U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

NHTSA
www.nhtsa.gov

DOT HS 811 448

March 2011

A Study of Motorcycle Rider Braking Control Behavior

REPORT DOCUMENTATION PAGE		*Form Approved* *OMB No. 0704-0188*
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE March 2011	3. REPORT TYPE AND DATES COVERED Final Report, September 2008 – September 2009
4. TITLE AND SUBTITLE A Study of Motorcycle Rider Braking Control Behavior		5. FUNDING NUMBERS DTNH-05-D-01002, Task Order 0016 Subcontract No. 8172-S-05 Task Order #1
6. AUTHOR(S) J.F. Lenkeit, B.K. Hagoski, A.I. Bakker		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Dynamic Research, Inc 355 Van Ness Ave #200 Torrance, CA 90501		8. PERFORMING ORGANIZATION REPORT NUMBER DRI-TR-09-12-4
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation National Highway Traffic Administration 1200 New Jersey Avenue, SE Washington, DC 20590		10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES This project was managed by Dr. Paul Rau of the National Highway Traffic Safety Administration.		
12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public through the National Technical Information Service www.ntis.gov		12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
This document reports a study wherein a motorcycle riding simulator was used to study how non-expert motorcycle riders use conventional brakes in emergency braking situations. Sport-touring and Cruiser motorcycle configurations were used. Sixty eight rider-subjects, divided into those who typically ride Cruisers, and those who primarily ride Sport motorcycles, were exposed to traffic situations requiring a range of braking from normal slowing to emergency braking. Braking behavior data were obtained from recordings of rider control inputs, motorcycle response, and interactions with other vehicles. Rider characteristic data were obtained from questionnaires. Data from these sources were analyzed to investigate possible relationships between rider characteristics, braking behavior and event outcome. Emergency braking behavior was analyzed based on two scenarios involving an opposing vehicle moving rapidly into the rider-subject's lane, requiring rider-subjects to brake in order to avoid collision. There were no cases where the rider-subject used only the rear brake, though some riders used only the front brake. Analyses of event outcome indicated that a rider's initial braking, with respect to both timing and magnitude, is important in determining the event outcome. Linear and logistic regression analyses produced generally poor correlation between individual rider factors and braking behavior or event outcome.

14. SUBJECT TERMS Motorcycle, rider behavior, simulator, braking, brakes			15. NUMBER OF PAGES 222
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (rev. 2-89)
Prescribed by ANSI Std. 239-18, 298-102

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTD)

TABLE OF CONTENTS (CONTD)

LIST OF FIGURES

LIST OF FIGURES (CONTD)

LIST OF TABLES

LIST OF TABLES (CONTD)

Executive Summary

A STUDY OF MOTORCYCLE RIDER BRAKING CONTROL BEHAVIOR

J.F. Lenkeit, B.K. Hagoski, A.I. Bakker
Dynamic Research, Inc.

This document reports a study whose objective was to gain a better understanding of how non-expert motorcycle riders use conventional brake systems in emergency braking situations. A previous 1981 NHTSA motorcycle study indicated that as many as 83% of US motorcycle riders involved in crashes did not use their front brakes prior to the crash. In the 28 years since that report there have been many changes related to motorcycle design and rider factors. Examples of change related to motorcycle design include the prevalence of hydraulic disc brakes, the availability of advanced brake systems including antilock and combined brakes, and the evolution of the modern sportbike. With respect to the rider population, in 1985 the average motorcycle owner was 28.5 years of age the, whereas in 2003, the average owner was 40 years of age. The availability of, and state mandated requirement for formal rider has increased substantially since 1981.

Example questions that were to be answered included:

- Which brake do riders use when faced with an emergency situation requiring braking – front, rear, or both?
- Are there rider braking behaviors than can be identified and used to predict the outcome of a possible collision event?
- Do rider factors such as age, experience, preferred motorcycle type, rider training etc. influence braking behavior?

The project made use of the DRI Driving Simulator, modified for use as a motorcycle riding simulator. The Simulator is a dynamically realistic, moving base, "rider-in-the-loop" research device. Its application takes advantage of the experimental control, flexibility, repeatability, measurement capabilities, and safety that are provided thereby. In this study rider-subjects were exposed to traffic situations requiring a range of braking from normal slowing to emergency braking necessary to avoid a collision.

Time history recordings were made of rider inputs and motorcycle and interactions with other vehicles. These data were processed to determine braking behavior variables. In addition each rider-subject completed several questionnaires related to their riding experience. Data from these sources were compared to investigate possible relationships between rider characteristics and braking behavior or event outcome.

Sixty eight rider-subjects participated in this study. Potential subjects were screened on factors such as age, years and type of riding experience, motorcycle(s) currently owned or ridden, etc. The study used two physical motorcycle configurations, Sport-touring and Cruiser. Correspondingly, the rider-subjects were divided into two groups, those who typically ride Cruiser type motorcycles, and those who primarily rider Sport-Touring motorcycles or Sportbikes. Within each group age range and experience were approximately evenly represented.

Each rider-subject completed two simulator runs, which required 20-30 minutes each to complete. The roadways depicted were straight with two lanes in each direction and numerous intersections. For approximately half of each roadway the graphical scene depicted a city or suburban environment, and for the remaining portion, a rural roadway environment. Traffic lights were present and in some cases, active. Roadway signage showed speed limits and the subjects were instructed to follow traffic laws as if they were actually riding. Other vehicles were depicted, some of which interacted with the subject vehicle to create the desired braking scenarios. Each simulator run included multiple scenarios which could cause the rider-subject to actuate the brakes.

Analyses of rider's emergency braking behavior was based on the two scenarios which had the highest number of cases of collision with an opposing vehicle. Both of these involved collision partners moving rapidly into the rider-subject's lane from the right side, requiring the rider-subject to brake in order to avoid collision.

Over the range of scenarios there were some cases of a rider-subject using just the rear brake, though many more where just the front brake was used. There were a few riders who, essentially, never used the rear brake. When the focus was narrowed to the two emergency situations, there were no cases where the rider-subject used just the rear brake, though again, some riders used only the front brake.

To study possible relationships between rider braking behaviors and event outcomes, a series of logistic regressions were performed comparing various braking measures, including rider braking behavior factors, with scenario outcomes. These analyses focused on the two scenarios having the highest number of collisions. Rider braking control inputs were interpreted in terms of commanded deceleration, allowing comparison of front and rear brake control inputs.

A number of models were considered using the occurrence of a collision (yes/no) as a dependent variable and various single and multiple term braking measures as the independent variables. For the more severe braking scenario, better regression results were obtained from models having acceleration terms with a time factor, either an acceleration term multiplied by time, or an acceleration term over a specific time interval. The best results for predicting collision in the more severe braking scenario were obtained with a logistic regression model with the independent variables:

- Area under the front brake command at 2.0 seconds
- Area under the rear brake command at 2.0 seconds

When the brake commands are interpreted in terms of acceleration, the area under the brake command curve represents a change in speed. This result is interesting in that both front and rear brake terms were significant, and the timing is approximately halfway through the nominal event. Additionally, he outcome predicted at 2 seconds was more likely to be correct than the prediction for the entire event, i.e., the speed reduction at 2 seconds was a better predictor of collision than the total speed reduction. This is probably because there were some cases where the rider slowed enough to maneuver around the opposing vehicle, so he neither stopped nor collided. These results suggest that the speed reduction achieved at some point during the event may be the best indicator of collision. From a rider behavior perspective, this indicates that how a rider applies the brakes, with respect to both timing and magnitude, in the initial portion of the braking is very important in determining the outcome of the event.

