JOURNAL OF FORENSIC SCIENCES

J Forensic Sci, March 2011, Vol. 56, No. 2
doi: 10.1111/j.1556-4029.2010.01657.x
Available online at: onlinelibrary.wiley.com

PAPER

PATHOLOGY/BIOLOGY

Samuel Nunn,[1] *Ph.D.*

Death by Motorcycle: Background, Behavioral, and Situational Correlates of Fatal Motorcycle Collisions*,†

ABSTRACT: Motorcycle fatalities in the United States continue to increase on both crude and adjusted bases. This paper examines fatal motorcycle accidents as a cause of death, using a retrospective analysis of motorcycle operator fatalities from 2003 to 2008 in the state of Indiana. During these six years, out of more than 18,000 motorcycle operators in crashes, 601 were killed. Based on police report data, motorcycle operators during this period are examined to reveal key factors that are in place when a motorcyclist is killed in a collision. The major correlates of death identified were objects of impact, risky behaviors, and speed. The largest positive effects on the chances of death were linked to trees, posts-signs-poles, bridge-guardrail-median, and other motor vehicles. In conjunction with speed, these objects were the primary mechanisms by which fatal injuries were sustained by motorcyclists. Various types of risky behavior were also major correlates of death by motorcycle.

KEYWORDS: forensic science, motorcycle fatality, mechanism of injury, road accidents, correlates of death, risky behavior

Motorcycles are a dangerous mode of transportation. Relative to four-wheeled vehicles, motorcycles pose a greater threat of death or serious injury to operators and riders. Per vehicle mile traveled in 1994, motorcycles were 11 times more likely than passenger cars to be involved in fatal collisions. By 2007, motorcycles were 27.5 times as likely to be part of a fatal collision (1). In the U.S. from 2007 to 2008, motorcyclist fatalities increased in 28 states and the District of Columbia, while overall traffic fatalities decreased in 46 states and D.C. In most of the U.S., death by motorcycle continues to increase (2).

Death by motorcycle is typically classified as unnatural—that is, as an unintentional accident that is the proximate or underlying cause of death (3,4). However, motorcycle "accidents" are complicated situational transactions in which motorcycle operators are in motion among other motor vehicles, pedestrians, bicyclists, and animals along public roads that are composed of a variety of natural and engineered objects. In fatal crashes, the motorcyclist typically collides with moving or stationary objects in the riding environment. Within this environment, the motorcycle operator combines individual background factors with various types of behavior and, through a combination of actions, collides with an object or engages in some other harmful action, sustaining an injury or injuries resulting in death. The mechanism of injury resulting in death usually comes from severe blunt force trauma, creating internal and external damage to the motorcyclist, especially head, neck, thoracic, and other axial–skeletal injuries (3,5–12). Injuries to the rider are instilled through collisions with objects and actions occurring within the physical location of the fatal accident. In short, motorcycle riders are killed in collisions with different types of objects, engaging them in different ways, influenced by different types of behavior. Further, motorcyclists might employ behavior that contributes to their demise. What are the correlates of death by motorcycle?

Autopsy, trauma, and hospital data often used in forensic research offer only a limited perspective on this question. Using trauma data, previous forensic analyses of motor vehicle fatalities have typically focused on the nature of injuries, answering questions about the physical wounds to the victim and other clinical aspects of motorcycle and motor vehicle crash injuries linked to the immediate cause of death (3,9–12). However, there are other questions about the underlying or proximate cause of death, the motorcycle crash, and how it initiates the "train of morbid events" that results in death. What were the broader background, situational, and circumstantial factors in the death of motorcyclists? How do these elements—a mix of conditions, behaviors, actions, and circumstances—contribute to the cause of death? Trauma data do not answer such questions so easily. Other data sources are needed to address the broader picture of death by motorcycle.

One data source underused in forensic analysis of fatal motorcycle collisions is the police crash report. These data have been used in the forensic literature (3,9–12), but usually in conjunction with other trauma data. Among these, the information contained in police report data are under-identified and not fully explored, and could provide additional significant insight into the mechanisms of injury and death at work within the accident. Law enforcement agencies respond to and investigate motorcycle collisions and

[1]Professor, School of Public and Environmental Affairs (SPEA); Director, Center for Criminal Justice Research (CCJR); and Indiana University-Purdue University, Indianapolis (IUPUI), 334 North Senate Avenue, Suite 300, Indianapolis, IN 46204.

*An earlier version of this paper was presented at the Center for Excellence in Rural Safety, State and Local Policy Program, Humphrey Institute of Public Affairs, University of Minnesota, October 12, 2009, in St. Paul, MN.

†Funded by annual traffic safety research grant awards from the Indiana Criminal Justice Institute to the Indiana University Public Policy Institute and Center for Criminal Justice Research.

Received 17 Nov. 2009; and in revised form 5 Feb. 2010; accepted 28 Feb. 2010.

complete detailed reports describing what happened. Police report data play a major role in insurance claims and as evidence in criminal cases and wrongful death litigation. In this context, the police crash report is the primary if not sole source of information about the multifaceted situational and circumstantial aspects of fatal motorcycle collisions. It includes descriptions of the collision circumstances, time, place, and physical setting; a description of the operator and aspects of the operator's behavior at the time of the crash; the geophysical conditions under which collisions occurred; descriptions of the objects of impact, as well as the police investigator's perception of the nature and location of injuries to the victim of the collision, and the injury status of the individual. Although such data have shortcomings (13), police crash reports are nonetheless an important source of information about selected forensic aspects of motorcycle collisions—how they happened, the means by which fatal injuries were received, and the nature of accidents that produced fatal injuries to the motorcyclist.

This paper uses police reports on fatal motorcycle collisions in the state of Indiana from 2003 to 2008 to identify major correlates of death by motorcycle and assess the comparative impacts of these correlates on the likelihood the motorcyclist was killed. A secondary objective is to use the findings to identify prevention and intervention strategies suggested by the analysis. To accomplish this, the next two sections review previous analyses of factors in fatal motorcycle crashes and describes motorcycle fatalities in Indiana through a description of the data used and an examination of the major correlates of fatal collisions. The fourth section describes the logistic regression analysis of the fatal outcome, identifying the comparative contributions of each correlate to the fatal accident. The last section discusses the findings in the context of (i) some forensic aspects of death by motorcycle and (ii) prevention and intervention programs that might reduce the mortality rate of motorcycle operators and their passengers.

