

Factors that Increase and Decrease Motorcyclist Crash Risk

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ABSTRACT

Many approaches have been used to understand issues facing riders, and particularly the factors that lead to crashes. One approach has been to visit the site of motorcycle crashes and collect evidence to understand causes. Simulators have been used to explore various capabilities of riders. Similarly, measurements have been made in controlled experiments. This paper will report on a naturalistic study which was deployed by the Motorcycle Safety Foundation (MSF) to investigate safe riding and crashes in natural riding. Over 366,000 mi (589,019 km) of riding were collected by 100 participants on their personal motorcycles. Large differences were observed between riders in areas such as riding frequency, where people ride, and how they ride. The paper identifies factors that increased and decreased risk for riders based on observed crashes and near-crashes.

INTRODUCTION

In their latest analysis of motorcycle crash statistics, the National Highway Traffic Safety Administration (NHTSA) reports that, although there were fewer motorcyclists killed in 2014 compared to 2013, there was a 5% increase in the number of injuries during that period (NHTSA, 2016). Factors such as protective equipment may contribute to the reduction in deaths, but more detailed research is necessary to investigate factors that might be related to an upward trend in motorcyclist injury. The injury rate (per 100 million vehicle miles traveled) increased from 434 (in 2013) to 459 (in 2014). Various agencies continue to emphasize the need for investigation into crash causation and related elements, including roadway, vehicle, drivers, riders, and rider-related factors (NHTSA 2006a, NHTSA 2006b).

A multitude of studies have attempted to describe events leading up to a crash, as well as rider inputs during the crash, using post-crash investigation methods. Although these studies are informative, observance of crash events via video and kinematic data collected during the actual riding event via naturalistic vehicle studies can reveal conditions that will otherwise remain unknown or misinterpreted. In one of the most widely known motorcycle studies, the authors report that riders tended to exhibit no evasive action to avoid the accident, and in fact rider statements about their evasive actions were usually not reflective of actual actions as indicated by physical evidence and witness accounts of the accident scene (Hurt, Ouellet, and Thom, 1981). This finding is just one indication that reliance on rider reporting, eyewitness accounting, and/or accident reconstruction is likely to lead to conflicting information about a crash. Another advantage of naturalistic vehicle studies is the addition of near-crash data which, as discussed in Guo, Klauer, Hankey, and Dingus (2010), provides a reliable surrogate measure of crash data. This near-crash database not only supplements the crash database (providing a larger sample for testing), but also offers real details about rider evasion of crashes and events leading up to dangerous situations.

The Motorcycle Safety Foundation (MSF) sponsored the first large-scale naturalistic motorcycle study (MSF 100 Motorcyclists Naturalistic Study), which was conducted by the Virginia Tech Transportation Institute (VTTI). Video and kinematic data were collected from 100 riders during their ordinary routine over a period of 2 months to 2 years per rider. This paper describes the crash and near-crash events discovered in the resulting database, and provides risk estimates (whether the risk of being involved in a crash or near-crash given exposure to a factor of interest is increased or decreased) based on collected variables that describe the riding environment and specific situational elements. The scope of this analysis will be risk to the overall sample population, not considering rider-specific demographics such as age, gender, motorcycle type, etc. These more specific considerations may affect risk estimates, and warrant future evaluation.

METHODS

Recruiting and Motorcycle Instrumentation

One hundred motorcycle riders, recruited from Arizona, California, Florida, and Virginia, participated in the study. Recruitment locations represent varied riding conditions, and rider recruitment also focuses on ensuring a variety of motorcycle types. Seven motorcycle models (each categorized as touring, cruising, or sport) were chosen from a variety of manufacturers, and participant motorcycles were required to be within this set in order to allow unobtrusive and effective instrumentation. The data acquisition system (DAS) was installed to collect video and kinematic data, including five video views (allowing a panorama of the rider and surrounding conditions), GPS data, internal readings such as acceleration and gyro, and strain gauge feedback from brake levers. Technicians installed instrumentation such that no permanent damage or change to the motorcycle would result upon de-installation.

Emphasis was also placed on recruiting from a broad range of rider demographics. Before participating in the study, riders completed several questionnaires to capture data such as demographic descriptors, riding history, training experience, and risk adversity. Riders also completed a basic balance and coordination exercise, a Snellen visual acuity test, and grip strength assessment. All elements of study participation were reviewed and accepted by the Virginia Tech Institutional Review Board (IRB) to ensure protection of participants.

Upon instrumentation and survey completion, riders were released with instructions to ride in their normal manner. Remote diagnostic capability allowed continuous health checks of the installed system, as well as monitoring of hard drive capacity. When a rider's hard drive was sufficiently full, a technician retrieved the drive and replaced it with a new drive. All retrieved data (encrypted during collection on the motorcycle to prevent participant identification) were uploaded at VTTI.

Overall Rider Demographics

The final participant group consisted of 78 male and 22 female participants, ranging in age from 21 years to 79 years. Participant motorcycle types included cruising (41), touring (38), and sport (21). Table 1 includes the final study design for the 100 riders.