Linear and logistic regression analyses were used to identify possible relationships between rider factors and rider braking behaviors and/or event outcomes. A few cases produced statistically significant results, but with poor correlation. The absence of correlation between individual rider factors and braking behavior or event outcome is in itself an interesting result. Conclusions that might be drawn from this include:

– Cruiser riders and sport touring riders have similar braking behavior, and neither is more or less likely to use only the rear brake in an emergency.

– Rider factors such as age, years experience, recent riding experience, etc are not good indicators of likelihood of collision in a path conflict emergency

This study demonstrated the viability of using a research grade riding simulator to study behavior of ordinary riders in realistic but potentially dangerous maneuvers in a safe, repeatable and efficient manner. A key element of this is that the riding simulator must be of high fidelity, and present a realistic representation of a real motorcycle that is compelling to the rider. Careful attention must be paid to realistically modeling the motorcycle dynamics, feel properties and other physical representation.

Section I
INTRODUCTION

The overall purpose of this project was to study motorcycle rider braking control in emergency stopping situations. The experiments were accomplished using a sophisticated moving base motorcycle riding simulator. Two motorcycle configurations were used with a total of 68 rider participants.

A. BACKGROUND

In 1981, Hurt, Ouellet, and Thom (Ref 1) suggested that as many as 83% of US motorcycle riders involved in crashes did not use their front brakes prior to the crash. This statistic has had significant injury and crash rate implications, and it suggested that the maximum braking capability of the motorcycle may not have been utilized in most crashes, at least in that era.

The many factors that have changed in the 28 years since that report include those related to motorcycle design features and rider population factors. Motorcycle design factors that may affect braking have changed substantially in some market segments. Two designs in particular are worth noting. Modern sportbikes have evolved from what were referred to as “café racers” in the time of the Hurt report. Whereas the café racers were typically general purpose motorcycles, modified by the user for performance and race-like styling, current sportbikes are conceived and designed for high performance acceleration, cornering and braking. Design characteristics of this type of motorcycle include a relatively short wheelbase, high and forward center of gravity and powerful brakes. This type of design tends to transfer more weight to the front wheel under deceleration, making the rear brake relatively less effective, though overall braking capability may be very high. These motorcycles are currently quite popular, and riders accustomed to this type of motorcycle may tend to favor use of the front brake. Cruiser motorcycles, currently the most popular style of motorcycle, may be seen as an evolution of what was referred to as the “semi chopper” of the Hurt era. As with the café racer, the semi-chopper was typically a general purpose motorcycle modified by the user. In this case however, typical modifications included modifying the front fork geometry, adding pull back handlebars, and perhaps a smaller diameter rear wheel. Modern cruisers follow this design trend and are available from most major manufacturers. Typical design factors include relatively longer wheelbase, lower saddle height, and lower and more rearward weight distribution. These design factors result in less weight transfer during deceleration, making the rear brake contribution to overall braking higher than for a motorcycle with greater rear-to-front weight transfer. Riders who are accustomed to this style of motorcycle are often thought to favor the rear brake.

Brake system design factors have also changed, for example, across all motorcycle designs, disc brakes are far more prevalent today than at the time of the Hurt report. A number of motorcycles are now also available with antilock brake systems (ABS), and/or combined braking systems (CBS) where one or both of the brake controls actuates both the front and rear brakes simultaneously. Such systems are currently offered by several manufacturers. Typically, the details of implementation such as the amount of front/rear biasing, methods of front/rear coupling, etc., vary by manufacturer and application.

Rider factors have also changed since the time of the Hurt report. The average rider age is very different now from what it used to be. In 1985 the age of the average motorcycle owner was 28.5 years, whereas in 2003, the average was 40 years (Ref 2). In 1985 motorcycle owners under the age of 24 represented 36% of the owner population and those over the age of 40 represented represent 21%. By contrast, in 2003 the under 24 age group represented 15% of the owner population and 53% of owners were over 40.

The National Agenda for Motorcycle Safety (Ref 3) cites “more widely available training” as a user population change that has occurred since the time of the Hurt report, which included a recommendation that formal training should be made a prerequisite, or at least a co-requisite, of motorcycle use. In 2008, 20 States required formal rider training for at least some motorcycle license applicants. Of these, 4 States required training for applicants under the age of 21, 13 for applicants under the age of 18, and 2 States required all applicants to have completed a formal training course (Ref 2).

NHTSA has completed studies (FY2007-2008) to evaluate the performance of CBS (as well as ABS) on motorcycles and to assess the possible performance benefits from such systems. However, it is useful to understand how riders are using conventional brakes in emergency stopping situations before considering any changes to FMVSS 122, the existing vehicle safety standard regulating the performance of motorcycle brake systems and components.

B. PROJECT OBJECTIVES

The objective of this study was to gain a better understanding of how typical, non-expert[1] motorcycle riders use conventional hand lever and foot pedal brake systems in emergency braking situations. Example questions that were to be answered included:

- Which brake do riders use when responding to an emergency situation requiring braking – front, rear, or both?

- Are there rider braking control behaviors than can be identified and used to predict the outcome of a possible collision event?

- Do rider factors such as age, experience, preferred motorcycle type, and rider training influence braking behavior?

The study undertook an experimental approach using a motorcycle riding simulator in order to measure and analyze the braking control behavior of a representative sample of typical male riders.

[1] *For the purposes of this study, non-expert riders are considered to be those who are not employed in any capacity as a motorcycle rider or instructor, and have no road racing experience at an expert or professional level*.

Section II
TECHNICAL APPROACH

The study used the DRI Driving Simulator modified for use as a motorcycle, with a motorcycle cab and corresponding vehicle dynamics and steering feel characteristics. The resulting Riding Simulator is a dynamically realistic, moving base, "rider-in-the-loop" research device. Its application takes advantage of the experimental control, flexibility, repeatability, measurement capabilities, and safety that are provided thereby. During a simulator run the riders encountered various riding environments and traffic scenarios designed to evoke both normal and emergency braking behaviors. For each simulator run, time history measurements were made of rider control inputs, motorcycle response and interacting traffic parameters.

The study used 2 motorcycle configurations or types, sport-touring and cruiser. Correspondingly, approximately half of the participants were riders who typically ride sport-touring or sportbikes, and the other half were cruiser riders. The 2 configurations were implemented in the simulator, and each group rode their respective configuration.

Each rider completed 2 simulator runs, each of which required 20-30 minutes to complete. The graphical roadways used were straight, with numerous intersections. For approximately half of each roadway the graphical scene depicted a city or suburban environment. For the remaining portion, a rural roadway environment was used. Traffic lights were present and in some cases, active. Roadway signage showed speed limits, and the participants were instructed to follow traffic rules as if they were actually riding. Other vehicles were depicted, some of which interacted with the subject vehicle to create the desired braking scenarios. Each simulator run included 14 events which could cause the rider to actuate the brakes. These were generally categorized as traffic, normal braking, urgent braking or emergency braking.

A cross-section of riders representative of the general riding population participated in the study. Potential participants were screened on factors such as age, years of riding experience, motorcycle(s) currently owned or ridden, involvement in motorcycle crashes, type of riding, and other demographic factors.

A. EXPERIMENTAL DESIGN

A Power Analysis was performed using the GPower 3.0.10 software (Ref 4) to estimate the needed sample size for the planned repeated measures within factors design. For the factors considered, a sample size of 64 participants was determined to provide seventy percent power based on a medium effect size of 0.3.

