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Contrasting Crash- and Non-Crash-Involved Riders: Analysis of Data from the Motorcycle Crash Causation Study

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Abstract

Motorcycle crashes and fatalities remain a significant public health problem as fatality rates have increased substantially as compared to other vehicle types in the United States. Analysis of causal factors for motorcycle crashes is often challenging given a lack of reliable traffic volume data and the fact that such crashes comprise a relatively small portion of all traffic crashes. Given these limitations, on-scene crash investigations represent an ideal setting through which to investigate the precipitating factors for motorcycle-involved crashes. This study examines motorcycle crash risk factors by employing data recently made available from the Federal Highway Administration Motorcycle Crash Causation Study (MCCS). The MCCS represents a comprehensive investigative effort to determine the causes of motorcycle crashes and involved the collection of in-depth data from 351 crashes, as well as the collection of comparison data from 702 paired control observations in Orange County, California. This dataset provides a unique opportunity to understand how the risk of crash involvement varies across different segments of the riding population. Logistic regression models are estimated to identify the rider and vehicle attributes associated with motorcycle crashes. The results of the study suggest that motorcycle crash risks are related to rider age, physical status, and educational attainment. In addition to such factors outside of the rider's control, several modifiable risk factors, which arguably affect the riders' proclivity to take risks, were also found to be significantly associated with motorcycle crash risk, including motorcycle type, helmet coverage, motorcycle ownership, speed, trip destination, and traffic violation history.

After reaching a modern-day low in the 1990s, motorcyclist fatalities have increased dramatically, both in their overall number and with respect to their proportion of all road crash fatalities in the United States. Since 1994, the number of motorcycle crash-related fatalities has more than doubled from 2,320 to 5,286 in 2016, as shown in Figure 1—an increase of 127% (*1*). These increases have occurred concurrently with a generally consistent decline in fatalities among other crashes over this same period. Given the magnitude of the increase in motorcyclist fatalities, there is a clear need to develop effective countermeasures, policies, and programs to address this public health dilemma. In turn, this requires an improved understanding of the various risk factors influencing the likelihood of crash involvement.

Against this backdrop of a persistent increase in motorcyclist fatalities, the National Highway Traffic Safety Administration (NHSTA) sponsored a pilot study, which was conducted by Westat and Dynamic Science, Inc., to develop and test a methodology to investigate the causal factors contributing to motorcycle crashes. This pilot study ultimately led to the Motorcycle Crash Causation Study (MCCS), which is the first large-scale, in-depth investigation of motorcycle crashes in the United States since the Hurt Report (*2*). The Federal Highway Administration selected Oklahoma State University, through the Southern Plains Transportation Center, to lead a team comprising world-leading motorcycle and crash data collection experts, including Dynamic Science, Inc., Westat, Inc., Dynamic Research, Inc., Collision and Injury Dynamics, Inc., and consultant James Ouellet.

As a part of the full-scale investigation, the data that are ultimately used in this paper were collected from 351 police-reported motorcycle injury crashes in Orange

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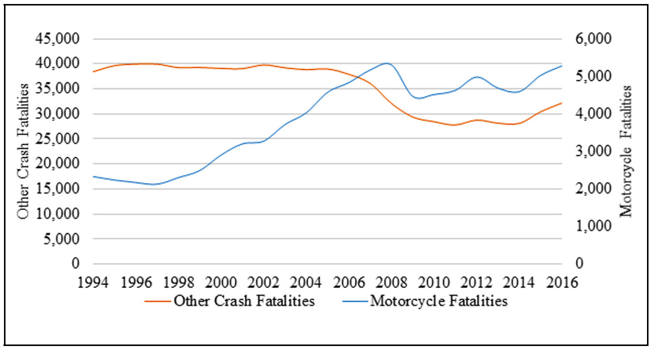

Figure 1. Fatality trends based on the Fatality Analysis Reporting System data.

County, California. These data included information about the crash-involved motorcyclists, as well as the circumstances contributing to the crash event. The case-control data, on the other hand, were collected through a series of roadside interviews at locations near where the crashes occurred, resulting in 702 paired control observations.

