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A heterogeneity based case-control analysis of motorcyclist's injury crashes: Evidence from motorcycle crash causation study

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ABSTRACT

The main objective of this study is to quantify how different "policy-sensitive" factors are associated with risk of motorcycle injury crashes, while controlling for rider-specific, psycho-physiological, and other observed/unobserved factors. The analysis utilizes data from a matched case-control design collected through the FHWA's Motorcycle Crash Causation Study. In particular, 351 cases (motorcyclists involved in injury crashes) are analyzed vis-à-vis similarly-at-risk 702 matched controls (motorcyclists not involved in crashes). Unlike traditional conditional estimation of relative risks, the paper presents heterogeneity based statistical analysis that accounts for the possibility of both within and between matched case-control variations. Overall, the correlations between key risk factors and injury crash propensity exhibit significant observed and unobserved heterogeneity. The results of best-fit random parameters logit model with heterogeneity-in-means show that riders with partial helmet coverage (U.S. DOT compliant helmets with partial coverage, least intrusive covering only the top half of the cranium) have a significantly lower risk of injury crash involvement. Lack of motorcycle rider conspicuity captured by dark (red) upper body clothing is associated with significantly higher injury crash risk (odds ratio 3.87, 95% CI: 1.63, 9.61). Importantly, a rider's motorcycle-oriented lower clothing (e.g., cannot easily get stuck in the machinery) significantly lowers the odds of injury crash involvement. Regarding the effectiveness of training, formal motorcycle driving training in recent years was associated with lower injury crash propensity. Finally, riders with less sleep prior to crash/interview exhibited 1.97 times higher odds of crash involvement compared to riders who had more than 5 h of sleep. Methodologically, the conclusion is that the correlations of several rider, exposure, apparel, and riding history related factors with crash risk are not homogeneous and in fact vary in magnitude as well as direction. The study results indicate the need to develop appropriate countermeasures, such as refresher motorcycle training courses, prevention of sleep-deprived/fatigued riding, and riding under the influence of alcohol and drugs.

1. Introduction & background

Recent statistics suggest that the annual number of motorcycle fatalities has increased by 48 percent since 2002, i.e., from 3365 fatalities in 2002 to 4976 fatalities in 2015 (NHTSA, 2016). This increase discernibly contrasts with a 32-percent decrease in fatalities to occupants of passenger cars and light trucks (NHTSA, 2016). Alarmingly, after accounting for per vehicle mile traveled, motorcyclists are fatally injured 29 times more frequently than their passenger vehicle counterparts (NHTSA, 2016). Owing to the expanding concern, the U.S. Congress recently passed a legislation to initiate the most comprehensive research effort targeted at identifying the causes of motorcycle crashes (NHTSA, 2017). As motorcycle safety remains a significant concern, different prevailing themes exist in the research arena. Extensive literature is focused on lowering the occurrence and unsafe outcomes of motorcycle crashes (Preusser et al., 1995; Sosin et al., 1990; Haque et al., 2010; Quddus et al., 2002; Savolainen and Mannering, 2007; Chin and Quddus, 2003). The key focus of the crash frequency and/or injury severity literature is to investigate how a confluence of factors may contribute to the occurrence and/or outcomes of motorcycle related crashes. To link motorcyclist's injury outcomes with explanatory factors, discrete outcome models are typically used such as multinomial logit (Shankar and Mannering, 1996), nested logit (Savolainen and Mannering, 2007), mixed logit (Shaheed et al., 2013), and ordered probit models (Quddus et al., 2002; Blackman and Haworth, 2013). Collectively, a variety of crash contributory

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factors such as driver-related factors (Schneider et al., 2012), roadway geometrics (Quddus et al., 2002; Haque et al., 2010), motorcycle characteristics (Savolainen and Mannering, 2007), and environmental factors (Rifaat et al., 2012) are identified to be associated with motorcycle crash outcomes. While such an analysis provides valuable insights into understanding the motorcyclists' injury outcomes, it does not shed light on the risk-taking behaviors of motorcyclists and how it relates to crash risk.

Another area of continuing research is the motorcyclist's crash risk and its associated factors. The behavioral literature focusing on motorcyclists attitudes toward road safety suggest that motorcyclists are less risk averse than other motorized road users (Fuller et al., 2008; Broughton et al., 2009). As motorcyclists are one of the most crash-prone groups, an understanding of how different behavioral, situational, and rider-specific factors relate to crash risk has also been sought. Several high-risk riding behaviors such as speeding, riding under influence, non-usage of helmets, unlicensed riding, and inexperience are correlated with higher crash rates (Lin et al., 2003; Schneider et al., 2012; Elliott et al., 2007; Moskal et al., 2012; Rowden et al., 2016). Keall and Newstead found that crash rates for motorcycles were four times that of passenger cars (Keall and Newstead, 2012). Note that the crash rate per vehicle for motorcycles was found to be only 30% higher than that for small vehicles, however, when adjusted for distances travelled, the crash rate for motorcycles became almost four times that of small vehicles (Keall and Newstead, 2012). Compared to older riders, riders aged 20–29 years had significantly higher crash rates (Keall and Newstead, 2012). Regarding high-risk behaviors, the odds of crash involvement were three times higher for riders who reported "frequent stunt" behaviors (Stephens et al., 2017). Likewise, a positive relationship was reported between self-reported traffic errors, control errors, and motorcycle crashes or crash liability (Cheng et al., 2015; Elliott et al., 2007). For the most part, the analysis of rider-specific behavioral factors, socioeconomic factors, demographics, and motorcycle driving experience related factors correlated with motorcyclist crash risks mainly builds upon data from the traditional police crash reports or questionnaire surveys (Schneider et al., 2012; Stephens et al., 2017; Elliott et al., 2007). While useful, such an analysis usually does not reflect the exposure of the population under study (i.e., motorcyclists) to the outcome of interest (i.e., motorcyclist crash). Also, insights regarding the interrelationships between explanatory factors and actual crash propensity cannot be easily obtained.