Riding performance was evaluated under 2 motorcycle-type conditions, cruiser and sport-touring. Participants were placed in one of the two groups based on their motorcycle-type preference. Each participant experienced the same order of events per road, with a total of 2 roads. Within each group, the order in which participants saw Roadway 1 and 2 was counterbalanced to minimize learning effects. Measures of performance included general hazard avoidance behavior, detection of signs and other traffic control devices, and specific rider braking control actions or responses. Subjective assessment data were also collected through pre- and post-ride questionnaires.

B. RIDING SIMULATOR SETUP

1. Simulator Overview

The DRI motion base Riding Simulator was used for this study. This is one version of the DRI Driving Simulator which is an operator-in-the-loop research grade device developed primarily to support human factors studies of rider or driver behavior. Originally developed approximately 15 years ago it has undergone periodic hardware, graphics, and software upgrades to take advantages of new evolving technologies.

The Simulator supports multiple, interchangeable cabs each of which is attached to a 4’x8’ steel sub-frame that is in turn fastened to the top platform of the motion system. Each cab features controls, displays and an operating environment unique to its vehicle type. Examples of controls unique to vehicle types are the accelerator pedal of a car, the twist throttle of a motorcycle, or the lever throttle of a Personal Water Craft. Each cab has its own steering control feel system, so that the operator receives the correct tactile/haptic feedback as they control and maneuver the vehicle.

Cabs are attached to the top of an electro-hydraulic 6 degree-of-freedom motion base which provides kinesthetic cues to the operator. The motion system can provide approximately 1.2m in 3 DF translation, and 25 degrees of rotation about 3 axes. In addition to the hexapod, the motorcycle cab has an additional roll degree of freedom relative to the platform.

Also attached to the motion platform are the projectors and screens of the graphics system. These provide the rider with an approximately 180 degree forward field of view. Very high speed graphic computers provide the visual scene content at 75Hz with a total measured throughput time delay of about 65ms. Photographs are used to support texture mapping in the visual scene to provide a high degree of visual realism.

A high fidelity sound system completes the immersive environment. Recordings of vehicle and engine sounds, road/tire interaction and wind noise are manipulated in real-time to provide the rider with the appropriate aural cues. The custom sound cue generation software drives professional grade mixers, equalizers and amplifiers; other sound devices can be mixed in as well. The sound system is integrated with the rider's helmet.

Behind and above the Simulator platform is the control room where simulator operators and researchers control and monitor studies. An intercom system provides communication between the control room and cab occupants, and video cameras mounted at the cab enable video recordings of participant/vehicle interaction. Numerous vehicle and environment related measures as well as participant control actions can be recorded for analysis.

2. Motorcycle Cab

The riding simulator motorcycle cab was set up to physically represent 2 motorcycle types, sport-touring and cruiser. This accounted for the fact that some riders were more accustomed to a cruiser type layout, while others were more accustomed to a sportbike type layout. The National Agenda for Motorcycle Safety (Ref 3) describes these motorcycle types as follows:

> Sport-Touring. “These motorcycles combine the comfort and some of the luggage capacity of touring motorcycles with the responsive handling of sportbikes. Usually powerful with relatively responsive handling, and high-performance brakes, sport-touring motorcycles offer fewer amenities than touring bikes. The ideal mission of a sport-touring machine is medium- and long-distance travel via curving roads.”

> Cruiser. “Currently the most popular category of the market, centered on traditional or classic American styling. Once dominated almost exclusively by Harley-Davidson, the cruiser category has attracted competition from all major manufacturers and is the entry category for new American manufacturers. The profile is long with a low saddle height. The emphasis in the cruiser category is on appearance, style, and sound, with less emphasis on performance. Owners frequently customize these machines.“

The motorcycle cab used is based on a 1987 Honda VFR700F modified for use in the simulator. This contemporary version of this basis motorcycle is very similar in size and rider control layout, and the motorcycle is generally categorized as a sport-touring motorcycle. To accommodate cruiser riders, a second set of controls, handlebars, footrests and seat was implemented, the arrangement of which was based on a typical cruiser, having forward mounted footrests, and handlebars that allow a more upright riding position. The relationship of the 2 configurations is shown in Fig 1.

For experimental efficiency it was necessary for the changeover between control and seat configurations to require minimal time and effort. To achieve this, a second set of footrests and foot controls were fabricated and mounted in the location shown in Fig 2. Each brake pedal had its own master cylinder and a hydraulic “Y” valve was used to switch between the 2 configurations. The gearshift mechanisms for the forward, cruiser, control and the rearward, sport-touring, control were mechanically linked. For the cruiser handlebars, the top fork leg mounted VFR handlebars were replaced with adaptors for handlebar clamps, which were used to mount appropriate cruiser type handlebars. A single set of handlebar mounted controls was used to switch between the

2 handlebar configurations. A substitute seat was fabricated that lowered the seating position to replicate the lower saddle height typical of cruisers. The seats were also easily interchangeable.