The ambitious scope and case-controlled nature of the study provides a rare opportunity for a sharper understanding of the potential factors contributing to the recent increase in motorcycle crashes and fatalities. To this end, the purpose of this study is to analyze the significance of leading risk factors that have been covered extensively in the crash risk literature. In addition, the paper considers the potential role of several crash factors that have received recent attention from researchers who studied riders' risk perceptions and attitudes.

Background

The literature on motorcycle crash risks has identified a broad list of factors that have been shown to be associated with motorcycle crashes. As the focus of this study is the identification of major crash factors associated with motorcycle riders, this brief discussion provides a summary of previous research under two broad categories based on whether the rider has any control over such risks.

The study makes a distinction between modifiable and non-modifiable factors based on the driver's ability to alter them immediately. Among the leading non-modifiable risk factors identified in the literature are the rider's age, gender, socioeconomic status, and level of education, even though many factors such as socioeconomic status do change over time. Although there can be several other non-modifiable risk factors, such as time of day of the crashes and seasonal crash patterns (see Namdaran and Elton (*3*) and Haworth et al. (*4*) for the effect of engine capacity and motorcycle type; Savolainen and Mannering (*5*) for an overview of risk factors behind injury severities, for example), this review largely draws on the literature that studied the risk factors associated with rider characteristics.

Understandably, research on crash risks has largely focused on modifiable risk factors, as these factors are responsive to the introduction of new safety countermeasures and the formulation of public policy to improve motorcycle safety. Motorist and motorcyclist errors and traffic violations, in particular, have received extensive attention from researchers because of the potential for crash reductions (*6*, *7*).

Because of the obvious desirability of case-controlled studies in establishing causal linkages between associated risk factors and motorcycle crashes, research utilizing control cases is of particularly relevance to this study. The earliest example was based on an in-depth investigation of 900 motorcycle accidents and an analysis of 3,600 motorcycle accident reports in Los Angeles, California, in which Hurt et al. reported that in most motorcycle accidents the primary causes of crashes were attributable to other vehicles, such as collisions into motorcycles resulting from right-of-way violations at intersections and lack of caution and awareness for motorcycle riders (*2*).

In a case-control study on 222 motorcycle crashes and 1,195 control motorcycles conducted by Haworth et al. (*4*), age, marital status, license status, riding experience, history of motorcycle training, helmet wearing, and alcohol consumption were found to be significant factors in increasing crash risk after adjusting for other explanatory factors. In another controlled study from Europe (MAIDS (*8*)), researchers analyzed 921 motorcycle accidents and 923 control events. They concluded that controlling for various other factors, license status and alcohol use were the major factors affecting crash risk when comparing accident and control events. It was also observed that the majority of the crashes occurred because of human error such as lack of attention, failure to notice motorcycles, and the low conspicuity of motorcycles.

As a result, both the introduction and stricter enforcement of several potential safety intervention programs have been advocated by researchers, including motorcycle training programs and adoption of helmet laws. In addition to motorcycle safety programs and better enforcement of motorcycle safety laws, several other safety countermeasures have been proposed. Such measures include mandatory safety helmets and eye protection, and broader adoption of NHTSA Traffic Safety guidelines in motorcycle licensing.

The following discussion samples from the wide-ranging literature in the field on both modifiable and non-modifiable factors that are shown to be associated with increased crash risks for motorcycle riders.

Age

The association between higher motorcycle crash risk, male gender, and younger age has been extensively documented. Despite their comparatively low exposure to driving, young people are more likely to experience vehicle accidents (*9–12*). Moreover, crash risk is closely associated with the amount of riding exposure (*7*, *13*). In two separate case-controlled studies, for example, Haworth et al. (*4*) and Mullin et al. (*14*) assessed the relationship between age, experience and motorcycle injuries in California and Auckland, New Zealand, respectively, and showed that older age riders were less prone to motorcycle injuries than younger age ones. In particular, the study by Mullin et al. (*14*) is worth noting in that their study found no significant relationship between riding experience and injury after adjusting for age and other potential confounding variables, giving credibility to the recent findings of the research on risk perceptions and attitudes of motorcycle riders, which tend to underscore the risk-seeking attitudes of young riders, and not the level of experience as the underlying factor in explaining the reduction of crash risks with older age.