Correlates of Fatal Motorcycle Collisions

Studies of motorcycle crash injury patterns are abundant and have been conducted in diverse national and international spatial settings, using different statistical, analytical, and graphical methods. This variety is both strength and weakness, as it suggests a consistent set of key correlates in motorcycle crashes, but also underscores widespread fragmentation of motorcycle crash research (14–16). There is consistent evidence about background, behavioral, geophysical, and situational correlates that accompany fatal motorcycle crashes, and at least the following factors have been implicated in analyses of death and serious injury in motorcycle crashes: age, gender, motorcycle design type, helmet use, alcohol and drug use, speed, rider perceptions of safety, crash experience, pillion passengers, risky riding behavior, risky personal behavior, licensing, training, light conditions, conspicuity, time of day, season, driving history, crash configuration, type of road junction, collision partner, precollision action, and object of impact (17–23).

Apart from age, gender, and alcohol involvement, other correlates of death by motorcycle have rarely been analyzed in forensic literature, partly because of an alternative focus on the nature and location of injuries, and their role in the immediate cause of death. Dying from the trauma inflicted in a motorcycle and other motor vehicle crashes can occur in many ways, and the immediate causes of death vary (3–7,12). An analysis of 59 motorcycle fatalities in Scotland found the following unsurvivable injuries: decapitation, liver destruction, ruptured ventricle, brainstem laceration, skull fracture, spinal cord transection, and various transections of the thoracic aorta (9). What is typically missing from these forensic profiles of motorcycle fatalities is the circumstances under which death occurred—what particular objects and actions were responsible for the injuries? If considered from this broader situational perspective, the mechanisms of injury in motorcycle fatal collisions—the underlying cause of death—are less varied. Fundamentally, crashes kill motorcyclists in one of the following three ways: (i) collision with another motor vehicle; (ii) collision with another stationary or moving nonvehicular object; or (iii) some other harmful action by motorcyclists—not involving directly striking an object—that results in their death. These three categories, however, hide considerable variation in the comparative deadliness of objects of impact and other harmful actions.

Objects of impact are what motorcycles collide with—some type of object, whether another motor vehicle, mailbox, tree, bicyclist, pedestrian, bridge abutment, or something else. Previous research suggests motorcyclist injury severity worsens when the collision is with a fixed object (24–29). These objects have varied levels of "give" or "fixedness" (their elastic limits) that might or might not resist the force of a colliding motorcycle and rider(s). Alternatively, riders are killed as a result of other harmful actions, such as falling off a motorcycle, overturning, or crashing off the roadway. Objects of impact and other harmful actions likely reflect different levels of fatality risk and will be (differentially) implicated in the motorcyclist's death. However, there have been few comparisons of motorcyclist fatalities associated with vehicle collisions, collisions with other objects, and loss of control.

Data and Overview of Indiana Motorcycle Fatalities

Indiana crash data are compiled within the Indiana State Police Automated Reporting Information Exchange System (ARIES). The population analyzed here consists of 18,225 motorcycle operators from 2003 to 2008 who were involved in collisions. Among them were 601 fatalities. Another 56 motorcycle pillion passengers died, but they are not included in this analysis because the background and behavioral correlates included in ARIES typically belong to the operator, not the passenger. Further, two of the situational correlates—precollision actions and speed limits—can be considered latent behavioral traits of the operator. Injured individuals who die within 30 days of the collision are part of the fatality group. This does not mean that the crash was not the cause of death for motorcycle operators who survive beyond 30 days, only that based on US National Highway Transportation Safety Administration rules, these ultimate fatalities are classified in ARIES as some type of less than fatal injury.

Using a state's crash data requires analysts to recognize what these data represent. Crash data are compiled by police from information available in the immediate time period of a crash and are a function of the police investigator's perception of the collision, the circumstantial and situational conditions present in the environment, the condition of the vehicle occupants as a result of the collision, and other aspects of the crash. The police officer's observations create the official picture of the collision, its participants, and their injury outcomes. This is a strength of crash reporting (e.g., it is always performed by police officers entering a standardized report), but one of its weaknesses as well (e.g., forms might be incomplete; officers might rely on vague options, such as other or unknown). Another strength of police crash report data is its systematic organization around three elements, each with a variety of descriptive variables attached: (i) collision characteristics, (ii) the nature of the vehicular and nonvehicular units involved, and (iii) characteristics of the people involved. Indiana data include categorical descriptions of the location and nature of injuries to collision victims. Regarding police descriptions of collision injuries, researchers have criticized "nature of injury" reporting as medically inaccurate; however, documentation of fatal outcome and the bodily location of injuries are considered more reliable (13,15,18,22).

The number of persons killed in Indiana motorcycle collisions trended upward between 1994 and 2008, and this trend is especially telling in comparison with the downward trend in passenger car fatalities (Fig. 1). Since 2004, more than 100 persons per year have been killed in Indiana motorcycle collisions. Among those killed from 2003 to 2008, more than 87% were men. About 50% of fatalities occurred in the evening and late night. Nearly 60% of deaths occurred on Fridays, Saturdays, or Sundays. Nearly 60% of deaths were from motorcycle crashes in rural areas. According to U.S. Centers for Disease Control mortality data (one of few data sources with the race of persons killed in motorcycle crashes), motorcycle fatalities in Indiana from 1999 to 2006 were overwhelmingly White (93%; [30]). In Indiana, among the more than 15,000 motorcyclists whose helmet use in collisions was known during 2003–2008, two-thirds were not wearing a helmet.

As noted earlier, crashes that instigate the "morbid train of events" generally kill motorcyclists in one of three ways: (i) collision with another motor vehicle; (ii) collision with a stationary or moving nonvehicular object; or (iii) some other harmful action. These three categories are shown in Table 1 as basic mechanisms of death by motorcycle in Indiana. By frequency, Indiana motorcyclists collided most often with other motor vehicles (51.5%) or lost control of the motorcycle in some fashion (28.4%). This accounts for 80% of all motorcycle collisions. Losing control of the motorcycle consists of several categories: "other actions" (e.g., "rollover" or "overturn" of the motorcycle), a crash "off the roadway" (which might or might not involve losing control), and falling from the motorcycle. The remaining 20% of motorcyclists collided with some other object. These three groupings have different relationships to fatal outcomes. The odds of death when colliding with other vehicles (.038) exceed that of losing control (.019) but are slightly less than that of colliding with other objects. The highest odds of death occur when motorcyclists collide with other objects (.048). In comparison with colliding with a motor vehicle, losing control or other harmful actions by motorcycle operators reduced the odds of death about one-half, while colliding with another object increased the odds about 1.3 times.