Table 1. MSF 100 Study Design

		Motorcycle Type		
Age Group	Gender	CRUISER	SPORT	TOURING
21-30	F	3	3	0
	M	10	4	1
31-40	F	2	2	0
	M	3	6	1
41-50	F	7	1	0
	M	3	4	8
51-60	F	2	1	1
	M	7	0	13
61-70	M	3	0	12
71-80	M	1	0	2
		41	21	38

The number of participants living in each location was as follows: California (47), Virginia (30), Florida (17), and Arizona (6). Out of 100 riders surveyed, 65% of all of the participants reported taking and passing at least one rider course (16% took two or more courses, while only 8% took three or more courses). Within the survey, the participants also reported how many months in their lifetime they had ridden motorcycles, which ranged from 1 to 684 months with an average of 203 months, or 17 years (SD=198 months). For the twelve months prior to study participation, the average estimated mileage indicated by the participants was 7,794 miles with a range from 40 to 40,000 miles (SD=7,607 miles).

Participants were recruited with the intention of being involved for one year or longer. Final participant involvement ranged from two months to two years, but the average enrollment was one year (SD=4.3 months). Reasons for abbreviated participation included relocation and selling the motorcycle of interest. Approximately 30,844 trips were recorded (a trip beginning when the motorcycle was started and ending when it was turned off). These trips represent around 9,354 hours of riding. If equipment installation days are summed across all participants, the total is 100.6 years of instrumented motorcycle time, with total mileage recorded of approximately 366,667 miles.

Data Dictionary Development

A concise, tested dictionary of descriptive terms is necessary to provide a thorough, consistent description of recorded crashes and near-crashes (CNCs). These terms must be equally applicable to the description of baseline events, which contain no observed CNCs and are used as comparison points to

calculate the relative CNC risk under various conditions. The video reduction dictionary developed for automobile, truck, and motorcycle incident analyses at VTTI (including the 100-Car and SHRP2 naturalistic studies) is currently composed of 95 variables to describe CNCs and baselines, and was based on input from the General Estimates System Coding and Editing Manual (NHTSA, 2003). A preliminary analysis of the MSF 100 Motorcyclists Naturalistic Study utilized a subset of these variables to get an initial sense of the events (Williams, McLaughlin, Williams, and Buche, 2015).

The follow-up study described here includes utilization of the remainder of the 95 variables to fully describe CNCs for motorcycles. Following the initial video reduction of the MSF CNCs, the entire dictionary was reassessed collectively by VTTI researchers in the light vehicle, truck and bus, and motorcycle groups. The goal was to consolidate CNC reduction variables as much as possible for use in all of these types of research, and to provide a video reduction dictionary that contained all variables and descriptors necessary for a complete analysis of any CNC for any type of vehicle. However, due to the unique nature of motorcycle-related events and factors affecting these types of occurrences which are not so pertinent to other type of transportation research (such as the inherent instability of the vehicle), special consideration of variables and extended, detailed conversation was necessary. This extended review of motorcycle-related research, including consideration of collected naturalistic data, resulted in the addition of motorcycle-specific variables throughout the dictionary. Further discussion and iteration of dictionary variables occurred during data mining and video review (discussed in subsequent sections), with the goal of accurately incorporating all foreseeable motorcycle-related conditions into data reduction options.

Data Mining Methodology

Crash and Near-Crash Events

Some CNCs were discovered through rider self-reports, but most were discovered through the application of data mining algorithms. These algorithms involved data mining, in which kinematic data such as lateral and longitudinal acceleration were passed through filters in order to discover points at which previously-defined conditions exist. These conditions were developed to indicate extreme situations where a potential near-crash or crash (as defined in the video reduction data dictionary) exists. The process of finding and verifying candidate events (whether they are actually events of interest, based on video review) was iterative. Improvements to the algorithms were made based on the success rate of finding actual CNCs. Various algorithms were used, including ones based on a low-speed drop (capsize), hard deceleration (normalized on a per-rider basis), and high speed into curve entry. The total number of candidate events in the dataset reviewed to find CNCs was over 10,000. All of these potential CNC scenarios were reviewed via video and data reduction by the VTTI Data Reduction Group. This group has over 15 years of experience with video reduction on large-scale naturalistic driving data, including rigorous quality control protocols, and video analysts selected for this study also had riding experience. Once candidate events were verified as potential CNC events, they were then passed along for full video reduction, using the 95 dictionary variables to provide a comprehensive description of the event, the rider, and the environmental factors.

Baselines

In order to perform Odds Ratio analyses (probability of event occurrence compared to event non-occurrence, specifically applied to Crash/Near-Crash events), researchers must collect and analyze epochs of riding containing no events (baseline epochs). The method of collecting baseline epochs for the MSF study were similar to methods used during other naturalistic studies at VTTI, with specific considerations for the unique situations inherent in motorcycle riding. Decisions affecting baseline selection include the total number of baselines per rider, length (time period) of the baseline, and conditions which are not allowed in baseline epochs (not representative of “normal” riding, when events of interest would occur).