Ownership and Valid License

Several studies investigated the role of riding a motorcycle without a valid license in motorcycle crash risk and found, in general, that diving with no valid motorcycle license results in higher risks of crashing and serious motorcycle injury in the U.S. and other countries (*2*, *15*). Ridership with no license is especially worrisome among fatally injured motorcycle operators and in young drivers (*16*). Several studies have also suggested that unlicensed motorcycle drivers were less likely to likely to report using the low-beam headlight in daytime, wearing body protection, or driving without drinking alcohol (*16*, *17*). Despite a long list of studies that examined the contribution of unlicensed drivers to motorcycle crashes, the role of vehicle ownership on crash risk is less clear. Kraus et al. (*16*), for instance, examined the frequency of having a valid license and motorcycle involvement in motorcycle crashes and found that motorcycle drivers who crashed and who did not own the motorcycle were more likely to be unlicensed than those owning the motorcycle, and owners involved in a crash were less likely to have a license than those not in a crash. Yet the study did not comment on the direct effect of vehicle ownership on crash risk. Although lack of a license, young drivers, and ownership are correlated, and the first two factors are clearly associated with increased crash risk (*18*), the contribution of ownership to crash risk controlling for the first two factors remains relatively unexplored.

Physical Impairment

Chen at al., in a study that targeted older motorcycle riders, found that several physical impairment factors, including hearing impairment, physiological flexibility, and balance factors, had a statistically significant effect on motorcycle crash risk (*19*).

Motorcycle Experience and Motorcycle Training

Although the literature provides clear evidence that higher driving experience is associated with a lower risk of motorcycle crashes and injuries (*20*), there is no such convergence of research findings on the effectiveness of formal driver training programs (*3*, *9*, *21*, *22*). Yet several studies emphasize the necessity for mandatory motorcycle training programs for riders. Such programs are also encouraged to be repeated for riders with recent traffic citations or for those involved in accidents.

Helmet Laws and Motorcyclist Conspicuity

Compared with non-helmeted riders, the role of safety helmets in reducing motorcycle head injuries and the impact of helmet laws on the incidence of head injuries have now been confirmed by several studies. (*17, 23–25*). An exhaustive summary of the helmet laws, as well as an overall review of the risk factors in motorcycle crashes, is provided in Lin and Kraus (*26*). The conspicuity of motorcycle drivers is an important area of crash risk research. In a controlled study, Wells et al. (*27*) observed that low conspicuity may increase the risk of crash injury and that the color of the helmet, reflective or fluorescent clothing, and daytime headlight status had a significant effect on the crash risk of motorcycles.

Data Summary

The data utilized as a part of this study were collected from 351 police-reported motorcycle injury crashes and 702 paired control observations in Orange County, California. Data collection for control riders was generally done 1 week after each crash at the same location and the same time of the day. Two case controls were recorded for each investigated crash.

Data collected included the observations of the rider, passenger, and other vehicle driver demographics, factors contributing to crash, environmental factors, safety equipment and clothing, motorcycle specifications, and dynamics, and compared the observations of crash and control motorcycle riders and passengers. Fourteen data collection forms were created to carry out in-depth investigations and record observations. Each of these forms consisted of a series of questions and designated spaces for entering the response. Descriptions of some of the forms are provided below.