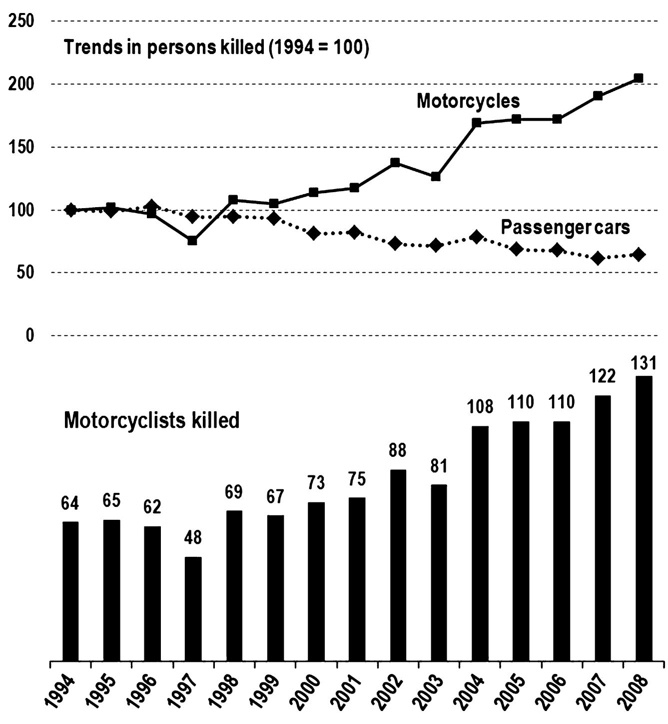

FIG. 1—*Overview of Indiana motorcycle fatalities, 1994–2008.*

Table 2 summarizes the key correlates of death by motorcycle, consisting of four broad variable groups: background of the motorcycle operator, latent behaviors attached to the operator, the geophysical circumstances of the collision, and the final situational elements, including objects of impact. Fatality rates among correlates vary considerably, from a low of 1% to a high of 28.6%. For the relatively small number of motorcycle operators who tested positive for drugs (n = 225), the probability of death was 28.6%. Alcohol was linked to a higher probability of death (11.1%). Trees are the most deadly object of impact—nearly one-quarter of motorcyclists colliding with a tree were killed. Motorcyclists whose pre-collision action was at the left of center or crossing the median were killed 17.3% of the time. Speed limits have a positive effect on fatality rates. Higher fatality rates are also produced by errant or risky driving (5.2%), darkness (6.7%), and curves (5.1%). Rural areas (4.5%) have a higher relative risk of fatality than urban areas (2.6%).

Individual background correlates in ARIES data include age, gender, and driver's license status. Age is a scale variable and covariate of injury status. The average age of dead motorcyclists (39.5) is almost 2 years older than surviving operators (37.6). However, the effects of age on death by motorcycle are not straightforward, and research into age effects is mixed; dead motorcyclists were much younger in a county analysis from Denmark (3), a 6-month review of motorcycle accidents in a U.K. hospital (5), and an analysis of motorcycle fatalities in Birmingham, U.K. (6). Further, an Auckland, New Zealand, analysis suggested older riders had a decreasing risk of death or injury (19). In the U.S., motorcyclists killed in crashes have been older, leading to public concerns about an age bubble linked to middle-aged and older riders (28). Gender has an effect on the likelihood of injuries in a motorcycle collision. Victims of motorcycle crashes are overwhelmingly men, so given that a crash has occurred, the probability is high that there was a male operator involved. Previous analyses have found female operators engage in less risky behavior (17,19,31,32). Driver's license status has been linked to reductions in serious injury or death by motorcycle (19,21). However, license status was not significantly linked to fatal injuries among this population of Indiana motorcycle operators.

Behavioral correlates include seven indicators: helmet use, alcohol and drug use, driving behaviors, speeding, passenger present, and fault. Helmet use is a behavioral decision, with a presumed inverse relationship between injury severity and helmet use (see [16]). Drugs and alcohol are widely recognized factors in motor vehicle collisions (16,24,33,34). For alcohol, a nonalcohol-related motorcyclist = 0 and an alcohol-related motorcyclist = 1. A motorcyclist is considered alcohol related if any of the following conditions are met: alcoholic beverages is listed as the primary factor of the collision; alcoholic beverages is listed as a contributing circumstance; the vehicle driver involved in the collision has a blood alcohol content test result greater than zero; the collision report lists the apparent physical condition of the vehicle driver as "had been drinking"; or the vehicle driver is issued an operating-while-intoxicated citation. For drugs, a motorcyclist who was not tested or returned a negative test = 0 and an operator with a positive drug test = 1. Two other types of behavior by motorcycle operators are measured. One indicates whether the motorcycle operator was engaged in risky or errant driving (0 = no, 1 = yes). An operator is

TABLE 1—*All Indiana motorcycle operators by broad object of impact and fatality status, 2003–2008.*

	Operators†				Confidence Interval		
Object of Impact (% of All Operators)*	Fatal	Nonfatal	Odds (Fatal)	Odds Ratio	Low	High	Sig (<0.05)
Another motor vehicle (51.5%)	337	8947	0.038	Ref	–	–	–
Losing control/no object (28.4%)	96	5018	0.019	0.51	0.31	0.71	Yes
Other objects (20.2%)	167	3468	0.048	1.28	1.12	1.43	Yes

*χ^2 = 54.21, df = 2, $p < 0.0001$.
†n = 18,033 motorcycle operators, where object of impact and fatality status are known.

engaged in errant/risky driving if any of the following are reported: unsafe speed, failure to yield, disregarding signals or signs, driving left of center, improper passing, improper turning, improper lane usage, following too closely, unsafe backing, overcorrecting/oversteering, running off the road, going the wrong way on a one-way road, jackknifing, or speed too fast for weather conditions. Also, motorcyclists make decisions about what speed to travel and high speeds contribute to more serious injuries. Presence of a pillion passenger is the sixth behavioral correlate. Actions of the operator that contributed to the circumstances of the collision (“Operator at fault”) are measured as driver did not contribute to primary cause of crash = 0 and operator did contribute to primary cause = 1, but this variable was not significantly linked to fatality status.