Baseline selection criteria were based on a case-control design in which the selected baseline cases are equivalent to the controls in case-control design. Thus, the distribution of exposure was the same between cases (crashes and near-crashes) and controls (no event), stemming from the same source populations. The number of baselines per rider was calculated as a percentage of total mileage during the entire study. Specifically, mileage amassed during trips in which the maximum speed was greater than 5 mph was calculated for each rider, and each rider’s percentage of the total mileage summed across all participants was used as his/her percentage of the total number of baselines. Based on time constraints and reduction requirements along with previous study results, an average of 70 baselines per rider (7,000 total baselines) was chosen as the minimum goal. A minimum of 5 baselines per rider was also required, so if the mileage-based percentage of 7,000 baselines was less than 5, the number was elevated to 5 in the final selection process. The length of the baseline epoch to be analyzed for the current study was chosen to be 6 seconds, based on the event reduction protocol used by VTTI data reduction. Analysts perform complete video review of a 6-second epoch during analysis of events (crashes and near-crashes), so corresponding 6-second baseline (non-event) epochs will also be analyzed for comparison to event analyses. Because baselines were required to represent exposure similar to event cases, situations in which events were not analyzed were removed from potential baseline data. Occurrences that were not allowed to be part of baseline epochs include the following:

- Low/no-speed data occurring before the motorcycle first reaches 1 mph during a trip (low speed data during the remainder of a trip were retained since crashes and near-crashes were known to occur during such conditions)
- Periods during which the motorcycle is on the kickstand
- Periods during which face or forward video is unavailable (video analysis is not possible)
- Instances in which the participant is not the rider
- Instances in which the rider is not on the motorcycle
- Instances of riding on a closed track (not typical of street riding)

After the previous requirements were defined, the baseline epochs were randomly chosen from qualifying files. There were 7,028 baselines randomly selected based on the requirements. The number of baselines per rider ranged from 5 to 373. Figure 1 illustrates the distribution of the final number of baselines per rider.

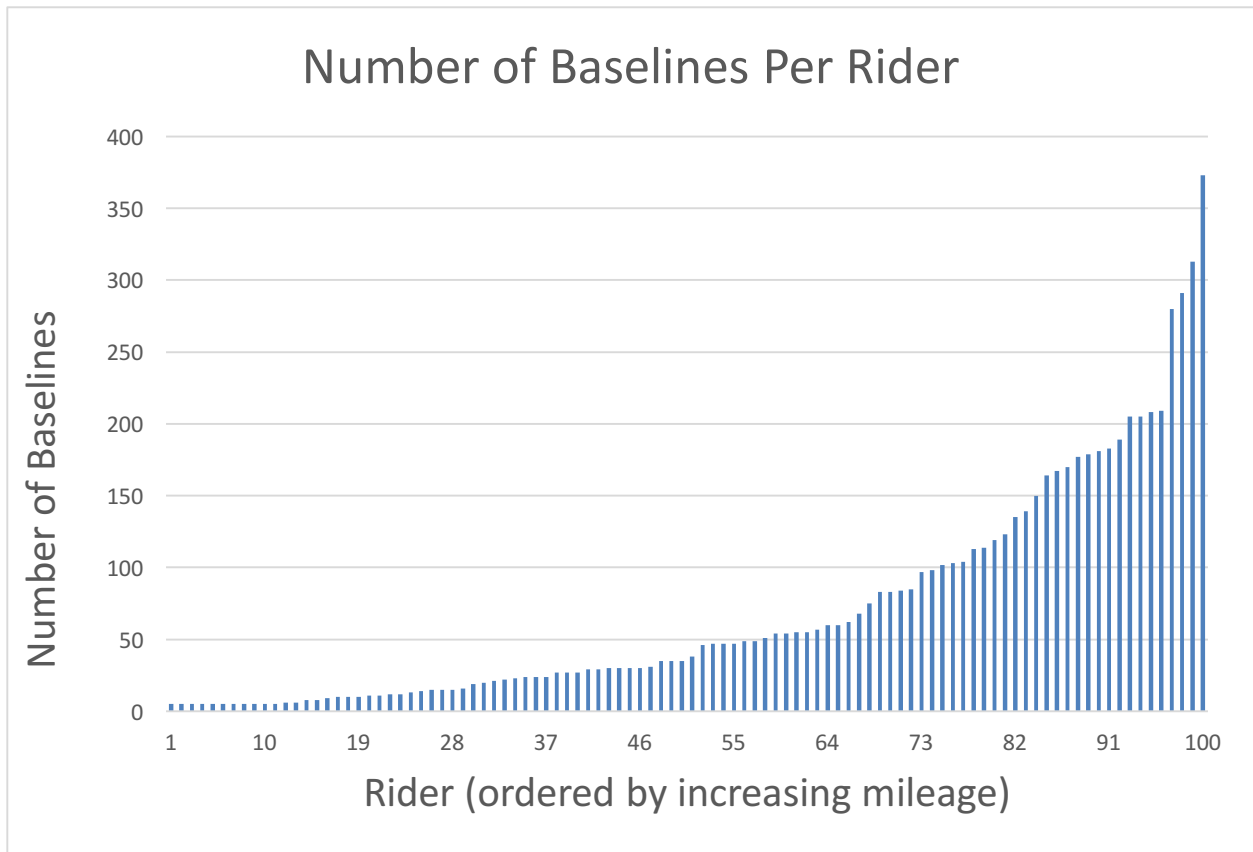


Figure 1. Number of baselines per rider

The baseline epochs were sent to the Data Reduction Group in randomized order for analysis. Randomly-selected baseline replacement epochs (partitioned by participant) were also sent to the reduction group in case a violation of any of the baseline requirements (such as “not the participant riding”) were recognized during video analysis. Replacement baseline epochs were selected in the same manner as the original baselines. Analysts reviewed each valid baseline epoch using a subset of the same variables used during CNC event video reduction (some dictionary variables are directly related to a crash or near-crash, and thus are not applicable to baselines). These baseline variables included the following:

- Riding Maneuver (going straight, negotiating a curve, turning)
- Riding Behavior(s) (e.g., exceeding speed limit, stop sign violation, illegal passing, failed to signal)
- Group Riding
- Passengers
- Environmental (Lighting, Weather)

- Roadway (Condition, Type, Lane Position, Traffic Density, Traffic Control, Junction, Alignment, Grade, Locality)

Video Reduction Methodology

The video reduction method utilized a VTTI video viewing tool which allows the analyst to view the five trip videos simultaneously (rider's face, forward roadway, rider's left side, rider's right side, and rear roadway) and synchronized time series motorcycle sensor data. As the analyst views the event, they enter applicable categories of all 95 dictionary variables into a computerized database for each crash or near-crash event. Analysts may pause, repeat, or go to any point in the epoch at any time, allowing review of all data associated with the event, and may also modify variable entries if necessary. In addition, an extensive quality control protocol ensures that variables are checked by supervisors for high data reliability. Lastly, the VTTI Motorcycle Research Group reviewed every CNC event along with the corresponding 95-variable reduction, and held discussions and event evaluations with the Data Reduction Group to provide the final level of quality assurance. A related method of quality control was conducted prior to the final review, to ensure that reduced event videos (and baseline videos) were indeed those of the consented rider. Although participants were instructed to notify the research team if someone else rode their motorcycle, as an extra check a statistically-based sampling protocol was used to view videos to verify the consented rider.

Risk Factor Analysis Methodology

To determine what factors are related to increases in crash/near-crash risk for motorcyclists, statistical testing that incorporates exposure and outcomes is employed. The general question to be answered is: are the odds of being involved in a crash or near-crash given exposure to a factor (such as a particular roadway or environmental condition) higher or lower than the odds when not exposed to this factor? Knowledge of the number of CNC cases under that condition (and not) and the number of baseline cases under that condition (and not) will answer this question.

As detailed earlier, epochs of CNC cases as well as epochs of baseline cases (stratified by participant mileage) were extracted from the study population and analyzed via video review. This review resulted in a description of each type of event (CNC and baseline) using the same identically-defined variables, and the same epoch length. From there, since this results in what is statistically termed a case-cohort study design, a probability-based statistical tool (odds ratios) may be utilized to calculate the risk increase or decrease in CNC risk for the factors investigated during video review. As detailed by Guo and Hankey (2009), an odds ratio method (when used with properly sampled baseline epochs) is an appropriate approximation to use in the risk analysis of naturalistic crash and near-crash data.

A mixed logistic regression model was used to produce odds ratio estimates to determine which relevant variables increase the risk of crash and near-crashes in motorcycles. Because the independent variables in this model are categorical with multiple levels, the model works by choosing one level as the reference category, and creating individual variables for each of the other levels. For example, with the

Surface Condition variable, the reference level was chosen as “Dry.” The model then creates a variable for each of the remaining categories that were observed in video epochs, which are “Wet” and “Icy.” The logistic regression model then tests whether the odds of a crash/near-crash are significantly different when riding on a wet or icy road surface compared to riding on a dry roadway.

In the Surface Condition case, if the odds ratio estimate is equal to 1, then the risk of a CNC under the tested variable level (wet surface, for example) is the same as that at the reference variable level (dry surface). If the odds ratio estimate is greater than 1, the risk of CNC under the tested level (wet) is that many times more than the risk at the reference level. For example, if the odds ratio estimate is 3, then the CNC risk when riding on wet roads is three times that of riding on dry roads. When the odds ratio is less than 1, the CNC risk is less for the tested level than that for the reference (there is actually a protective effect of the tested variable). So if the odds ratios estimate is 0.5, the CNC risk while riding on wet roads is half that of riding on dry roads. The model also provides a confidence interval (lower and upper limits) for the odds ratio estimate, which is the interval within which the odds ratio estimate will fall with 95% confidence. If this interval includes numbers that are *all* greater than one (or all less than one), there is statistical significance in the odds ratio estimate. If the interval encompasses some values greater than one and some less than one (e.g., 0.8 to 1.2), then a conclusion cannot be made with 95% confidence that the risk is greater or less than the reference.

For each variable of interest, risk calculations included either all categories of that variable, or some type of aggregation of categories, based on both frequency count and similarity between categories. The following list indicates final categories observed within all analyzed variables, including aggregate categories. The Reference is the category against which all other categories were tested (normally the “null” or minimal category for that variable).