- **Crash Form (CF):** contains information related to the crash such as time and day of the crash, number of vehicles and pedestrians involved in the crash, crash configuration, and weather and lighting conditions at the time of the crash.
- **Motorcycle Rider (MR) and Control Motorcycle Rider (CR) Forms:** contain information from crashes and control cases about the pre-crash data such as the travel speed before crash, loss of control, avoidance actions taken; trip information such as trip origin and destination, number of miles ridden and duration of ride before crash; helmet data such as the presence of helmet and helmet coverage; riding experience, other riding habits, type of protective clothing/gear worn while riding and other background information such as age and license details.
- **Motorcycle Mechanical (MM) and Control Motorcycle Mechanical (CM) Forms:** contain details from crashed motorcycles and control cases regarding their specifications such as manufacture, model, type, weight, VIN, odometer reading, motor displacement, and so forth. Information was also collected regarding any mechanical problems, suspension, brake system, frame, fuel tank, and other miscellaneous components of the crashed motorcycles.
- **Environment form (EF):** contains information regarding the location and its surroundings where the crash occurred such as the type of land development, type of intersection, speed limit and a number of lanes; roadway surface type and condition, traffic control on the path of travel, pavement markings and contributing environmental factors.

Various categorical variables were condensed to form smaller categories. Any kind of motorcycle rider training was combined under one category, and the same was followed for the license validity. These categorical variables were then converted into dummy variables. To represent N categories of a categorical variable, N–1 binary (0 or 1) or dummy variables were created. The continuous variables in the analysis were the rider's age and travel speed (mph). Table 1 represents the summary statistics for the crash and case-control motorcycles. The categories that do not add up to 100% are because of the missing/unknown data. Despite the scope and size of the MCCS data, however, missing values remain a notable shortcoming of the dataset, as suggested by the frequency of unknown data variables for select variables.

Methodology

Given the case-control nature of this evaluation, the data are well suited for analysis using logistic regression as the dependent variable is dichotomous in nature—taking a value of 0 for non-crash events and 1 for crash events. The general form of the binary logistic model is shown in Equation 1.

$$Y_i = \text{logit}(P_i) = ln\left(\frac{P_i}{1 - P_i}\right) = \beta X, \qquad (1)$$

where the dependent variable, Y_i, is the logistic transformation of the probability of individual i being involved in a crash, denoted as P_i. The vector X represents a series of explanatory variables affecting the crash risk of each motorcyclist (e.g., age, training history, type of motorcycle), β is a vector of regression parameters associated with each of these explanatory variables that is estimable using maximum likelihood techniques.

Results and Discussion

The logistic regression model was estimated in RStudio (*28*), beginning with a few independent variables of interest based on the results of the literature review. Given the paper's focus on rider characteristics, the model specification was finalized by following stepwise regression methods with an effort to choose the best fitting model that resulted in the highest explanatory power and parsimony. The two criteria used to evaluate alternative model fits were the (1) lowest Akaike Information Criterion (AIC), and (2) the lowest absolute value of log-likelihood values. The final model specification was based on the inclusion of the leading crash risk factors associated with motorcycle riders, and other explanatory variables that are shown to be significant risk factors in the literature. As with any model fitting exercise, some additional variables (such as other potential vehicle and rider characteristics) were excluded because of high collinearity, the unavailability of data or missing values in the sample dataset. Future research with expanded model specifications is expected to further build on the findings of the present study.

Table 2 provides the estimated parameter estimates, the associated standard errors, p-values, and odds ratios. The variables that were found to be statistically significant at a 5% level or less are shown in bold font. The logistic regression model employed here implies that the estimated coefficient variables should be interpreted based on the corresponding odd ratios to each variable. Odds ratios less than 1 imply that the variable decreases the probability of a crash, whereas ratios greater than 1 imply an increase in the probability. For example, an increased level of travel speed by 1 mph was found to be