Figure 1. Cruiser and Sport-Touring Motorcycle Cabs

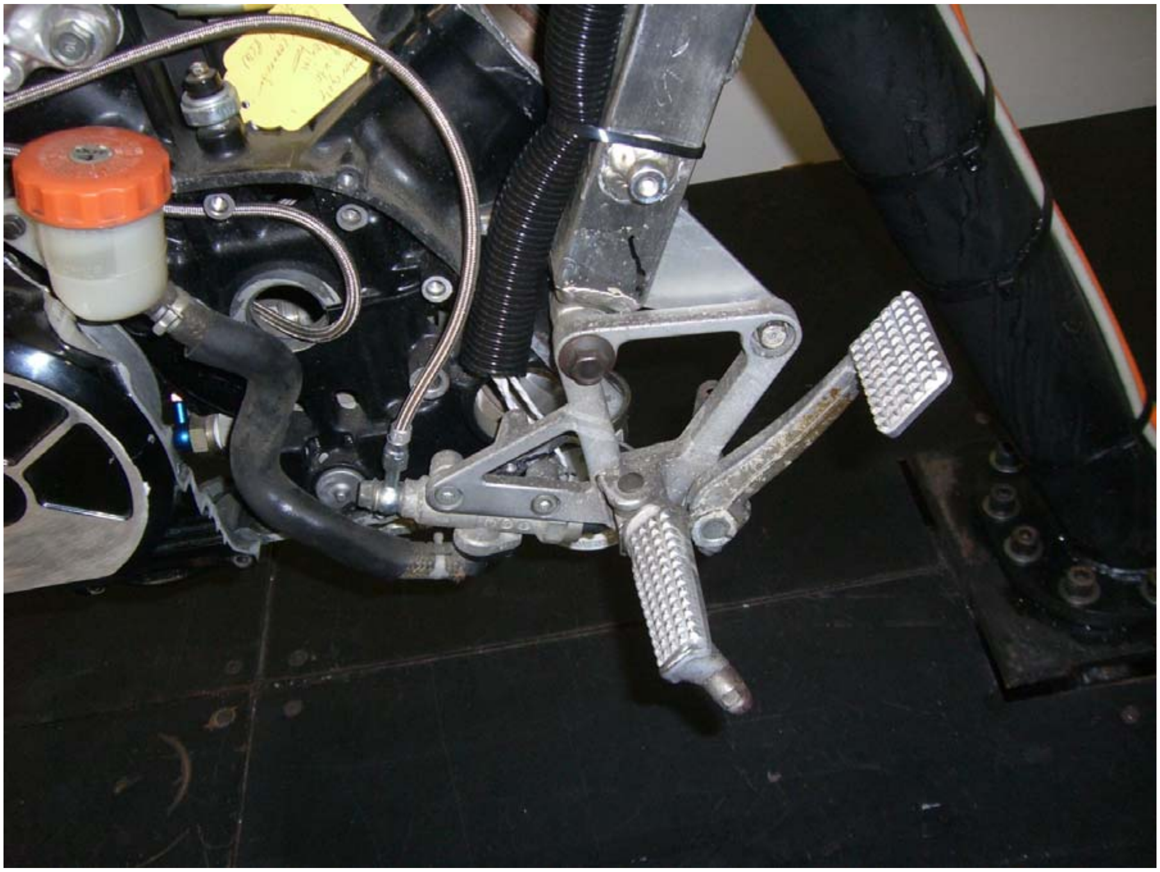


Figure 2. Forward Mounted Footrest and Rear Brake Pedal

An important feature of the motorcycle cab is the Moog Q-line model Q100 high fidelity steering control force loader, which enables a realistic representation of the speed varying steer torque gradient. This control force loader is designed for primary control applications having high fidelity force and torque simulation requirements.

3. Vehicle Dynamics Model

The vehicle dynamics model was implemented using BikeSim, a commercially available software package for modeling the dynamic response of motorcycles and scooters. The BikeSim motorcycle model has 26 degrees-of-freedom. Using BikeSim, specific motorcycle models are developed and modified through the use of numerous data screens, each of which is a graphical user interface (GUI) with a particular aspect of the motorcycle model definition. For example one screen is used to define the basic motorcycle dimensions and properties, including wheelbase, saddle height, center of gravity location, moments of inertia, etc. Other screens are used to access parameters and characteristics for suspension, drivetrain, tires, brakes, etc.

Two slightly different vehicle dynamics models were implemented for this study, neither of which represented a specific real-world motorcycle. The 2 models represented a generic cruiser and a generic sport tourer. Representative dimensions and mass properties were used based on measurements of motorcycles and motorcycle components previously made at DRI. The main differences between the 2 simulation models were that the cruiser had a longer wheelbase, and a lower and further aft center of gravity (cg) than the sport tourer. The brake component properties, tire properties, masses and moments of inertia were the same for the 2 simulation models. The rationale for this approach was that the basic properties of each of the simulated motorcycles should be representative of the type of motorcycle physically represented, but that to the extent possible, neither should have a brake performance advantage or disadvantage compared to the other. With this implementation, if weight transfer is ignored, both simulated motorcycles would produce the same deceleration for the same brake force input. In real world motorcycles however, cruisers are generally longer and lower than sport tourers, and this geometry produces less rear-to-front weight transfer under braking than shorter and higher cg sport tourers and sportbikes. Taking weight transfer into account, and for identical brake components and tires, typical cruiser dimensions may make their rear brakes more effective than those for sportbikes, so it was speculated a priori that cruiser riders may tend to use more rear brake than sportbike or sport tourer riders. Conversely, the front brakes of sportbikes and sport tourer may be more effective than those for cruisers, and it was thought that their riders might tend to use more front brake effort.

When implemented in the simulator the vehicle dynamics model was found to be relatively well behaved and realistic at speeds above approximately 35 mph. However, the BikeSim model was less well-behaved dynamically as speed decreased. At speeds in the range of 0-25 mph the model was very difficult to stabilize and directional control was poor. Various analytical and model modification steps were tried (including extensive discussions with Mechanical Simulation Corporation) in an attempt to improve the low-mid speed range characteristics, with some success. However, as the deadline to begin testing approached, while it was possible to ride the model from very low to very high speeds, it was decided that the realism of the model in the range below approximately 20 mph was not sufficient to allow its use by general rider participants in the Simulator. As a result it became necessary to make adjustments to scenarios to keep the speed of the motorcycle in its better-behaved dynamic range (above 20 mph) and also to augment the stability of the motorcycle model at lower speeds. Below 15 mph rider steering inputs were ignored by the simulation, and a simple model was used to keep the motorcycle upright. At speeds above 30 mph the rider had complete control of the lateral-directional characteristics of the model and no stability augmentation was used. Between approximately 15 and 30 mph the rider steering inputs were blended with the stability augmentation, with the rider input becoming progressively more dominant with increasing speed. Riders were briefed that they should not expect realistic steering behavior until approximately 25 mph, and when starting a run they should accelerate to 30 mph as quickly as possible and avoid attempting to steer at very low speeds. Overall, the rider participants found the lateral-directional response characteristics to be acceptable and subjectively satisfactory, especially for this study which focused on rider braking control.

BikeSim allows implementation of detailed engine torque and drivetrain characteristics. For this study however a generic, relatively high torque engine model was implemented for both motorcycle models. This engine model was chosen to enable the rider to accelerate quickly from rest. In addition an automatic transmission drivetrain model was used to preclude possible difficulties with riders shifting gears

4. Data Acquisition

Virtually any control input, vehicle motion, or response variable of interest is available in the driving simulator, and can be recorded as a function of time. For this study, the following variables were recorded during each run:

- Rider steer torque and steer angle inputs
- Rider hand lever and foot pedal brake force inputs

- Corresponding front and rear wheel brake torques
- Corresponding front and rear longitudinal slip values (wheel angular velocities)
- Accelerator position
- Motorcycle pitch, roll, and yaw angles and angular rates
- Motorcycle longitudinal acceleration
- Forward speed
- Lateral lane deviation
- Position and motion of obstacle and other interacting vehicles
- Video recording of rider’s right hand (front brake control, right foot (rear brake control), rider’s forward view of roadway scene
- Roadway segment information

The time history data were sampled at 25 samples/sec per channel, and stored in ASCII format. Note that a sample representing 40 ms is actually obtained by averaging (filtering) 10 samples at 4 ms intervals over the 40 ms, which provides effective smoothing of the data.

5. Aural Cues

To provide additional realism aural cues were presented to the rider by means of headphone transducers mounted in the helmet. Recordings were made of engine sounds at various rpm, and wind noise at various speeds. Sound cue audio files were generated from these raw recordings to be used as 3-5 second audio loops at each condition of engine speed or road speed. The Simulator sound software process these sounds in real time by modifying the frequency content and overall sound pressure level of each individual sound on the basis of road or engine speed, and mixing these appropriately.

6. Graphical Roadways

A graphical roadway was created specifically for this study. The road was straight and undivided with two lanes in each direction, separated by a double yellow line, and having standard road geometry with respect to lane width, placement of markings, etc. The roadway was approximately 39 km in length, divided into a suburban/city portion, with intersections approximately every 760 m and a posted speed limit of 40 mph, and a rural portion with intersections every 3050 m and a posted speed limit of 65 mph. Figure 3 shows the roadway geometry. Roadside scenery was added, including buildings, traffic lights, trees, parking lots, etc., appropriate for the simulated environment. Figures 4 and 5 show typical roadside scenery for the suburban and rural settings. The roadway could be ridden in either direction, so that participants riding in one direction experienced the suburban section first, and participants riding in the other direction experienced the rural section first. All participants completed one run in each direction. The environmental conditions depicted for this simulator study were clear skies and daytime lighting conditions.