- LOCALITY (best description of surroundings that may influence traffic flow)
 - Open (open country, open residential) (*Reference*)
 - Moderate residential/business/industrial
 - Urban
 - Highway (interstate/bypass/divided highway controlled access, bypass/divided highway, access not controlled)
 - Miscellaneous/Other (airport, church, playground, school, other)
- INTERSECTION INFLUENCE (whether an intersection is influencing the subject’s movement, path, and/or speed)
 - No (*Reference*)
 - Yes, traffic signal
 - Yes, stop sign
 - Yes, uncontrolled
 - Yes, parking lot, driveway entrance/exit
 - Yes, interchange
 - Yes, other
- RIDER BEHAVIOR (participant’s behavior that might contribute to an event)
 - None (*Reference*)

- Aggressive riding (e.g., passing on the right, intentional signal or signage violation (such as rolling stop), speeding, following too closely)
- Avoidance (e.g., avoiding another vehicle, animal, pedestrian, cyclist, object)
- Lack of knowledge or skill/Inattention (e.g., improper turn execution, sudden or improper braking, did not see other vehicle during lane change or merge)
- Combination of behaviors
- PRE-INCIDENT MANEUVER (rider's action just prior to the event or baseline epoch start time)
 - Going straight, constant speed (*Reference*)
 - Going straight, other (accelerating, decelerating, starting or stopping in lane, passing or overtaking another vehicle)
 - Leaving or entering parking position or parked
 - Turning or negotiating a curve (turning left, turning right, U-turn, or curve)
 - Changing lanes or merging
 - Maneuvering to avoid an object (pedestrian, pedalcyclist, vehicle, animal, object)
 - Other (backing up other than for parking, other)
- TRAFFIC DENSITY (density of surrounding vehicles that affect participant's maneuverability)
 - Stable (level-of-service A1, A2, B, C) (*Reference*)
 - Unstable (level-of-service D, E, F)
- LANE SHARING (whether the participant is sharing the lane with another motorcycle (side by side))
 - No (*Reference*)
 - Yes, to left
 - Yes, to right
 - Yes, to right and left
- GROUP RIDING (whether the participant is intentionally riding with other motorcyclists)
 - Solo Bike (*Reference*)
 - Non-solo (pair or larger group)
- VEHICLE LANE ASSIGNMENT (whether the participant is lane splitting)
 - Not lane splitting (collapse all not indicating lane splitting) (*Reference*)
 - Lane splitting
- WEATHER (weather conditions at the beginning of the event or baseline epoch)
 - Clear/Partly Cloudy (*Reference*)
 - Overcast
 - Fog
 - Mist/light rain
 - Rain and fog
 - Raining
- SURFACE TYPE (the type of road surface)
 - Paved smooth (*Reference*)
 - Paved rough
 - Gravel/dirt road
 - Gravel/dirt road over pavement
 - Grass
- SURFACE CONDITION (the condition of the road surface as it affects motorcycle traction)

- Dry (*Reference*)
 - Wet
 - Icy
- ROADWAY ALIGNMENT (description of the road curvature in the participant's direction of travel)
 - Straight (*Reference*)
 - Curve left
 - Curve right
- ROADWAY GRADE (description of the roadway profile in the participant's direction of travel)
 - Level (*Reference*)
 - Grade up
 - Grade down
 - Hillcrest
 - Dip
- RIDER IMPAIRMENT (possible participant impairment(s) that may affect behavior, judgement, or ability)
 - None apparent (*Reference*)
 - Headphones/earbuds
 - Other/Unknown (can't tell)
- REAR SEAT PASSENGERS (whether anyone is riding on the motorcycle behind the participant)
 - 0 (*Reference*)
 - 1
- LIGHTING (lighting conditions at the beginning of the event or baseline epoch)
 - Daylight (*Reference*)
 - Dawn/dusk
 - Darkness (Lighted and not lighted)
- VEHICLE LANE POSITION (position of the participant's motorcycle in the lane)
 - Center (*Reference*)
 - Left
 - Right
 - No lane (subject motorcycle is not in an area intended for traffic)

All variables which were recorded for CNC and baseline events that had a significant relationship to the risk of the motorcyclist being involved in a crash or near-crash (based on the logistics regression model) were tested further using the described odds ratio estimation technique. This analysis provided conclusions about significant risk increase or decrease associated with specific parameters.

RESULTS

The following results provide a description and categorization of the crashes and near-crashes found in the MSF 100 Motorcyclists Naturalistic Study dataset. There were 30 crashes and 122 near-crashes (152 total CNC events). One crash (not included in the 30) was observed in the data but removed from all analyses because it was not representative of typical street riding (it was a crash on a race course). Of

the 100 participants, the number of CNC events per rider ranged from 0 to 13 (55 of the riders experienced at least one event).

Event Description

The primary Incident Type for the 30 crashes is summarized in Table 2. The most common case was a ground impact at low speed, which is defined more fully in the data dictionary as “...two-wheeled vehicle falls coincident with low or no speed (even if in gear), due to issue not defined in other Incident Type categories. The rider allows the bike to lean while it is being stopped, just beginning to move from a stop, or making a turn at low speed. Vehicle upright stability is lost due to lack of input by the rider to counteract the effect of gravity.” (Williams, McLaughlin, Williams, and Buche, 2015).