Table 1. Statistical Data Summary for Crashes and Control Cases

Variable	Category	Crash (%)	Case-control (%)
Trip destination	Home	79 (22.51)	61 (8.69)
	Work, business	35 (9.97)	62 (8.83)
	Recreation/social	32 (9.12)	288 (41.03)
	Errand, shopping	14 (3.99)	102 (14.53)
	Family, friends, relatives	29 (8.26)	32 (4.56)
	Personal business/obligations	6 (1.71)	92 (13.11)
	Others	21 (5.98)	63 (8.97)
	Unknown	135 (38.46)	2 (0.28)
Travel speed (mph)	Less than 25	59 (16.81)	12 (1.71)
	25–49	133 (37.89)	402 (57.26)
	50 and above	156 (44.44)	285 (40.60)
	Unknown	3 (0.85)	3 (0.43)
Age (years)	Less than 25	90 (25.64)	75 (10.68)
	25–34	101 (28.77)	135 (19.23)
	35–44	48 (13.68)	98 (13.96)
	45–54	56 (15.95)	183 (26.07)
	55 or more	53 (15.10)	208 (29.63)
	Unknown	3 (0.85)	3 (0.43)
Gender	Male	335 (95.44)	657 (93.59)
	Female	16 (4.56)	45 (6.41)
Level of education	Graduate school, advanced degree, professional degree	15 (4.27)	61 (8.69)
	College/university graduate	42 (11.97)	185 (26.35)
	Partial college/specialty/technical school	93 (26.50)	300 (42.74)
	High school diploma or GED	23 (6.55)	142 (20.23)
	Less than high school diploma	6 (1.71)	12 (1.71)
	Unknown	172 (49.00)	2 (0.28)
Valid license	No	20 (5.70)	1 (0.14)
	Yes	331 (94.30)	701 (99.86)
MC training	None	45 (12.82)	103 (14.67)
	At least one (any type)	142 (40.46)	597 (85.04)
	Unknown	164 (46.72)	2 (0.28)
Recent traffic convictions	None	61 (17.38)	413 (58.83)
	At least one	119 (33.90)	287 (40.88)
	Unknown	171 (48.72)	2 (0.28)
Rider owns motorcycle	No	38 (10.83)	33 (4.70)
	Yes	313 (89.17)	668 (95.16)
	Unknown	0	1 (0.14)
Physical impairment	None	124 (35.33)	539 (76.78)
	Some type (vision or hearing reduction/loss, respiratory or neurological conditions, etc.)	55 (15.67)	159 (22.65)
	Unknown	172 (49.00)	4 (0.57)
MC type	Sports	155 (44.16)	214 (30.48)
	Others	195 (55.56)	488 (69.52)
	Unknown	1 (0.28)	0
Helmet coverage	Partial	41 (11.68)	222 (31.62)
	Full	199 (56.70)	430 (61.25)
	Others	13 (3.70)	41 (5.84)
	Unknown	98 (27.92)	9 (1.28)
Upper body clothing MC oriented	No	87 (24.79)	388 (55.27)
	Yes	114 (32.48)	312 (44.44)
	Unknown	150 (42.74)	2 (0.28)
Motor displacement/engine size (cc)	Less than or equal to 300	40 (11.40)	58 (8.26)
	301–600	89 (25.36)	90 (12.82)
	601–900	65 (18.52)	135 (19.23)
	901–1200	74 (21.08)	146 (20.80)
	More than 1200	83 (23.65)	273 (38.89)
	Unknown	1 (0.28)	0

(continued)

Table 1. (continued)

Variable	Category	Crash (%)	Case-control (%)
Front tire tread depth	Less than 5/32”	269 (76.64)	465 (66.24)
	5/32” or more	78 (22.22)	234 (33.33)
	Unknown	4 (1.14)	3 (0.43)

Note: MC = motorcycle; GED = Geneeral Education Development.

associated with a decrease in the probability of being involved in a crash by almost 9% (1–0.9086). Although this result may seem unexpected at first, one must bear in mind the conditions under which the data were collected. As varying levels of travel speed also suggest changes in a host of environmental factors with considerable impact on crash risks, a potential research question is expected to further analyze whether riding at speeds greater than surrounding traffic increases crash risk.