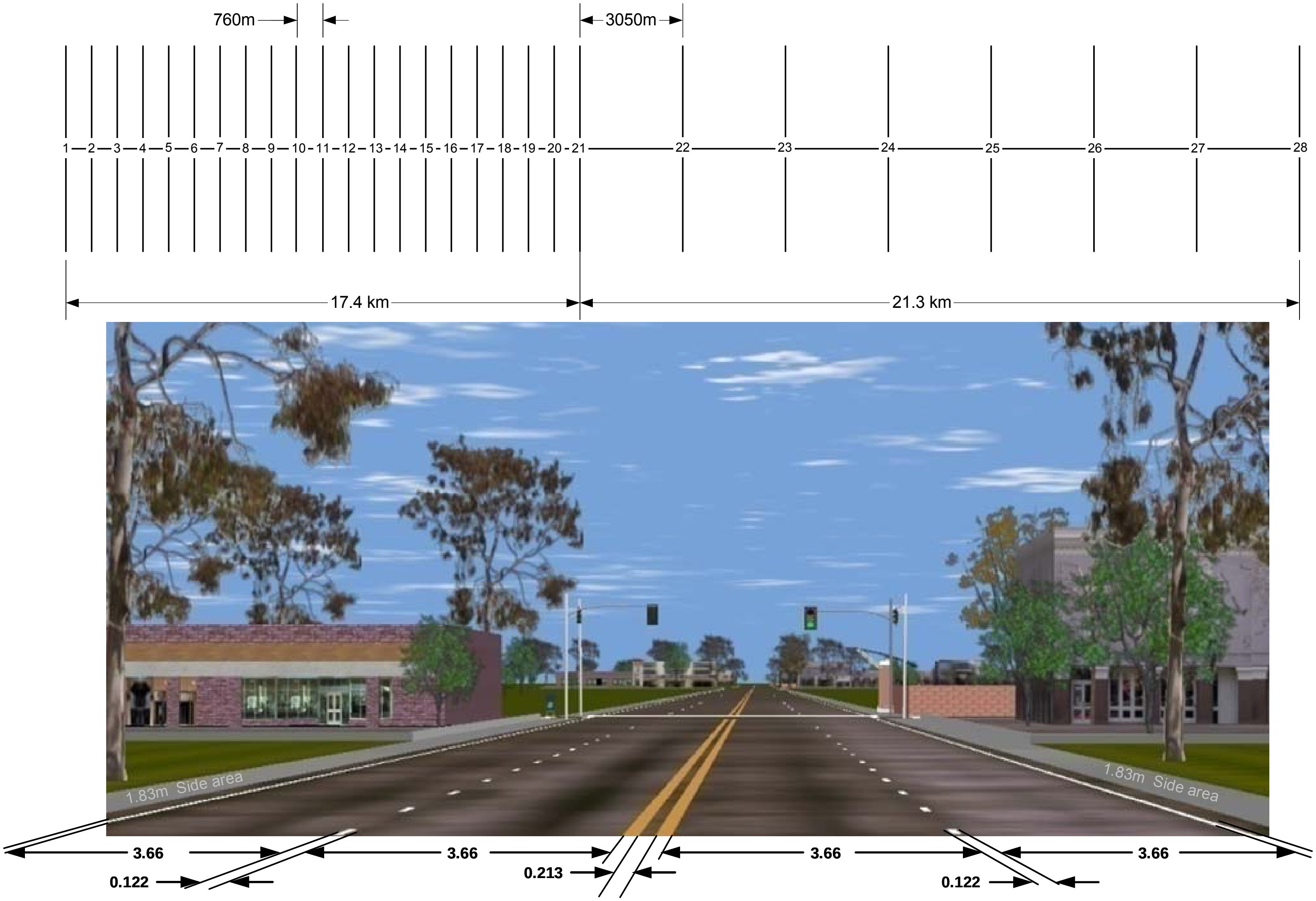


Figure 3. Roadway Geometry

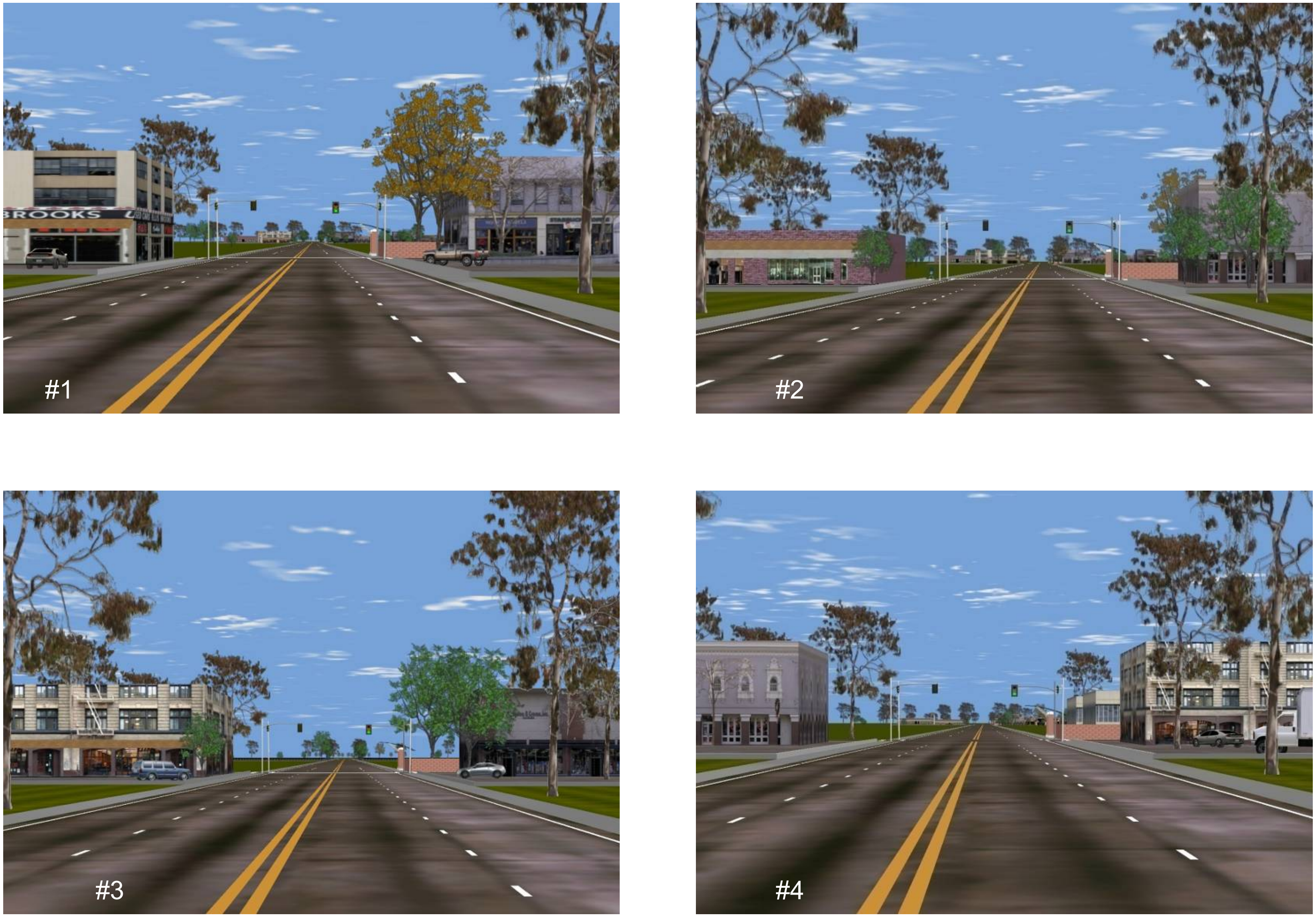


Figure 4. Example Suburban Intersections

Figure 5. Examples of Rural Intersections

7. Riding Scenarios and Tasks

Riding scenarios were designed to present the rider-participants with a range of braking situations. Note that in the context of this report, the word scenario is used to describe a series of events or circumstances presented to the rider for the purpose of eliciting a control response from the rider, in particular a braking control response. Typically, this was accomplished by having an interacting vehicle do something that required braking by the rider, although traffic lights were also used. The focus of this study was on rider braking behavior in emergencies. Because these situations are relatively uncommon in everyday riding, it would have been unnatural to present numerous emergency events in a single run. Each run comprised a series of scenarios, separated by periods of "normal" riding. Each of the 2 runs concluded with an emergency scenario. Prior to the emergency braking scenario, other, more typical, braking situations were presented in order to allow the riders to become accustomed to the braking behavior of the simulated motorcycle at various levels. Scenarios were designed to fall into the following general classifications:

- Traffic: These scenarios were intended to allow the rider to become familiar with nearby traffic. Typically, braking was not required in these scenarios, but riders may have braked or prepared to brake.

- Normal braking (NB): These scenarios required braking in the approximate range of 0.1 - 0.2 g.

- Urgent braking (UB): These scenarios required braking in the approximate range of 0.3 - 0.5 g.

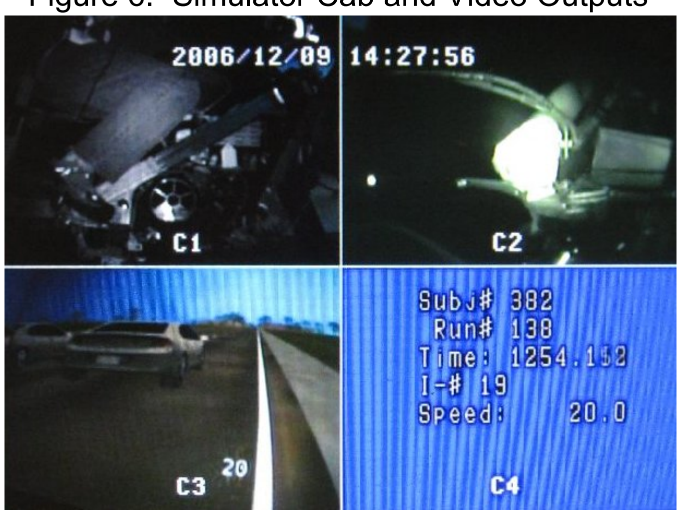
- Emergency braking (EB): These scenarios were designed such that braking in the range of 0.55 – 0.7 g was required in order to successfully complete the maneuver.

Each participant completed 2 runs, one in each direction. Each run included a sequence of 14 scenarios. The details of the scenarios, including the sequence, are described in Appendix A.

8. Video Recording

Two cameras were mounted on the center portion of the handlebars. One of these was used to record the rider-participant's forward view; the second was aimed at the participant-rider's face in order to help monitor the participant from the control room. Video from this camera was not recorded. A third camera was aimed to capture the rider's right hand and front brake lever control, and a fourth captured the rider's right foot and rear brake pedal control. Video signals from the forward view, right hand and right foot were routed to a splitter to enable simultaneous recording of the 3 signals, and then to a DVD recorder. Figure 6 shows a typical scene taken during the study. These video data were collected for archival and data interpretation purposes.

Figure 6. Simulator Cab and Video Outputs



(clockwise: participant's right foot, participant's right hand, run information, forward view)

C. RIDER PARTICIPANT SELECTION AND PROTOCOLS

A cross-section of riders representative of the general riding population were recruited to participate in the study. Potential participants were screened on factors such as age, years of riding experience, motorcycle(s) currently owned or ridden, involvement in motorcycle crashes, type of riding, and other demographic factors. In particular, factors included:

- Rider age
- Nature of majority of riding – weekend rides or commuting
- Riding experience over the last 3 years – miles/year

Participants' ages ranged from 20-60 years, with approximately uniform distribution over that range. Other demographic factors were collected for possible correlation analysis. These included: motorcycle rider training experience, miles ridden in recent years, types of motorcycle owned and/or ridden, and some (self reported) assessment of the rider's attitude or risk taking proclivity. A total of 68 riders participated in the main tests. The riders were all males (gender effects were not studied).

1. Recruiting and Screening

A number of sources were used to recruit typical rider participants for this study. DRI keeps a database of people who participate in Driving Simulator and other studies. The database includes information on driver license types, so as a first step, participants from previous Driving Simulator studies having motorcycle licenses were contacted. An advantage of this group was that they are familiar with the Simulator and associated procedures. Other methods were used to recruit new participants. Messages were posted with various local internet rider groups, and initial response from these internet postings were fairly brisk, though most of the interested parties were over 40 years of age and tended to be sport-touring riders. To find riders with a cruiser preference, local chapters of Harley

Owners Group were contacted, and local Harley-Davidson dealerships were asked to post a flier in their shops. The response from this was adequate, though again most of the responders were over 40 years of age. A message posted on Craigslist yielded numerous responses from younger riders. All recruitment material directed interested parties to contact a DRI staff member via phone or email and complete a short questionnaire which included questions regarding their riding history and other information. These responses were compiled and reviewed, and qualified candidates were contacted to confirm their interest and schedule further screening and a possible study time and date.

2. Participant Protocols and Experimental Procedures

Upon arrival at DRI, participants were greeted by a Research Assistant (RA) and escorted to a participant waiting room adjacent to the Simulator. Participants were given an information packet explaining the general nature of the study, the protocols and procedures to be used, and the safety precautions including procedures to be followed in the event of a simulator emergency. The participants were asked to carefully review these documents and discuss and questions with the RA. These documents are given in Appendix B.

Prior to beginning an experimental session, the participants were asked to fill out a riding experience questionnaire which included questions about their riding experience, style and preferences. After completing the riding session, participants were asked to fill out a post-session questionnaire which included questions that related to the scenarios they experienced during the study. A copy of each questionnaire is contained in Appendix B. The responses to the questions are summarized in Appendix D.

In addition to the questionnaires, all participants were given visual acuity and peripheral vision tests. They were also asked to take a hand grip strength measurement test with their right hand using the Seahan Hydraulic Hand Dynamometer. Participant was asked to squeeze the dynamometer with as much force as possible. Results were recorded to the nearest kilogram force.

This study was accomplished with the review, approval, and oversight of the DRI Institutional Review Board (IRB). This included a review of the Plan, protocols, and other procedures undertaken to ensure the safety and well being of the participants.

D. EXPERIMENTAL PROCEDURES

1. Safety Precautions

Extensive safety precautions and procedures are in place in the Driving Simulator and the DRI facility, in general. Some additional steps were taken peculiar to the motorcycle cab version, and this study in particular.

Participants were requested to arrive at DRI prepared to wear long pants and close-toed shoes, and to bring riding gloves to wear during the session. During simulator runs riders were required to wear an approved DOT (Department of Transportation) open-faced motorcycle helmet that was properly sized and adjusted. The helmets were connected to the simulator operations intercom to allow communication between the rider and RA.

As an added precaution, a safety harness was worn while seated on the simulator cab. The harness was an industrial type fall harness with straps around the legs, arms and across the chest, and a “D” ring on the back between the shoulders. The “D” ring was attached to a strap, the other end of which was attached to hard points on the simulator platform. The harness and strap assemblies were adjusted for comfort and to allow the necessary range of motion for riding.