Geophysical correlates include lighting conditions, type of road junction, roadway geography, roadway surface condition, and weather conditions. Lighting conditions have been found to be an important correlate of motorcycle collisions. More collisions occur during daylight because more motorcycles are out and about. However, collisions at night tend to have certain characteristics (e.g., alcohol, drugs, risky behavior) that contribute to death and serious injury. Lighting conditions are measured as daylight = 0, dark—not lighted = 1, dark—lighted = 2, or dawn/dusk = 3. Three variables measure the structure, geography, and condition of the road on which the collision occurs. The type of road junction is no junction = 0, an interchange or ramp = 1, a T- or Y-intersection or roundabout = 2, and a four-way or larger intersection = 3. The geography of the crash site is straight road = 0, hill or grade = 1, curve = 2, or nonroadway crash = 3. The road surface is dry = 0 or other = 1. Weather conditions are clear = 0, cloudy = 1, or other = 2, but were not significantly linked to fatal outcomes.

Situational correlates include peak traffic periods, urban/rural setting, speed limit, motorcyclist’s precollision action, and object of impact. Daily motorcycle collisions follow peaks coinciding with periods during which most vehicles are streetbound. With nonrush hours as the reference = 0, morning or evening rush hour collisions are coded 1. The collision setting is rural (0) if located outside a municipality, otherwise it is urban (1). The reported speed limit for each unit is a proxy for the overall speed environment of the collision, with <35 mph as reference (0). Actions preceding the collision are, in effect, the last set of decisions a motorcyclist makes prior to the crash. Precollision actions are measured along six categories. Objects of impact are examined through a comparison of (0) loss of control/no object with eight other categories of objects. All situational correlates but rush hour were significantly linked to fatal injury outcomes.

Logistic Analysis of Death by Motorcycle

Correlates of fatal motorcycle collisions were considered in four discrete blocks and examined using the binary logistic regression procedures in PASW Statistics (formerly SPSS; IBM Corporation, Somers, NY), release 17.0.2. The dependent variable was binary: the motorcyclist survived (0) or died (1). The correlates of death were selected and entered based on a theory that the fatal injury outcome of the motorcycle accident is created through a roughly ordered sequence of background, behavioral, geophysical, and situational correlates. A motorcyclist has individual background characteristics (age, gender, license status) that combine with behavior (use of helmet, alcohol, or drugs; carrying a passenger; speeding; or engaging in particular driving behaviors) during the incidence of collisions, that in turn occur under various geophysical circumstances (lighting, road junctions, road character, road surface, weather, and time), and end in the final interaction of specific situational factors (speed limit, precollision actions, and the object of impact). The initial analysis examined the effect of all 20 correlates on fatality rates block by block. After examining sequential entry of the four blocks, six correlates not significantly linked to fatal injury were dropped (drivers license, road geography, road junction type, weather, rush hour, and urban/rural locality), and the model was re-estimated. The results of this reduced model are shown in Table 3.

When only background variables are examined, age is a significant covariate (and remains so in each block of entry), increasing the odds of death by 1.5% for each year of age. When motorcycle operators are women, the odds of death are reduced by 37%. Having a valid motorcycle license or endorsement was not significantly linked to fatal status. However, the comparative importance of background factors changes when behavioral indicators are introduced. Age and gender remain significant, but various behaviors increase the chances of death: positive drug test (OR = 4.3), alcohol-related status (OR = 3.4), errant/risky driving (OR = 2.3), an operator at fault in the collision (OR = 2), and speeding (OR = 2.5). Use of a helmet reduced the odds of death by 21%. Carrying a passenger also reduced the chances of death (OR = 0.66).

After geophysical circumstances are entered, all previously significant background and behavioral variables remained so, but only two geophysical factors remained in the final model, one increasing and the other decreasing the likelihood of death. Light conditions classified as dark, whether under lighted or unlighted conditions, increased the odds of death 1.4 times. A nondry roadway surface reduced the odds of death by 43%. Otherwise, road geography had little independent effect. Various road junction types were not significantly linked to fatality status. Crashes on curves increased the odds of death 1.2 times, but dropped out as a significant correlate in the full model. Weather conditions had no significant effect on the odds of death in the final reduced model, although when entered with background and behavioral factors only, conditions other than clear weather (e.g., smoke or fog) nearly doubled the odds of death. This effect was not significant when final situational correlates are taken into account.

The final situational block introduces the precollision action of the motorcycle unit, the object of impact, and the surrounding speed limit. Odds ratios are in comparison with “losing control” of the motorcycle. The largest positive effects on the chances of death

TABLE 2—*Distribution of Indiana motorcycle operators surviving and killed during 2003–2008, by background, behavioral, geophysical, and situational correlates.*