The results offer several risk factors for both the modifiable and non-modifiable risk groups. As expected, the leading demographic variable in crash literature, rider’s age, was found to be significant in contributing to motorcycle crashes (OR = 0.9729, p = 0.01). Although not found significant in this study, male gender, and the rider’s level of education, a proxy variable for socioeconomic status, were kept as control variables because of their common inclusion in crash risk specifications in the literature. Similarly, even though another non-modifiable factor, the presence of physical impairments of the rider, such as vision or hearing reduction/loss, respiratory or neurological conditions, was not observed to be significant at the typical 5% significance level, its relatively low p-value (0.1163) suggests that the paper’s results are in agreement with the reported adverse effects of physical conditions in the literature. Several other potential risk factors included in the dataset, such as psychological concerns resulting from conflicts with friends and family, financial distress, and physiological concerns, including fatigue, hunger, thirst, and headache, were also tested in alternative model specifications not shown here, but were found to be insignificant.

As mentioned previously, the modifiable risk factors are of particular importance because of their potential in devising new safety countermeasures and introducing new policies in public safety. In what seems to be a reflection of exposure of the rider’s to crash risk, the study found a negative and statistically significant relationship between the travel speed of the motorcycle and crash events. That is, the odds of being involved in a crash decrease as the motorcycle travel speed increases (OR = 0.9086, $p < 0.001$).

Of the rider characteristics that are within the rider’s control, factors related to rider risk attitudes and behavior are especially worth noting. Recent traffic convictions, which suggest a heightened level of risk-seeking behavior, was found to be a significant factor in predicting crash risk. Riders with no recent traffic convictions were estimated to have approximately 51% lower levels of crash risk (OR = 0.4887, p = 0.0069).

Suggesting a similar dynamic in capturing rider’s risk attitudes, motorcycle type was also found to be closely related to the crash risk. When the vehicles were grouped under two groups as sports and non-sports motorcycles, results indicate that riding a non-sports vehicle reduces the probability of a crash by 48% (OR = 0.5241, p = 0.0337).

Although almost all crashes involved riders wearing a motorcycle helmet, the riders with fuller helmet coverage were significantly associated with increased crash risk (partial helmet coverage refers to helmets that fall short of full face coverage and lack a wrap-around face shield). Suggesting a similar risk profile to riding a sports motorcycle, having full helmet coverage seems to be capturing the increased risks that are introduced by more aggressive rider behavior. Specifically, partial helmet coverage was found to be associated with lower likelihood of motorcycle crashes by 55% as compared with full helmet coverage (OR = 0.4525, p = 0.0422), likely because of the varying risk-taking attitudes of riders with different helmet types. Combined with the observation that most cruiser riders tend to wear partial helmets, these results suggest the likely role of motorcycle type as an indirect factor in signaling rider risk attitudes.

The ownership of the motorcycle was also found meaningful in estimating crash risk. The non-motorcycle-owners were found to be less likely involved in a crash as compared with owners (OR = 0.1415, p = 0.0219). This previously unreported potential relationship in the literature could be especially promising in capturing rider risk perceptions and attitudes, as further discussed in the paper’s concluding discussion.

Although a few variables such as gender and helmet wearing are widely reported to be significant risk factors in the literature, the paper’s estimates found them to be insignificant both because of a lack of variation in these variables between the crash and control groups, and an emphasis of the study being on crash risks alone. In the case of helmet use, the lack of non-helmeted study participants is largely reflective of the fact that California is one of 19 states with a universal helmet use law. Other