2. Run Procedures and Schedule

After completing the questionnaires, discussing any questions, and completing the preliminary tests, the riders were escorted to the simulator platform by the RA. There the RA reviewed the safety instructions, and assisted the rider into the safety harness and helmet. Upon completion of these tasks, the RA went to the control room to oversee the session. The platform was elevated and the warm-up run started. The warm-up run was intended to familiarize the rider with the properties of the simulated motorcycle simulator and to become acquainted with the roadway. The length of the warm-up run was dependant on the time required for the rider to become familiar and at-ease with the simulator, similar to becoming comfortable with an unfamiliar motorcycle. Research staff would offer assistance as needed. Warm-up runs were not restricted in time but most participants completed them in a few minutes.

To minimize any steering difficulties associated with the BikeSim model, the low speed stability characteristics of the motorcycle simulator were explained to the riders. They were informed that the simulated motorcycle simulator was most stable above 30mph and that when starting from rest or accelerating from below that speed they should attempt to reach that speed quickly and minimize steering activity below that speed.

The main runs proceeded in a similar manner to the warm-up. The same road was used but braking scenarios were added throughout. Details of scenarios are found in Appendix A. The run schedule is summarized in Table 1. The first roadway took approximately 25 minutes to complete, after which, participants took a short break and then continued with the second roadway. The second, and last roadway, took another 25 minutes to complete. After the completion of the simulator portion of the study, riders were escorted back to the waiting area and asked to fill out a post-session questionnaire. When the questionnaire was complete, each participant was given an honorarium and thanked for their participation. Their general well being was ensured before they left the facility.

Detailed instructions and study procedures are contained in Appendix C of this report.

Table 1. Run Schedule

Description	Estimated Time to complete
Review of study materials with Research Assistant, including completion of necessary paperwork	25 min
Warm-up and familiarization	As needed
Roadway 1	30 min
Break	10 min
Roadway 2	30 min
Debriefing	As needed
Approximate Total Time	100 min

E. DATA ANALYSIS

1. Experimental Measures

The data channels recorded are listed in Section II B4, above. These raw data were post processed to develop the quantitative response and performance measures listed in Table 2 that were used for analysis.

Table 2. Response and Performance Measures

Measure	Notes	Mnemonic
Front brake reaction time (sec)		F_ReacTime
Front Peak Control Force Overall (g commanded)	1	F_Peak_CF_g
Front Peak Control Force Rate Time (sec)		F_Peak_CF_time
Front Peak Control Force Rate Time (sec)		F_Peak_CF_dot_g
Front Duration of Brake Input (sec)		F_InputDuration
Front Mean Control Force (g commanded)	1	F_Mean_CF_g
Front Mean Square Deviation of Control Force (g commanded^2)	1	F_MS_Dev_CF_gsq
Front Mean Control Force to 80% of Speed (g commanded)	1,2	F_Mean_CF_80_g
Rear Reaction Time (sec)		R_ReacTime
Rear Peak Control Force Overall (g commanded)	1	R_Peak_CF_g
Rear Peak Control Force Rate Time (sec)		R_Peak_CF_time
Rear Peak Control Force Rate Time (sec)		R_Peak_CF_dot_g
Rear Duration of Brake Input (sec)		R_InputDuration
Rear Mean Control Force (g commanded)	1	R_Mean_CF_g
Rear Mean Square Deviation of Control Force (g commanded^2)	1	R_MS_Dev_CF_gsq
Rear Mean Control Force to 80% of Speed (g commanded)	1,2	R_Mean_CF_80_g
Mean Longitudinal Acceleration (g)	1	MeanAx
Peak Longitudinal Acceleration (g)	1	PeakAx
Peak Pitch Angle (deg)		PeakPitchAngle (deg)
Front Peak Longitudinal Slip Ratio (0 to 1)		F_Peak SlipRatio
Rear Peak Longitudinal Slip Ratio (0 to 1)		R_Peak SlipRatio
Peak to Peak Lateral Lane Deviation (m)		PP_LatLaneDev
Mean Square Lateral Lane Deviation (m^2)		MS_LatLaneDev
Peak to Peak Roll Angle (deg)		PP_Phi
Peak to Peak Steer Angle (deg)		PP_Delta
Mean throttle (%)		MeanThrottle
Initial Speed (km/h)		InitialSpeed
Collision		Collision
Collision Speed (km/h)		CollisionSpeed
Run aborted		RunAborted
Speed when run aborted (km/h)		AbortSpeed
Front to rear brake distribution for means (%F commanded g)	3	FrontRearDistribution
Front to rear brake distribution to 80% of initial speed (%F commanded g)	2,3	FrontRearDistribution80
Deceleration needed so as not to hit oncoming vehicle for selected runs (g)	4	axneeded
Front brake, area under commanded g curve multiplied by time (1st moment)	5	ATF

Measure	Notes	Mnemonic
Front brake, area under commanded g curve	5	AF
Rear brake, area under commanded g curve multiplied by time (1st moment)	5	ATR
Rear brake, area under commanded g curve	5	AR
Area under Ax curve multiplied by time (1st moment)	5	ATAx
Area under Ax curve	5	AAx
Area under front brake commanded g curve at 1.2 sec (g-sec) for selected runs	5	AF_12
Area under front brake commanded g curve at 1.4 sec (g-sec) for selected runs	5	AF_14
Area under front brake commanded g curve at 1.6 sec (g-sec) for selected runs	5	AF_16
Area under front brake commanded g curve at 1.8 sec (g-sec) for selected runs	5	AF_18
Area under front brake commanded g curve at 2.0 sec (g-sec) for selected runs	5	AF_20
Area under rear brake commanded g curve at 1.2 sec (g-sec) for selected runs	5	AR_12
Area under rear brake commanded g curve at 1.4 sec (g-sec) for selected runs	5	AR_14
Area under rear brake commanded g curve at 1.6 sec (g-sec) for selected runs	5	AR_16
Area under rear brake commanded g curve at 1.8 sec (g-sec) for selected runs	5	AR_18
Area under rear brake commanded g curve at 2.0 sec (g-sec) for selected runs	5	AR_20

Notes

1. All control force data were converted to equivalent commanded "g" by multiplying the force data by the brake gain for each control. This was necessary because front and rear brake gains, i.e. the amount of deceleration that results from a given input force, are not typically equal for front and rear brake controls. By making this conversion, the relative contributions of front and rear braking can be compared on an equivalent basis.
2. Values reported at 80% of initial speed were intended to capture information on the initial portion of braking.
3. Front to rear brake distribution represents the percentage of total commanded braking attributed to the front brake. It was calculated as follows:

$$\text{F/R distribution} = 100\ x\ \frac{a_{x\ commanded\ front}}{a_{x\ commanded\ front} + a_{x\ commanded\ rear}}$$

where:

$a_{x\ \text{commanded front}}$ = the commanded mean front brake force in equivalent "g"
$a_{x\ \text{commanded rear}}$ = the commanded mean rear brake force in equivalent "g"

A value of 100% means all braking was done using the front brake, a value of 50 means the braking was evenly divided between front and rear, and a value of 0 means all braking was done with the rear brake.

4. "Deceleration needed" was a measure calculated for selected, collision prone, scenarios. These scenarios were designed to trigger the motion of potential collision partner based on the subject vehicle speed, such that a specific level of braking was needed on the part of the subject vehicle to avoid collision. It was used in conjunction with average deceleration to compute to calculate a percentage of under or over braking by a rider-participant in those scenarios.