	Description	Operators (n = 18,225)*		Prob (Fatal) (%)	χ^2	Sig.
		Nonfatal	Fatal			
Background						
1. Age[†]	Age (mean years)	37.6	39.5	–	–	
2. Gender	Male (ref)[‡]	15,945	573	3.6	16.2	$p < 0.001$
	Female	1600	26	1.6		
3. License status	Valid non-MC license (ref)	9174	320	3.5	2.9	–
	Motorcycle license	6449	236	3.7		
	No license	1083	28	2.6		
Behavioral						
4. Helmet use	No helmet use reported (ref)	12,264	465	3.8	16.7	$p < 0.001$
	Helmet use reported	5360	136	2.5		
5. Alcohol	Not alcohol-related unit (ref)	15,879	408	2.6	301.7	$p < 0.001$
	Alcohol-related unit	1745	193	11.1		
6. Positive drug test	Not tested or negative (ref)	17,449	551	3.2	255.8	$p < 0.001$
	Positive drug test result	175	50	28.6		
7. Pillion passenger	No passenger (ref)	15,024	536	3.6	7.2	$p < 0.01$
	Passenger present	2600	65	2.5		
8. Speeding	Unit not speeding (ref)	15,773	442	2.8	150.7	$p < 0.001$
	Unit speeding	1851	159	8.6		
9. Errant/risky driving	No errant/risky driving	11,307	272	2.4	89.6	$p < 0.001$
	Errant/risky driving	6317	329	5.2		
10. At fault	Operator not at fault	12,083	427	3.5	1.7	–
	Operator at fault	5541	174	3.1		
Geophysical						
11. Road geography	Straight-level (ref)	11,580	326	2.8	46.4	$p < 0.001$
	Straight-hill/grade	2158	85	3.9		
	curve	3618	186	5.1		
	Nonroadway crash	224	3	1.3		
12. Junction type	No junction involved (ref)	10,639	382	3.6	13.3	$p < 0.01$
	Interchange or ramp	395	25	6.3		
	T-, Y-intersection/roundabout	2582	77	3.0		
	Four-way or more intersection	3891	117	3.0		
13. Surface condition	Dry (ref)	16,060	574	3.6	13.7	$p < 0.001$
	Other	1513	26	1.7		
14. Weather	Clear (ref)	14,098	487	3.5	1.1	–
	Cloudy	2813	95	3.4		
	Other conditions	674	18	2.7		
15. Lighting	Daylight (ref)	12,789	363	2.8	69.6	$p < 0.001$
	Dark (not lighted)	1882	126	6.7		
	Dark (lighted)	2075	83	4.0		
	Dawn/dusk	840	29	3.5		
Situational						
16. Rush hours	Nonrush hours (ref)	15,982	557	3.5	2.8	–
	Morning/evening rush hour	1642	44	2.7		
17. Locality	Urban (ref)	9959	257	2.6	45.3	$p < 0.001$
	Rural	7631	344	4.5		
18. Speed limit	Under 35 (ref)	6000	118	2.0	98.9	$p < 0.001$
	35 < 40	2834	79	2.8		
	40 < 45	1874	75	4.0		
	45 < 50	2093	86	4.1		
	50 < 55	679	37	5.4		
	55 < 60	3191	171	5.4		
	Over 60	313	24	7.7		
19. Precollision action	Going straight (ref)	12,602	484	3.8	165.6	$p < 0.001$
	Stop/start/slow/enter/leave lane	1894	28	1.5		
	Turning	1854	19	1.0		
	Pass/merge/change lane	628	29	4.6		
	Left of center/cross median	208	36	17.3		
	Other action	397	5	1.3		
20. Object of impact	Loss of control/no object (ref)	5209	97	1.9	310.7	$p < 0.001$
	Animals	866	14	1.6		
	Other traffic units	172	3	1.7		
	Fixed objects next to road	264	5	1.9		
	Posts, poles, signs	191	30	15.7		
	Tree	135	32	23.7		
	Edge of road infrastructure	1544	48	3.1		
	Bridge, guardrail, median	296	35	11.8		
	Another motor vehicle	8947	337	3.8		

*Excludes missing cases (unknowns) in each correlate category.
[†]Mean ages significantly different, ANOVA, $p < 0.001$.
[‡]ref, reference category in logistic regression model.

TABLE 3—*Correlates of death by motorcycle, reduced form model.*

Correlates (*n* = 17,346 Motorcycle Operators, Where All Correlates Are Known)	B	SE	95% Confidence Interval, Exp(B)† Lower	Exp(B)	Upper
Background					
Age	0.015	0.003	1.01	1.02***	1.02
Female operator	−0.459	−0.212	0.42	0.63*	0.96
Behavioral					
Helmet used	−0.239	0.108	0.64	0.79*	0.97
Alcohol-related unit	1.229	0.116	2.72	3.42***	4.29
Positive drug test	1.451	0.205	2.85	4.27***	6.39
Passenger present	−0.423	0.141	0.50	0.66**	0.86
Speeding	0.932	0.118	2.01	2.54***	3.20
Operator at fault	0.689	0.160	1.46	1.99***	2.72
Errant/risky driving	0.828	0.140	1.74	2.29***	3.01
Geophysical					
Lighting (daylight = 0)					
Dark	0.379	0.128	1.14	1.46**	1.88
Dark (lighted)	0.276	0.141	1.00	1.32*	1.74
Nondry surface	−0.556	0.215	0.38	0.57**	0.87
Situational					
Speed limit (<35 = 0)					
35 < 40	0.343	0.153	1.05	1.41*	1.90
40 < 45	0.743	0.157	1.54	2.10***	2.86
45 < 50	0.782	0.153	1.62	2.19***	2.95
50 < 55	1.079	0.209	1.95	2.94***	4.43
55 < 60	1.142	0.134	2.41	3.13***	4.08
60+	1.716	0.255	3.38	5.56***	9.17
Precollision (going straight = 0)					
Stop/start/slow/enter/leave lane	−0.966	0.209	0.25	0.38***	0.57
Turning	−1.158	0.246	0.19	0.31***	0.51
Cross-median/left of center	1.065	0.208	1.93	2.90***	4.36
Object of impact (lose control = 0)					
Posts, poles, signs	1.747	0.253	3.49	5.73***	9.42
Tree	2.422	0.254	6.84	11.26***	18.55
Bridge, guardrail, median	1.452	0.230	2.72	4.27***	6.70
Another motor vehicle	1.216	0.141	2.56	3.37***	4.45

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.
†Exp(B), odds ratios (OR). Only significant correlate coefficients shown. Constant is not shown.
Model chi-square (32 df) = 867.9, $p < 0.001$.
−2 LL at zero = 5095, −2 LL at termination = 4255.

were linked to four objects: trees (OR = 11.2), posts/signs/poles (5.7), bridge/guardrail/median (4.3), and other motor vehicles (3.4). In comparison with speeds under 35 mph, each faster speed limit increases the odds of death—crashes in 60+ mph zones are 5.6 times more likely to kill a motorcyclist.