Crash propensity is defined as the likelihood of rider's involvement in injury crash events, compared to non-crash events. In particular, compared to non-crash events, how different trip related factors, physical, psychological, and exposure-related factors relate to the likelihood of motorcycle rider's involvement in injury crash events? An analysis of differences in the behavioral, situational, and rider-specific factors of motorcyclists involved in injury crash and non-crash events can ultimately facilitate formulation of actionable crash prevention countermeasures. A case-control data structure is needed for quantification of risk of associated factors on crash propensity. That is, detailed data are needed for riders involved in crash and non-crash events. To the authors knowledge, no comprehensive, large-scale study of motorcycle crashes had been conducted in the U.S. since the commonly called Hurt Study (Hurt et al., 1981), which included an on-scene investigation of motorcycle crashes in Los Angeles between 1976 and 1980 (Hurt et al., 1981). Thus, due to non-availability of suitable data, meager evidence exists in published literature regarding relative risks of key behavioral and crash specific factors, and how such key-risk factors relate to motorcycle crash propensity (i.e., involvement of a motorcycle rider in an injury crash vs. a non-crash event). Such an analysis is central to the formulation of actionable countermeasures for preventing motorcycle crashes.

With these forethoughts in mind, the main objective of this study is to quantify how different behavioral, psycho-physiological, and exposure-related factors relate to the likelihood of rider's involvement in injury crash events. To achieve this, a matched case-control study design is adopted to calculate relative risks of several exogenous factors. A unique aspect of this study is the incorporation of matched controls (motorcyclists not involved in crashes) which provide a basis for comparisons of rider and vehicle characteristics. The controls are matched with the case events (motorcyclists involved in injury crashes) for time of day, weather, road type, urban/rural, and other factors, and thus can be regarded as similarly-at-risk controls. From a methodological standpoint, unlike the traditional conditional estimation of relative risks, comprehensive heterogeneity based statistical analysis is conducted that accounts for the possibility of both within- and between matched case-control variations. In addition, heterogeneity in the relative risks, both due to observed and unobserved factors, is addressed. Compared to the commonly-used random parameters models that typically assume the same mean for each random parameter, the study accounts for possible heterogeneity in the means of the random parameters which vary as a function of several observed factors. To the best of authors' knowledge, the use of such a method has not been used/reported in a retrospective matched case-control design context.

2. Methodology

2.1. Development of case-control strategy

The notion of *crash propensity* is the likelihood of the motorcyclist's involvement in an injury crash event. From here onwards, the term "crash propensity" is used to refer to the risk of rider's involvement in an injury crash. *Risk factors* refer to the explanatory variables associated with an increased likelihood of motorcycle crash. Crash frequency data are typically analyzed to understand risk factors associated with motorcycle crashes (Chin and Quddus, 2003; Schneider et al., 2012; Blackman and Haworth, 2013). While useful, such an analysis usually does not reflect the exposure of the population under study (i.e., motorcyclists) to the outcome of interest (i.e., motorcyclist crash). To circumvent this, a retrospective matched case-control design is adopted in this research to better understand the association of risk factors with the motorcyclist crash propensity (Fig. 1). The two units that assemble a case-control design are the *cases* and *controls*. Cases are riders involved in injury crashes during a specific time-period, whereas, controls are riders that are not involved in crashes during the same time while exhibiting similar exposure as their case counterparts. The controls provide a basis for comparison of motorcycle, environment, and rider characteristics. To better understand crash propensity while accounting for overall exposure of the population (cases and controls in this case), each case is matched with two controls by time of day, day of week, weather, road type, urban/rural, location, and travel direction (Fig. 1). Importantly, the controls in this study can be regarded as "similarly-at-risk" controls. Once controls are generated, they can be coupled with cases to formulate a binary response outcome which can then be modeled using appropriate statistical methods. With such a 1:2 matched case-control study design, collecting data on exposure and other specific factors eventually allows quantification of relative risks that may be useful for countermeasure development. At a basic level, the comparison of the frequency of key factors in cases and controls can spot differential involvements.

2.2. Data source

The methodological framework shown in Fig. 1 is inspired by epidemiological and ecological research (Barzilai et al., 2003; Atzmon et al., 2004). The proposed approach utilizes their methodological strengths in systematic analysis of case-control approaches by pairing presence and absence of certain disease (injury crashes in this case). The pairing of cases (e.g., presence of disease) and controls (absence of disease) leads to development of strata, which is a matched triplet in the case of this research (Fig. 1). The retrospective matched case-