The low-speed (“capsize”) crashes are a unique dataset that is not found in traditional crash studies. Though they occur at low (or negligible) speed, they are events that are important to riders. They also have the potential to reveal a breakdown in rider task execution, baseline proficiency, or a temporary reduction in readiness to ride (e.g., fatigue and attention) that could result in problems during a continued ride. These low-speed “crashes” appear to be relatively typical among everyday riding, and are included in the risk analysis. They are events that riders want to avoid, and their analysis provides a basis for continued exploration and categorization of all motorcycle incidents.

Table 2. Incident Types for 30 Crashes

Incident Type	Number of Cases	Percentage of Crashes
Ground impact - low speed	17	56.67%
Road departure (left or right)	3	10.00%
Other vehicle turn across path	3	10.00%
Rear-end, striking	2	6.67%
Ground impact - while underway	1	3.33%
Poor curve negotiation	1	3.33%
Rear-end, struck	1	3.33%
Other vehicle straight crossing path	1	3.33%
Subject vehicle turn into path (same direction)	1	3.33%

Near-crashes were also included in the risk analyses as a type of occurrence to avoid, an event requiring extra vigilance or riding practice, and one that is a surrogate for the less frequently-occurring crash event. Table 3 includes descriptors for crash *and* near-crash cases involving only the subject (no other vehicles or objects were involved). In these 53 single vehicle conflicts, over half (55%) of all cases involve the subject motorcycle negotiating a curve leading into the incident. These 53 cases represent 29 different riders.

Table 3. Event Descriptors for Single Vehicle Crashes and Single Vehicle Near-Crashes

Precipitating Event	Pre-incident Maneuver	Number of Events	Percentage of Single Vehicle Conflicts
Subject over left lane line	Negotiating a curve	18	34%
Subject over left edge of road	Turning right	1	2%
Subject over right edge of road	Going straight, but with unintentional "drifting" within lane or across lanes	1	2%
	Negotiating a curve	4	8%
Subject over right lane line	Negotiating a curve	2	4%
This vehicle lost control - excessive speed	Going straight, constant speed	1	2%
	Going straight, decelerating	3	6%
	Negotiating a curve	3	6%
This vehicle lost control - insufficient speed	Backing up (other than for parking purposes)	1	2%
	Entering a parking position, moving forward	1	2%
	Going straight, constant speed	1	2%
	Going straight, decelerating	2	4%
	Leaving a parking position, moving forward	2	4%
	Making U-turn	1	2%
	Negotiating a curve	1	2%
	Starting in traffic lane	1	2%
	Stopped in traffic lane	1	2%
	Turning left	1	2%
	Turning right	2	4%
This vehicle lost control - other cause	Backing up (other than for parking purposes)	1	2%
	Negotiating a curve	1	2%
This vehicle lost control - poor road conditions	Going straight, constant speed	1	2%
	Going straight, decelerating	1	2%
	Turning right	2	4%

Table 4 includes descriptions of the 99 crashes and near-crashes that involve at least one other vehicle or object. The Incident Types listed are for the primary event only (in some cases, there will be an initial event such as a rear-end collision avoidance near-crash, followed by a second event such as a ground impact crash).

Table 4. Incident Types for Multi-Vehicle Crashes and Multi-Vehicle Near-Crashes

Primary Incident Type	Number of Events	Percentage of Multi-Vehicle Conflicts
Rear-end, striking	35	35%
Sideswipe, same direction (left or right)	21	21%
Other vehicle turn across path	8	8%
Opposite direction (head-on or sideswipe)	7	7%
Animal-related	6	6%
Other vehicle turn into path (opposite direction)	6	6%
Other vehicle turn into path (same direction)	5	5%
Pedestrian-related	3	3%
Backing into traffic	2	2%
Rear-end, struck	2	2%
Subject vehicle turn into path (same direction)	1	1%
Other	1	1%
Pedal cyclist-related	1	1%
Other vehicle straight, crossing subject path	1	1%

Factors that Increase Risk

Table 5 includes the factors that resulted in a significant increase in risk of experiencing a crash or near-crash compared to the provided reference level, along with the odds ratio and 95% confidence interval (there is a 95% chance that the odds ratio is between the indicated lower and upper limit). Some of the confidence intervals are quite large (which happens if the number of events for that factor is small), but the entire range includes values greater than 1, thus an increased risk related to that factor is probable. Factors that are listed in the Risk Factor Analysis Methodology section but not included in Table 5 were not found to significantly increase the risk of crashes and near-crashes.

Table 5. Odds Ratios Estimates for Factors with Increased CNC Risk

Variable	Level	Reference	Odds Ratio	Lower 95% Confidence Limit	Upper 95% Confidence Limit
Intersection Influence	Yes, Uncontrolled	No	40.693	17.312	95.654
Intersection Influence	Yes, Parking lot, driveway entrance/exit	No	8.481	3.539	20.322
Intersection Influence	Yes, Traffic signal	No	2.903	1.421	5.933
Rider Behavior	Aggressive riding (only)	None	17.932	9.63	33.39
Rider Behavior	Lack of knowledge or skill/Inattention (only)	None	9.333	4.33	20.115
Rider Behavior	Combination of behaviors	None	30.427	14.888	62.184
Pre-incident Maneuver	Maneuvering to avoid object	Going straight, constant speed	11.824	1.134	123.302
Surface Type	Gravel/Dirt road	Paved, smooth	9.378	1.818	48.377
Roadway Grade	Grade down	Level	4.326	2.403	7.787
Roadway Grade	Grade up	Level	1.889	1.048	3.405
Traffic Density	Unstable	Stable	3.564	1.48	8.581
Roadway Alignment	Curve right	Straight	2.063	1.026	4.148