A limited set of factors reduced the likelihood of being killed. If a collision occurs, the odds of a fatal outcome are reduced if the motorcycle operator was woman. Wet roads tend to reduce the odds of death, but this is an artifact of speed, because motorcyclists are likely to slow down on a wet road. Further, two other precollision actions that imply slow speeds (stopping or starting, turning) also reduce the odds of being killed: turning or being engaged in a lower-speed driving behavior lowered the odds of death by more than 43%. Carrying a passenger dampened the odds of death (OR = 0.86). Motorcyclists who collided with pedestrians, bicyclists, animal-drawn vehicles, animals, and other objects adjacent to the road did not have death rates significantly different from losing control.

Discussion

Forensic Aspects of Death by Motorcycle

Being killed on a motorcycle is an unnatural death, caused by accidental unintentional injury. This analysis set out to identify the correlates of death by motorcycle, to better understand motorcycle crashes as a cause of death. It compared the impacts of background and individual characteristics of the motorcycle operator, latent behavioral choices of the operator in the context of the fatal ride, geophysical conditions at the collision site, and the situational context of the final collision transaction on death of the motorcyclist. How did those elements contribute to the cause of death? What do the correlates say about the mechanisms of injury and death in motorcycle accidents?

Objects of impact are the underlying mechanisms of injury in death by motorcycle—they are, in effect, the weapons of accidental blunt force trauma that create the injuries that lead to the immediate cause of death. Trees had the largest positive effect among all objects on the odds that a colliding motorcyclist would be killed (OR = 11.3). Other engineered systems and subassemblies that are part of the road infrastructure were also lethal—bridge components, guardrail ends and faces, and median infrastructure generated large odds ratios (= 4.3). Like trees, these are deeply embedded objects able to resist very high levels of force before exceeding their elastic limit. The physics of collisions help explain why objects of impact are a major correlate of death by motorcycle, and why lethality varies among objects. Riders and their motorcycles comprise a total force (mass times speed) that collides with the road surface or another object on or embedded in the proximate road environment. Rooted objects with higher elastic limits (e.g., trees, bridge abutments) have more capacity to resist the opposing force of a motorcycle and rider. Many roadside objects are anchored (e.g., a tree, phone pole, light post, mail box) and more capable of transferring force back to the motorcyclist. The returning force creates injuries to motorcyclists.

In conjunction with the object of impact, higher-speed collisions substantially increase the risk of death. Operating within higher-speed environments or engaging in speeding (OR = 2.5) presents higher lethal danger to motorcyclists. High-speed impacts create the traumatic effects of abrupt deceleration ("velocity change in a crash" or delta-v; [35]). Combining speed with the motorcyclist's mass creates the force that imparts fatal injuries to the motorcyclist. Faster speeds combined with fixed environmental objects or infrastructure mean higher likelihoods of death (i.e., if the inertial mass and elasticity of fixed embedded objects exceed the force of the motorcycle and rider, more damage is instilled in the colliding motorcyclist than the object; [34]). Injury patterns in fatal high-speed crashes are likely to be the most traumatic, especially from collisions with strongly rooted objects.

Age increased the chances of death. The effects of age among the correlates of death by motorcycle are likely related to (i) less physical resiliency on the part of older riders to patterns of injury generated in motorcycle crashes and (ii) the slower reaction time and reduced sensory and perceptual ability of older riders to avoid lethal crashes (28,31). Given the same pattern of injuries, the logistic model suggested the odds of death for the 60-year-old would increase in comparison with a 25-year-old, although this increased likelihood would fluctuate under different situational, geophysical, and behavioral combinations surrounding the motorcycle accident. But controlling for all other correlates, older riders were more likely to die than younger riders.

Risky behaviors contribute a great deal to motorcyclists being killed. When motorcycle operators were linked to drugs or alcohol, their death rates were worse than those of nonalcohol or nondrug motorcyclists. This is consistent with earlier observations about the role of alcohol in motorcycle collisions (4,16,24,33,34), although fewer studies of motorcycle injury pattern have controlled for drugs. The presence of drugs contributed significantly to serious injury in the Indiana data (OR = 4.3). Both alcohol and drugs involve risky behaviors that increased the odds of death. Related to this, lighting as a major correlate of death is at least partly an artifact of risky behavior—in short, darkness masks risky behavior. Individuals are able to engage in dangerous or risky behaviors with less risk of detection or enforcement during periods of darkness. People are more likely to drink at night, and alcohol reduces motorcyclist performance and response time. In addition, sight distance is shortened at night. Operators are likely to speed more frequently in areas where they cannot be seen clearly or easily apprehended—that is, in areas with few guardians capable of deterring the operator from engaging in risky actions.

Public Policy and Preventive Aspects

Earlier forensic research on motorcycle fatalities suggested that many injury patterns produced in fatal collisions are so serious that faster emergency response or better emergency room care are unlikely to prevent many fatalities. Researchers noted that "the greatest potential to reduce the death rate lies with accident prevention/injury reduction measures, rather than through improved treatment of injuries" (9, p. 127). They conclude that more and better preventive strategies or focused interventions should have a higher likelihood of reducing the number of motorcyclists killed. In line with this thinking, several preventive implications can be pulled from the Indiana data.

Public policy implications of the object of impact analysis include more careful consideration of (i) locations chosen for signage and other roadside objects and (ii) choices for the type, density, and elastic limits of roadside architecture put in place in areas with more operating motorcyclists. This could be called a *target softening* initiative that creates roadside arrangements less harmful to motorcyclists or other motor vehicle occupants. A key to this is knowing *where* there are more motorcycle collisions producing serious injuries or death. If there are spatial clusters of motorcycle death or serious injury, preventive programs could be put in place in the midst of the hot spots. Placement of roadside objects is likely to involve decisions of public traffic engineers and local construction managers, which should be informed by good location information. Knowing where motorcyclists are more likely to die from colliding with another object provides information to traffic engineers about where to soften roadside objects of impact in the appropriate areas. Installing sign posts made of wood (lower elastic limit) instead of steel or concrete (higher elastic limits) could reduce future injuries and fatalities.

A target softening program to reduce death by motorcycle would require a geographical underpinning in at least two ways. One concerns the places where certain types of behavior are likely to occur. Roads that permit higher speeds (and even higher speeds if speeding is involved) are likelier venues for accidents that lead to death. Road types that host higher speeds will include interstates, ramps, or other roads with higher posted speed limits. Second, areas (e.g., counties) within the state that have curvier roads and wider changes in elevation might exhibit a lower tolerance for motorcycles operated at higher speeds. This could also mean, more broadly, areas where more motorcyclists are likely to be riding—more scenic areas capable of distracting a rider with nice vistas. Thus, one step toward better prevention and intervention programs is to use collision and injury data to pinpoint target populations within the state, and to focus safety resources there.