Table 2. Model Results for the Probability of Being Involved in a Crash

Variable	Estimate	Standard error	*P*-value	Odds ratio	95% Confidence interval
Intercept	7.128	1.314	<0.001	–	na
Age (in years)	–0.028	0.011	**0.0100**	0.9729	(0.952,0.993)
Gender					
Male	0.074	0.541	0.8915	1.0766	(0.391,3.343)
Female (base)	na	na	na	na	na
Level of education					
Graduate school, advanced degree, professional degree	–0.0006	0.934	0.9995	0.9994	(0.169,6.713)
College/university graduate	–0.748	0.844	0.3754	0.4733	(0.097,2.702)
Partial college/specialty/technical school	–0.389	0.824	0.6370	0.6777	(0.145,3.74)
High school diploma or GED	–1.063	0.868	0.2206	0.3454	(0.067,2.048)
Less than high school diploma (base)	na	na	na	na	na
Physical impairment					
None	–0.455	0.290	0.1163	0.6344	(0.36,1.122)
Some type (vision or hearing reduction/loss, respiratory or neurological conditions etc.) (base)	na	na	na	na	na
MC training					
None	0.314	0.354	0.3746	1.3689	(0.677,2.724)
At least one (base)	na	na	na	na	na
Recent traffic convictions					
None	–0.716	0.265	**0.0069**	0.4887	(0.289,0.819)
At least one (base)	na	na	na	na	na
Rider owns motorcycle					
No	–1.955	0.853	**0.0219**	0.1415	(0.019,0.615)
Yes (base)	na	na	na	na	na
Trip destination					
Home (base)	na	na	**na**	na	na
Work, business	–0.6822	0.371	**0.0656**	0.5055	(0.242,1.04)
Recreation/social	–2.218	0.352	<**0.001**	0.1088	(0.054,0.214)
Errand, shopping	–2.658	0.458	<**0.001**	0.0701	(0.027,0.166)
Family, friends, relatives	0.206	0.433	**0.6339**	1.2287	(0.524,2.872)
Personal business/obligations	–3.031	0.627	<**0.001**	0.0483	(0.012,0.149)
Travel speed	–0.096	0.011	<**0.001**	0.9086	(0.888,0.929)
Helmet coverage					
Partial	–0.793	0.390	**0.0422**	0.4525	(0.207,0.96)
Full (base)	na	na	na	na	na
MC type					
Sports (base)	na	na	na	na	
Others	–0.646	0.304	**0.0337**	0.5241	(0.287,0.948)
Motor displacement/engine size					
Less than or equal to 300	–0.152	0.494	0.7584	0.8590	(0.318,2.219)
301–600	–0.244	0.437	0.5765	0.7835	(0.33,1.84)
601–900	–0.323	0.420	0.4422	0.7240	(0.315,1.644)
901–1200	–0.328	0.413	0.4274	0.7204	(0.318,1.611)
More than 1200 (base)	na	na	na	na	na
Front tire tread depth					
Less than 5/32” (base)	na	na	na	na	na
5/32” or more	–0.662	0.300	**0.0272**	0.5158	(0.282,0.917)
Model goodness-of-fit diagnostics					
AIC: 487.32					

Note: Variables found to be significant at least at the 5% level are shown in bold font. MC = motorcycle; GED = General Education Development; na = not applicable.

variables such as riding experience, drug/alcohol use, upper body clothing, and manufacturing year of the motorcycle were also examined but did not prove to be significant either. Gender, level of education, and motorcycle training were taken as control attributes in the model.

Finally, of the two other motorcycle-related risk factors that were tested for significance, the front tire tread depth was found significant but motorcycle engine size was not. The lack of significance for vehicle size fails to support the results reported by Namdaran and Elton (*3*) and Haworth et al. (*4*) in noting motor displacement was a significant predictor of motorcycle injury accidents. High front tire tread depth (5/32" or more), on the other hand, was found to decrease the chances of being in a crash by 48% (OR = 0.5158, p = 0.0272). Again, tire tread depths could be signaling either a potential slip in maintenance or a more aggressive driving behavior, with adverse effects on motorcycle crash risk in both cases.

Conclusion

The purpose of this paper is to contribute to the motorcycle safety literature by relating rider risk attributes and, in particular, those latent attributes that signal risk perceptions and behavior, to motorcycle crash events. In doing so, the results of the paper not only provide further evidence that several previously reported factors survive new scrutiny based on the MCCS' robust dataset with a control group, they introduce new risk factors to deepen the level of understanding in the field. Building on the existing literature, the results provide further evidence that crash risks are highest among younger riders, as well as those with a recent history of traffic convictions.

Suggesting potential latent mechanisms that capture rider risk perceptions and behavior, results also indicate that riders' risk-seeking attitudes could be manifesting themselves in the form of motorcycle type, helmet coverage, and tire tread depth, for example. Potential lapses in proper vehicle maintenance could also be the reason behind the observed effect for tread depth, however.