The largest risk of a CNC is for the motorcyclist whose motion, path, or speed is affected by an intersection that is uncontrolled in the participant’s direction of travel (no signal or other signage in the participant’s direction), with 40 times the risk of no intersection effect. The observed CNC cases for this situation, consisting of 7 crashes and 11 near-crashes, include a variety of situations and intersection types. Although the majority are “typical” intersection-related cases such as various types of conflicts with other vehicles intending to turn at the intersection, there are also some unique situations such as riders who are attempting to make a U-turn or maneuver down an unpaved, non-maintained roadway toward an intersection. Thus, this study captures commonly researched events like another vehicle making a left turn across a motorcycle’s path, but also other less frequently investigated situations that are not available through traditional accident/fatality reports. The overriding result in this analysis is that there are a variety of crash and near-crash situations that might occur at rider uncontrolled intersections, and due to the large risk of such occurrences, riders should be especially vigilant in this situation. Likewise, other types of intersections such as parking lot and driveway entrances/exits and intersections with traffic signals present increased risk of CNC involvement.

Certain rider behaviors also indicate increased CNC risk. Coding was available to record multiple behaviors which fall into the categories aggressive riding, avoidance, and lack of knowledge or skill/inattention, as described in the Risk Factor Analysis Methodology section. If behaviors across more than one category were observed, the rider was categorized as exhibiting a “combination of behaviors.” The baseline reference is none of the listed behaviors. Note that the behaviors described here are based largely on actions only, but with assumptions sometimes necessary about why the action was executed. For example, signal violation may be intentional (aggressive riding--the rider saw the red light but rode through it) or unintentional (inattention--the rider did not see the red light). Behavior

categories are available to allow this distinction when necessary, and in the few cases in which behavior is coded based on some intention, video analysts are well-trained and use all information available to make that distinction. In most cases, however, the behavioral action is the only recorded factor (the “why” is left open). For instance “following too closely” may be due to either inattention or frustration, but only the action is recorded.

When aggressive riding (such as speeding or passing on the right) occurs as the only behavior, the risk of CNC is 18 times that of not exhibiting any of the behaviors. When lack of knowledge or skill/inattention is the only observed type of behavior, the risk of CNC is 9 times that of the “no behavior” case. When observed behaviors include a combination of the categories (for example, the rider is behaving aggressively and exhibits a lack of knowledge or skill), their risk of CNC involvement is 30 times that of no behaviors. Other factors leading to a two or more times increase in CNC risk include maneuvering to avoid an object (vehicle, pedestrian, inanimate object, etc.), riding on a gravel or dirt road, riding on road that is not level, riding in traffic that is heavy with unstable flow, and riding through a right curve.

Factors that Decrease Risk

Table 6 includes the factors that resulted in significant decrease of risk of CNC from the reference level, and the associated 95% confidence intervals. All of the Locality types compared to Open Country/Open Residential produced a potentially protective effect (riding in these areas seem to protect against CNC occurrence, compared to riding in areas where no or few buildings or other structures are visible). Identifying the mechanism behind this decreased risk for riding in areas other than Open Country/Open Residential will require further investigation. Examples of explanations would be increased vigilance, a less lax style of riding, or not pushing ones abilities as much as when riding in less busy surroundings such as the open areas. Riding with a passenger also presents a slightly significant decrease in CNC risk. In this top-level general population analysis, no other factors from the variable list in the Risk Factor Analysis Methodology section indicated a significant protective effect in terms of CNC involvement. The next level of analysis would be exploration of the possibility that rider-specific factors such as age or motorcycle type may offer protective effects.

Table 6. Odds Ratios Estimates for Factors with Decreased CNC Risk

Variable	Level	Reference	Odds Ratio	Lower 95% Confidence Limit	Upper 95% Confidence Limit
Locality	Urban	Open country/ Open residential	0.134	0.019	0.936
Locality	Highway	Open country/ Open residential	0.153	0.069	0.339
Locality	Miscellaneous/Other	Open country/ Open residential	0.164	0.061	0.438
Locality	Moderate residential/ Business/Industrial	Open country/ Open residential	0.365	0.191	0.699
Rear Seat Passengers	1	0	0.347	0.128	0.937

Application of Findings

Naturalistic riding results can be applied to instruction in the situations in which risk has been identified (emphasizing vigilance and actual practice). Current MSF *RiderCourse* training already provides instruction in multiple areas in which these advances are applicable, such as Basic Operation, Preparing to Ride, Risk and Riding, Basic Street Strategies, and Strategies for Common Riding Situations (Motorcycle Safety Foundation, 2014). The following list includes some supporting and supplemental data from this study that could augment the classroom training material provided in the MSF *RiderCourse* program. The application of the material (on-road portion of the course) is likewise improved by focusing extra attention and time on areas in which risk was discovered (such as curve negotiation, maneuvering to avoid an object, and low-speed maneuvers).