Helmet use drives down the odds of death. Most motorcycle accident research suggests helmet laws have reduced the incidence of death by motorcycle, and new helmet laws would likely do the same. While that is true, this analysis shows that other situational aspects of motorcycle collisions (i.e., other correlates of death) can sometimes reduce or eliminate the benefits of helmet usage. The Indiana data suggest helmets reduce the risk of death, although there are circumstances under which helmets will make no difference in the fatal outcome. Massive thoracic trauma can render any prophylactic benefits of helmets ineffective.

The fatal injury patterns identified in Indiana police reports nonetheless suggested the importance of helmets, and one policy response to the continuing trend of increasing motorcycle deaths could be reinstitution of helmet laws. However, mandatory helmet laws are a controversial set of issues few state legislators want to address. Posed as an alternative to mandatory helmet laws, a quick and comparatively cheap program to address motorcycle safety could be a free helmet initiative. In a variety of ways, use of a helmet should reduce a person's chances of serious injury or death, so any free helmet used by a recipient should at least lower that person's likelihood of being killed, and from a purely risk analytic perspective a free helmet program might be justified. Of course, all recipients might not use the free helmets every time they ride, and other qualifiers, such as nonuse, would reduce the effectiveness of a free helmet program. Further, when motorcycle operators engage in other forms of risky behavior, such as speeding or impaired driving, the benefits of a helmet might be muted. It would take more careful cost–benefit analysis to figure whether such a program would prevent injury and improve safety.

Alcohol and drugs are major correlates of death by motorcycle and can be considered from different perspectives. From a forensic perspective, assessing the role of alcohol in motorcycle crashes falls to drug and alcohol testing by forensic laboratories, and the interpretation of those toxicological results. This creates a demand on the toxicology units of state and local forensic laboratories. It is not clear how frequently toxicology results are ultimately used by the courts, but there is clearly a high demand for toxicological examinations by local forensic service agencies. Large backlogs in testing and reporting can emerge.

From a preventive perspective, there are programs that could mitigate drug and alcohol's role in fatal motorcycle accidents. Sobriety checkpoints at appropriate times and days are one common response. Beyond that, another law enforcement approach could use the correlates of death by motorcycle to identify empirically valid behavioral or place-related profiles of motorcyclists based on the time of day, day of week, and personal and behavioral characteristics linked to fatal accidents. Police report data in specific localities and regions can be used to create a picture of the various motorcyclist background and behavioral characteristics present, the places where these behavioral choices are most likely, and the general times and places where these combinations occur. If it is dark, there is higher likelihood of fatal injury, and individuals who died in motorcycle collisions were more likely to be alcohol or drug involved, engaging in risky driving behaviors, and not wearing helmets. So, based on a profile of fatal motorcycle operators as 21- to 44-year-old men, and more likely to get killed on a Friday, Saturday, and Sunday during hours of darkness, police could have a statistical version of reasonable suspicion that motorcyclists matching that profile will also be linked to a higher likelihood of alcohol or drugs or other risky behaviors. From a law enforcement perspective, using such a profile to justify a 2 AM Sunday traffic stop of a motorcyclist would likely fall short of real probable cause. On the other hand, if the individual was found to be impaired, a defensible argument could be made that by detaining or arresting the motorcyclist, and thereby stopping a potentially "morbid chain of events" from developing down the road, the police have saved lives.

Considering other preventive approaches, pursuing more stringent motorcycle operator licensing may not reduce fatal accidents, given that license status was not a significant correlate of death in the reduced model of Indiana fatalities. However, some licensing strategies might target problem groups. As noted earlier, older motorcyclists are more likely to die in crashes. State licensing authorities could institute more frequent written and skills tests to renew motorcycle endorsements, in the hopes that such tests might reveal deteriorating response and control capabilities by older riders.

Finally, by identifying the major correlates of death in motorcycle collisions, this analysis could help inform motorcycle rider licensing, training, and educational programs. In collisions, motorcycle operators are often faced with choices about actions to take, objects to avoid, and alternative motorcycle maneuvers to avoid colliding with other vehicles and objects in the riding environment. Crashes can occur quickly, across a span of seconds, with the time period established by how far ahead an individual motorcycle operator might be scanning, so that potential preventive maneuvers might be attempted; this in turn depends on the overall situational context of the crash—speed, the condition of vehicle operators, single or multiple vehicle collisions, particular location characteristics, circumstances, visibility, and other factors. Given the variety of situational and behavioral factors interacting to produce motorcycle crashes, it is reasonable to envision that for some motorcycle collisions, there is the moment during which a motorcyclist might have a choice of crashing into a moving vehicle, jumping off the motorcycle, laying the motorcycle down and sliding, crashing into a bush or tree, swerving, or alternatively driving off the road, heading for an open ditch, or colliding with a mailbox. Which of these evasive strategies should be pursued to reduce the incidence of death? The logistic analysis suggested a motorcyclist might crash into a passenger car and come away with less damage than is sustained in a fixed object collision. From an injury prevention perspective, it might make more sense for a motorcyclist—if given the chance to exercise choice and execute an appropriate action—to lose control of the motorcycle or do as much as possible to avoid striking any objects.

Although generally underused in the forensic literature, police report data, such as those examined in this analysis, can provide more detailed forensic profiles of the chain of morbid events leading to death by motorcycle. As used here, police data provide a broader perspective and additional insights into the cause of death in motorcycle accidents. Future research should focus more frequently on the connection between hospital and trauma information and police reporting on death by motorcycle.

Acknowledgments

Special appreciation is directed to Kenna Quinet, Matt Nagle, Bill Newby, and the anonymous reviewers for their insights and suggestions.