According to the theory of planned behavior (*29*), for instance, rider behavior is determined through a combination of driver attitudes and intentions. Based on the theory, Ulleberg and Rundmo offered a causal mechanism through which attitudes toward safety and risk perception and personality traits ultimately manifest themselves in risky behavior (*30*). Risk homeostasis theory further expanded this theory by suggesting that behavior emerged from the interaction of two broad groups of individual considerations related to risk and utility perception (*31*, *32*). In a classic paper on perceived crash risk, for example, Mannering and Grodsky showed that perceived risk was greatly influenced by the riders' perspectives, and was associated with age, gender, distance ridden, geographic region, and experience (*33*).

More recent work showed that risk-taking behavior is predicated on calculated decisions that take into account both perceived risks and risk utilities. For some riders, and younger ones in particular, increased utility experienced from engaging in risky behavior, such as an expression of independence, or a means of thrill-seeking or impressing other people (*31*, *32*), may offset any restraining factors that would be expected from an increase in perceived risk. In fact, whereas some studies suggested that higher and more realistic perception risk should be associated with lower crash risks (*34*, *35*), others also suggested that improvements in risk perception may not translate into reduced risk-taking levels or modified risk-taking behavior (*36*).

In light of the complex patterns that drive individual risk perceptions and behaviors suggested by this literature, the paper's results are expected to provide new insights for continued inquiry in the field. Consider the results reported on motorcycle ownership, for instance. Although motorcycle ownership has received attention in previous research, these studies examined the effect of ownership when combined with other factors such as the rider's license and young age. Although establishing a potential causal relationship between motorcycle ownership and crash risks warrants further inquiry, the paper's results indicate that an adverse selection mechanism may be at work. In economics, for instance, adverse selection refers to the tendency of high-risk individuals to self-select into purchasing insurance policies, anticipating a payoff at the expense of the insurance provider. In the case of non-owner motorcycle riders, these individuals may be in a position to have access to borrowed vehicles only because either they or the owners of the vehicles are reasonably assured of the riders' relatively defensive driver behaviors.

Further, a similarly unexpected sign was reported for the effect of travel speeds on crash risk. The results hint at a potential increase in crash exposures at lower travel speeds immediately preceding the crash events. As travel speeds change, so do the environmental risk factors that contribute to the crashes. Lower travel speeds likely imply some congestion, different roadway characteristics, and increased overall hazard and exposure profile for motorcycle riders. This finding remains a promising future research area to study the role of travel speed relative to posted speed limit for further insights into a better understanding of motorcycle crash risks. Another trip characteristic, trip destination, which was found to be significant, seems to corroborate this mechanism. Commuting-related categories, trips home and to work, were found to be associated with higher levels of crash risks, whereas leisure trips result in lower levels of crash risk.

As a causal investigation of such unobserved, yet crucial elements of rider behavior, often requires carefully designed research studies, the recently disclosed MCCS is expected to provide the basis for a series of future studies that will rely on both the granularity of its data and the availability of control cases in making causal inferences. Despite the ambitious scope and level of detail achieved by the MCCS, however, the MCCS dataset does have notable limitations, such as the study's confinement to Los Angeles, CA for a broader generalization of its findings, limited crash and test sample sizes for some event types, and considerable missing data values for potentially important confounding variables. Future research studies that rely on the MCCS dataset are expected to further identify such shortcomings. This study, therefore, provides preliminary results that point toward potential avenues for future research. In particular, the results should be especially relevant for researchers who have been contributing to the fast-growing literature on rider risk attitudes and crash risks. The rich trove of data contained in the MCCS can be further used to verify the results reported on rider behavior through primarily survey studies on risk attitudes. In conclusion, in addition to testing the validity of leading crash risk parameters by utilizing the MCCS data, the study shows that the risk perceptions and behavior literature can be further strengthened through proxy risk factors variables that capture rider risk perceptions and behaviors.

Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: HC, IK, PTS; data collection: HC; analysis and interpretation of results: HC, IK, PTS; draft manuscript preparation: HC, IK, PTS. All authors reviewed the results and approved the final version of the manuscript.

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