchers have attempted to relate various factors (independent variables) to motorcycle crash or injury severity (dependent variable). In order to understand risk factors that increase the likelihood of injury severity in motorcycle crashes, various modeling techniques have been used by researchers. Statistical methods that have been commonly used by researchers in analyzing factors affecting motorcycle crash-related injury severity include: log-linear models (e.g., Haque et al., 2012); ordered logit (ologit) and ordered probit (oprobit) models (e.g., O'Donnell and Connor, 1996; Quddus et al.,. 2002; Rifaat et al., 2012); multinomial logit (MNL) models (e.g., Shankar and Mannering, 1996; Savolainen and Mannering, 2007; Jones et al., 2013); multinomial probit (MNP) models (e.g., Chimba and Sando, 2010; Eustace et al., 2010); nested logit (nlogit) models (e.g. Savolainen and Mannering, 2007), mixed logit (mlogit) models (e.g., Pai et al., 2009; Shaheed et al., 2013), etc.

Shanker and Mannering (1996) used a multinomial logit (MNL) model in analyzing single-vehicle motorcycle crash severity using data from the state of Washington. Savolainen and Mannering (2007) used nested logit (nlogit) and multinomial (MNL) models in analyzing injury severities of single-and multi-vehicle crashes employing crash data from Indiana. Chimba and Sando (2010) used multinomial logit (MNL) and multinomial probit (MNP) models in assessing motorcycle injury severities using data from Florida. Eustace et al.

(2010) used a multinomial probit model (MNP) when analyzing risk factors associated with motorcycle-related fatalities in Ohio. Shaheed and Dissanayake (2011) utilized a logistic regression model in studying risk factors associated with motorcycle crash severity in Kansas. Shaheed et al. (2013) used a mixed logit (mlogit) model to examine two-vehicle crash severities involving a motorcycle utilizing data from Iowa. Jones et al. (2013) investigated factors influencing the severity of crashes caused by motorcyclists in Alabama by using a multinomial logit (MNL) model. Based on the foregoing discussion, it is obvious that a variety of methods have been selected and utilized by researchers.

Lin and Kraus (2008) point out that some inconsistent results have been observed on the relationship of universal helmet laws and motorcycle deaths and can be partly attributed to the differences in the analytical models utilized. Compared with other models, Lin and Kraus (2008) also suggest that when more than two levels of motorcycle injuries are the outcome variable, proportional odds models (such as ordered logit and ordered probit models) in which the correlation of multiple crashes involving the same individual is adjusted for by the generalized estimating equation (GEE) are more appropriate.

By far, the ordered logit (ologit) and multinomial (MNL) models have been the most popular choices in the analysis of crash and injury severity data (Savolainen et al., 2011). Each analysis method used has its strengths and weaknesses, which need to be identified and known with regard to the type of data to be analyzed and the assumptions underlying a particular method. It is widely believed that crash severity and injury severity as dependent variables are typical ordinal variables (e.g., Lin and Kraus, 2008; Wang and Abdel-Aty, 2008; Eustace et al., 2010; Savolainen et al., 2011). An ordinal variable is the one where the order matters but not the difference between the values. For example, injury levels defined as non-incapacitating injury, incapacitating injury, and fatal injury, these present three levels with increasing order of injury severity but you can’t determine the difference between them. However, according to Savolainen and Mannering (2007) one potential problem with ordered probability models in determining injury severity levels underlies with the police officers’ underreporting of non-injury crashes. This may result in biased and inconsistent model coefficient estimates. Another potential problem is the restrictive nature of parallel lines (same slope) assumption of ordered models, which restricts the slope to be the same value for all outcome levels (Long 1997; Park 2009, Williams, 2006, Mergia et al., 2013).

Most of the reviewed publications do not explain how this condition was met or if the condition was tested. Due to this problem with ordered logit models, some researchers recommend the use of unordered multinomial models in evaluating the effects of variables in each injury severity because they do not impose restrictive conditions typical of ordered logit models (Savolainen and Mannering 2007). For these kinds of models, besides losing the ability to account for the ordinal nature of injury data (i.e., ordering of injury-severity outcomes), however, multinomial logit models are principally susceptible to correlation of unobserved effects from one injury-severity level to the next, which lead into violation of the model's independence of irrelevant alternatives (IIA) property (Chimba and Sando, 2010; Eustace et al., 2010; Savolainen et al., 2011).