References

1. Fatality Analysis Reporting System (FARS). Vehicles involved in fatal crashes, 1994-2008—state: USA, FARS Encyclopedia, National Highway Transportation Safety Administration, http://www-fars.nhtsa.dot.gov/Trends/TrendsGeneral.aspx (accessed September 14, 2009).
2. Persons killed, by state and person type—state: USA, year, FARS Encyclopedia, National Highway Transportation Safety Administration, http://www-fars.nhtsa.dot.gov/States/StatesCrashesAndAllVictims.aspx (accessed September 14, 2009).
3. Larsen CF, Hardt-Madsen M. Fatal motorcycle accidents in the county of Funen (Denmark). Forensic Sci Int 1988;38(1–2):93–9.
4. Shibata A, Fukuda K. Risk factors of fatality in motor vehicle traffic accidents. Accid Anal Prev 1994;26(3):391–7.
5. Andrew TA. A six-month review of motorcycle accidents. Injury 1979;10(4):317–20.
6. Whittington RM. Motorcycle fatalities: analysis of Birmingham Coroner's records. Injury 1981;12(4):267–73.
7. Ankarath S, Giannoudis PV, Barlow I, Bellanmy MC, Matthews SJ, Smith RM. Injury patterns associated with mortality following motorcycle crashes. Injury 2002;33(6):473–7.
8. Coben JH, Steiner CA, Owens P. Motorcycle-related hospitalizations in the United States, 2001. Am J Prev Med 2004;27(5):355–62.
9. Wyatt JP, O'Donnell J, Beard D, Busuttil A. Injury analyses of fatal motorcycle collisions in south-east Scotland. Forensic Sci Int 1999; 104(2–3):127–32.
10. Toro K, Hubay M, Sotonyi P, Keller E. Fatal traffic injuries among pedestrians, bicyclists and motor vehicle occupants. Forensic Sci Int 2005;151(2–3):151–6.
11. Lemieux CE, Fernandes JR, Rao C. Motor vehicle collisions and their demographics: a 5-year retrospective study of the Hamilton-Wentworth Niagara Region. J Forensic Sci 2008;53(3):709–15.
12. Ndiaye A, Chambost M, Chiron M. The fatal injuries of car drivers. Forensic Sci Int 2009;184(1–3):21–7.
13. Agran PF, Castillo DN, Winn DG. Limitations of data compiled from police reports on pediatric pedestrian and bicycle motor vehicle events. Accid Anal Prev 1990;22(4):361–70.
14. Chesham KJ, Rutter DR, Quine L. Motorcycling safety research: a review of the social and behavioural literature. Soc Sci Med 1993; 37(3):419–29.
15. Lin MR, Kraus JF. Methodological issues in motorcycle injury epidemiology. Accid Anal Prev 2008;40(5):1653–60.

16. Lin MR, Kraus JF. A review of risk factors and patterns of motorcycle injuries. Accid Anal Prev 2009;41(4):710–22.
17. Kraus JF, Franti CE, Johnson SL. Trends in deaths due to motorcycle crashes and risk factors in injury collisions. Accid Anal Prev 1976; 8:247–55.
18. Peek-Asa C, Kraus JF. Injuries sustained by motorcycle riders in the approaching turn crash configuration. Accid Anal Prev 1996;28(5):561–9.
19. Mullin B, Jackson R, Langley J, Norton R. Increasing age and experience: are both protective against motorcycle injury? A case-control study. Inj Prev 2000;6:32–5.
20. Lardelli-Claret P, Jimenez-Moleon JJ, de Dios Luna-del-Castillo J, Garcia-Martin M, Bueno-Cavanillas A, Galvez-Vargas R. Driver dependent factors and the risk of causing a collision for two wheeled motor vehicles. Inj Prev 2005;11:225–31.
21. Magazzu D, Comelli M, Marinoni A. Are car drivers holding a motorcycle licence less responsible for motorcycle-car crash occurrence? A non-parametric approach. Accid Anal Prev 2006;38:365–70.
22. Pai CW, Saleh W. Modelling motorcyclist injury severity by various crash types at T-junctions in the UK. Saf Sci 2008;46(8):1234–47.
23. Haque MM, Chin HC, Huang H. Modeling fault among motorcyclists involved in crashes. Accid Anal Prev 2009;41(2):327–35.
24. Shankar V, Mannering F. An exploratory multinomial logit analysis of single-vehicle motorcycle accident severity. J Safety Res 1996; 27(3):183–94.
25. Quddus MA, Noland RB, Chin HC. An analysis of motorcycle injury and vehicle damage severity using ordered probit models. J Safety Res 2002;33:445–62.
26. Lin MR, Chang SH, Huang W, Hwang HF, Pai L. Factors associated with severity of motorcycle injuries among young adult riders. Ann Emerg Med 2003;41(6):783–91.
27. Holdridge JM, Shankar VN, Ulfarsson GF. The crash severity impacts of fixed roadside objects. J Safety Res 2005;36:139–47.
28. Savolainen P, Mannering F. Probabilistic models of motorcyclists' injury severities in single- and multi-vehicle crashes. Accid Anal Prev 2007; 39(5):955–63.
29. Li MD, Doong JL, Huang WS, Lai CH, Jeng MC. Survival hazards of road environment factors between motor-vehicles and motorcycles. Accid Anal Prev 2009;41(5):938–47.
30. Centers for Disease Control and Prevention, National Center for Health Statistics. Compressed Mortality File, 1999–2006. CDC WONDER Online Database. Compressed Mortality File 1999–2006 Series 20 No. 2L, 2009, http://wonder.cdc.gov/cmf-icd10.html (accessed October 19, 2009).
31. Mannering FL, Grodsky LL. Statistical analysis of motorcyclists' perceived accident risk. Accid Anal Prev 1995;27(1):21–31.
32. Lin MR, Huang W, Hwang HF, Wu HDI, Yen LL. The effect of crash experience on changes in risk taking among urban and rural young people. Accid Anal Prev 2004;36(2):213–22.
33. Williams M, Hoffman ER. Alcohol use and motorcycle accidents. Accid Anal Prev 1979;11:199–207.
34. Evans L. Traffic safety. Bloomfield Hills, MI: Science Serving Society, 2004.
35. Joksch HC. Velocity change and fatality risk in a crash—a rule of thumb. Accid Anal Prev 1993;25(1):103–4.

Additional information and reprint requests:
Samuel Nunn, Ph.D.
Center for Criminal Justice Research
Indiana University Public Policy Institute
334 North Senate Avenue, Suite 300
Indianapolis, IN 46204
E-mail: snunn@iupui.edu