- Section 4: About Basic Operation (Basic Turning)
 - Current instruction: “Whether called a turn, corner, or curve, changing direction requires special attention.” Supporting data: Study results indicate that riding in a right curve doubles the risk of a crash or near-crash compared to riding on a straight roadway. This type of event includes taking the right curve too wide or at excessive speed and crossing over the lane line into the oncoming lane (termed a near-crash due to the evasive maneuver required to regain control and proper lane position).
 - Current instruction: General emphasis on the importance of appropriate speed in curve maneuvers. Supporting data: Study results indicate that excessive speed (one of 12 rider behaviors observed in curve-related crashes and near-crashes) is a factor in 45% of the events.
- Section 6. Risk and Riding
 - Current instruction: “Crashes, if they ever happen, occur mostly in curves and at intersections.” Supporting data: See Section 4 regarding curves; the risk of crashes and near-crashes are increased at various types of intersections: traffic signaled intersections (nearly 3 times), parking lot/driveway intersections (8 times), and intersections uncontrolled in the rider’s direction (40 times). Note that the indicated risk increases include near-crashes, not only crashes (including any type of loss of control, even if regained).
 - Current instruction: “There is rarely a single cause of any crash. Usually there are many factors that interact, or combine, to result in a crash. You do not want to ignore even minor factors because you want to break the chain of events that may lead to a crash.” Supporting data: Studies show that some of the factors that increase the risk of being involved in a crash or near-crash include locality (open country or residential areas), the effect of intersections, the type of road surface (gravel or dirt roads), the traffic flow (heavy, unstable flow), roadway grade (not flat), and roadway alignment (curves, especially right-handed). Practicing under these conditions, riding with extra vigilance, or just avoiding the risky situations will decrease one’s chance of being involved in a crash.
- Section 7. Basic Street Strategies
 - Current Instruction: Be visible, especially in curves and at intersections. Supporting data: See Section 6 regarding curves and intersections.

- Current Instruction: “Use your eyes and mind to determine how and when to adjust position as situations unfold. Factors in front make up most of the hazards that affect you. You want to be able to identify them as early as possible so you can respond well ahead of time and do not have to react to an emergency at the last possible moment.” Supporting data: This study shows that having to maneuver to avoid an object (such as a pedestrian, cyclist, vehicle, animal, or other object) increases the crash/near-crash risk by nearly 12 times.
 - Section 8. Strategies for Common Riding Situations
 - Current Instruction: General emphasis about the variety of intersection types to be cautious around. Supporting data: See Section 6 for risk factors related to specific types of intersections (emphasize these).
 - Current instruction: “Crash studies show running off the road accounts for many crashes.” Supporting data: Study results indicate that 67% of all single-vehicle crashes and near-crashes involved curve negotiation, and 63% of those were run-off-road or lane line crossing cases.
 - Current instruction: Special consideration for starting on a hill. Supporting data: Any type of maneuver on a grade should be practiced—studies show that riding on an uphill grade doubles the risk of crash/near-crash, and riding on a downhill grade increases this risk four-fold.
 - Current instruction: Detailed steps for crossing over obstacles. Supporting data: See Section 7, maneuvering to avoid an object increases risk by nearly 12 times.
 - Section 8. Special Riding Situations
 - Current instruction: Types of road surfaces to be aware of, and how to react to them. Supporting data: Riding on a gravel or dirt road is related to 9 times the risk of crash/near-crash involvement than riding on paved, smooth roads.

CONCLUSIONS

The data from the MSF 100 Motorcyclists Naturalistic Study includes nearly 31,000 trips for 100 riders. Data mining methods uncovered 152 crash/near-crash events (30 of which were crashes, including 17 low-speed ground impacts), with 55% of the total participant population experiencing at least one of these incidents during their participation in the study. All of the crashes and near-crashes included in the risk analyses involve some type of control loss for the rider, whereas the baseline reference events include no loss of control.

Discovery of the factors that increase the risk of motorcycle crashes (and near-crashes) is useful in understanding how these events occur during every day riding, and also provides opportunities to supplement or improve rider training. In this study, 65% of the participants reported that they have passed at least one rider training course, whereas the national average as of 2014 was 44% (Motorcycle Industry Council, 2016). Therefore the study sample is at least as well-trained as the overall population.

One particular avenue for application of the study findings that would enable far-reaching safety improvement is the MSF training curriculum. Programs such as the MSF Basic *RiderCourse* offer global

classroom and on-road training. Since 1974, over 7 million motorcyclists nationwide have successfully completed this course (Motorcycle Safety Foundation, 2016). These naturalistic study results fit nicely into the current curriculum, and increase the probability that riders will receive the messages and be encouraged to practice maneuvers in order to decrease their risk of being involved in a crash or near-crash. Formal education and training serve to improve a rider's vigilance and provide the opportunity for riding practice, both of which can improve the chance of a rider accurately interpreting the riding task and properly responding, even in an emergency situation.

Another byproduct of this study that facilitates the investigation of naturalistic riding is the data dictionary that was constructed specifically for motorcycle riding situations. This detailed tool is not a duplicate of the crash/near-crash dictionary previously utilized for automobile analysis, but was developed and refined based on naturalistic riding data, unlike any other motorcycle safety analysis tool currently available. Its continued usage will facilitate further understanding of what actually happens during motorcycle riding.

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