Hujer (2010) suggests that two ways of avoiding the IIA errors include the use of nested logit models or the use of multinomial probit models. In addition, the mixed logit models have been suggested for the same reasons (Pai et al. 2009; Malyshkina and Mannering 2010). Another method, which is recommended, capable of overcoming problems of both ordered logit and multinomial logit models is the use of the generalized ordered logit (gologit) models, which are capable of relaxing the restrictive nature of conventional ordered logit models and at the same time keeping the ordered nature of injury severity variables (Williams, 2006; Wang and Abdel-Aty, 2008; Wang et al., 2009; Mergia et al., 2013).

IMPLICATIONS FOR EDUCATION, RESEARCH, PRACTICE AND POLICY

Safer motorcycle riding, which translates into reducing the number of motorcyclists' crashes and their injury severity should involve key stakeholders working together to integrate and leverage the 3'E's of traffic safety, i.e., Engineering, Enforcement and Education into one context to maximize key resources. These should be activities that will reduce motorcyclist injury severity risk factors or in other words, increasing or enhancing the protective factors.

Implications for Education

Some risk factors contributing to motorcycle severe injuries can be counter-measured through educational and enforcement strategies. This aspect should implement various issues including the following:

- Enhance and expand current motorcycle training and outreach programs to reach all motorcycle operators, motor vehicle drivers and transportation professionals in order to improve motorcycle safety throughout the nation. Emphasis should highly target novice riders and refresher training programs for experienced riders especially those who can be identified as potential risk riders.
- Since low physical conspicuity is believed to be one of the contributing factors in a substantial percentage of motorcycle injury-causing crashes, there is a need to institute laws requiring daytime use of headlights and encouraging measures that enhance better visibility of motorcycle riders on the road such as wearing retroreflective clothing and helmets.
- Alcohol/drugs use and excessive speeding are two persistently major concerns of traffic safety. Educational campaigns and enforcement campaigns with high visibility should be expanded and continued throughout the country with an increased stress to both motorcycle and motor vehicle drivers on the awareness of the effects of speeding, alcohol/drugs impairment, careful driving on road bends and vertical grades.
- It is recommended to use a combination of educational efforts such as media, advertisement boards, licensing bureaus, and motorcycle riders' organizations and clubs.

Implications for Research

While efforts to implement countermeasure strategies designed to reduce motorcycle crash-related injuries and fatalities in the auspices of education, enforcement, and engineering are on the continuous basis, correspondingly research efforts on behavioral safety, motorcycle safety technology, etc., should continue. Research efforts should be designed to build on what we know and learn today and expand our knowledge of motorcycle injury severity and improved safety performance for future implementation into existing programs.

Implications for Policy

From our review of the literature several implications for policy concerning reducing motorcycle injury severity in the United States should include some of the following:

- Encourage all states to adopt stronger helmet use laws by enacting universal helmet use laws that protect all motorcyclists. Maintain and enforce all-rider helmet use laws. In addition, local enforcement officers should help their states and local jurisdictions in making sure that they are effectively enforcing all rider helmet use laws and other laws that pertain to traffic safety.
- Make sure all states' motor vehicle licensing bureaus or agencies are promoting and requiring motorcycle operator licensure or endorsement for anybody who purchases, registers and/or rides a motorcycle.
- Promote the installation of antilock braking systems (ABS) to all motorcycles sold in the United States as records show that motorcycles with ABS reduce the likelihood of motorcycle-related fatalities per registered motorcycle compared to identical models not equipped with ABS.
- States and other responsible agencies should ensure motorcycle helmets sold in all states meet federal standards.
- Encourage all states to pass a law that requires all motorcycles to have headlights on all of the time in order to improve motorcycle conspicuousness and also encourage wearing protective clothing and other polices that will enhance and improve motorcyclists' visibility on the road.

Implications for Practice

Implications for practice may target engineering solutions as a component of 3 E's of traffic safety with regard to reducing injury severity related to motorcycle. This aspect should aim at improving and retrofitting existing transportation infrastructure and incorporating in safety features when designing new transportation infrastructure. Engineering measures may include:

- Responsible jurisdictions should identify and develop solutions for known locations prone to motorcycle crashes.

- Conduct road safety audits in order to qualitatively estimate and report on potential road safety issues and hence identify opportunities for safety improvements for all road users
- Make roads resistant to skidding and provide advance-warning signs especially designed to target and alert motorcycle riders.

CONCLUSION

This chapter discussed important issues pertaining to motorcycle crash related injury severity in the United States. Issues related to trends and type of motorcycle crashes, helmet use laws and their effectiveness in reducing severe injuries and deaths; the risk and protective factors related to motorcycle injury severity in the United States were discussed. In addition, methodological challenges related to evaluating factors affecting motorcycle injury severity were highlighted, and finally implications for education, research, practice and policy including laws and enforcement were briefly introduced so that the overall motorcycle safety situation could be improved.

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