5. First moment values were calculated as:

$$AT = \sum_{k=k_0}^{n} a_x t_k \Delta t$$

Area or summation values were calculated as:

$$A = \sum_{k=k_0}^{n} a_x \Delta t$$

where:

AT =

- ATF - Front brake, area under commanded g curve multiplied by time
- ATR - Rear brake, area under commanded g curve multiplied by time
- ATAx - Area under Ax curve multiplied by time

A =

- AF - Front brake, area under commanded g curve
- AR - Rear brake, area under commanded g curve
- AAx - Area under longitudinal acceleration curve
- AF_12 - Area under front brake commanded g curve up to 1.2 sec
- AF_14 - Area under front brake commanded g curve up to 1.4 sec
- AF_16 - Area under front brake commanded g curve up to 1.6 sec
- AF_18 - Area under front brake commanded g curve up to 1.8 sec
- AF_20 - Area under front brake commanded g curve up to 2.0 sec
- AR_12 - Area under rear brake commanded g curve up to 1.2 sec
- AR_14 - Area under rear brake commanded g curve up to 1.4 sec
- AR_16 - Area under rear brake commanded g curve up to 1.6 sec
- AR_18 - Area under rear brake commanded g curve up to 1.8 sec
- AR_20 - Area under rear brake commanded g curve up to 2.0 sec

a_x = acceleration variable value at each step, (front commanded, rear commanded or vehicle deceleration)
k = index variable related to each data point
k_0 = start point of summation
n = end point of summation

t = time value at each step
Δ_t = time step

For these values the summation was started when potential collision partner began to move (the initial braking stimulus). The end point was either the time at which the subject motorcycle slowed to 16 km/h or the time at which the subject motorcycle reached a collision point. The exceptions are the values that were computed over a specific value of time, e.g., AR_12 was calculated for 1.2 seconds after the start point.

2. Principal Components Analysis

In several cases the regressions were performed using principal components derived from Principal Components Analysis of rider factors. Principal Component Analysis (PCA) is a mathematical procedure that transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible.

The results of the PCA for rider-participants having valid data for scenarios EB-2 and UB-4 are given in Table 3. The rider factors were grouped into 3 components, as follows:

– Component 1 (Distance) is primarily composed of measures of distance traveled recently: Miles Ridden in 2008, Group Riding Miles in 2008, and Average Miles per Year from 2006 to 2008.

– Component 2 (Years) is primarily composed of measures of total riding experience: Age, Total Years Riding, and Skill Rating.

– Component 3 (Frequency) is primarily composed of measures of riding frequency and type of riding: Rider Frequency Rating, Commuting Miles in 2008, and Aggressiveness Rating.

Table 3. Principal Components for Rider Factors

Rider Factors	Component		
	1	2	3
Miles Ridden (2008)	**.969**	-.042	.182
Group Riding Miles (2008)	**.967**	-.083	-.096
Average Miles / Year (2006 - 2008)	**.778**	.128	.515
Age	-.106	**.946**	-.073
Total Years Riding	.035	**.945**	-.100
Skill Rating	.023	**.394**	**.305**
Ride Frequency Rating	.175	-.009	**.824**
Commuting Miles (2008)	.018	-.015	**.823**
Aggressiveness Rating	.202	-.199	.242

3. Logistic Regression

Logistic regression can be a useful method for studying data such as these where the dependent variable is dichotomous. Logistic regression attempts to fit data to an equation of the form:

$$\theta = \frac{e^{(\alpha+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_i x_i)}}{1+e^{(\alpha+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_i x_i)}}$$

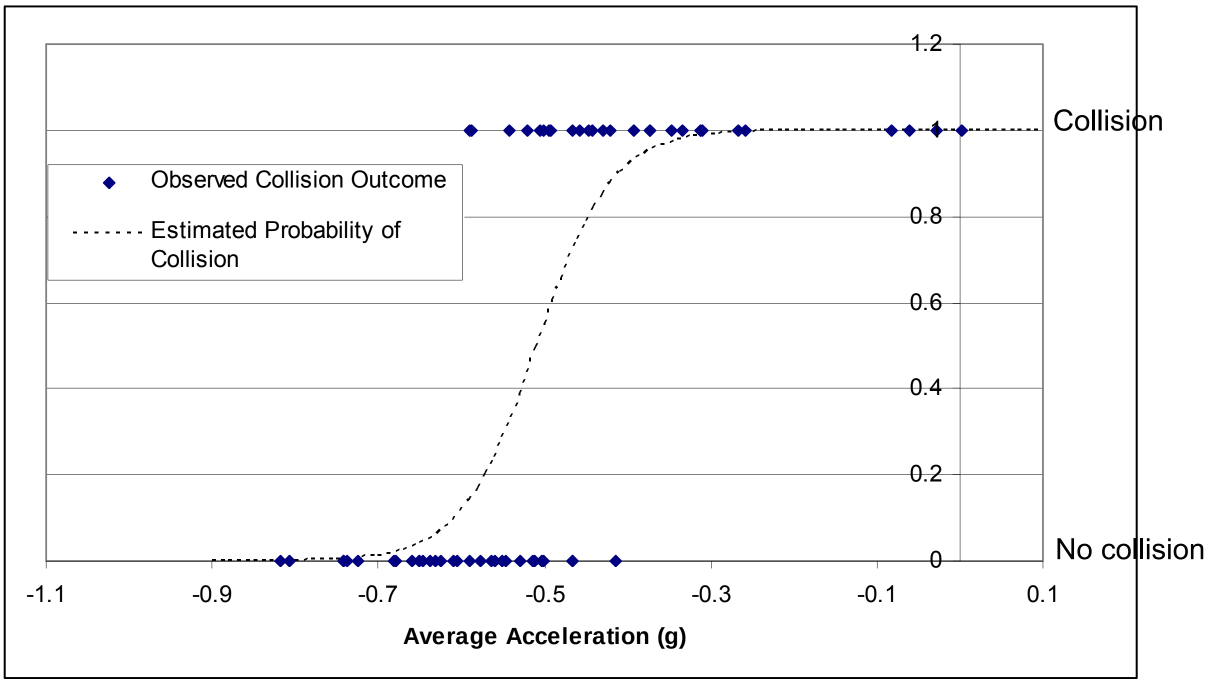
where:

θ = estimated probability of collision or capsize
α= constant, (the probability of occurrence when the independent variables all equal zero)
β_i = coefficients for each independent variable
x_i = independent variables

An example logistic regression for Scenario EB-2 is shown in Fig 7. In this example the occurrence of collision was the dependent variable, and average acceleration was the single independent variable. A value of 0 means there was no collision, and a value of 1 means there was a collision. The data are fitted with a curve of the form shown above and having:

$$\alpha = 11.35 \quad \beta = 22.28$$

Figure 7. Example Results for Logistic Regression



Single and multi-variable logistic regression methods were used to relate the true/false event outcomes with computed braking measures, including those related to rider braking behavior. Independent measures included:

- Front brake reaction time
- Peak front brake command
- Time of peak front brake command
- Rate of front brake command leading to peak value
- Duration of front brake command

- Average front brake command
- Mean square of front brake command
- Average front brake command (g) at 80% of initial speed
- Rear brake reaction time
- Peak rear brake command
- Time of peak rear brake command
- Rate of rear brake command leading to peak value
- Duration of rear brake command
- Average rear brake command
- Mean square of rear brake command
- Average rear brake command (g) at 80% of initial speed
- Average longitudinal acceleration
- Peak longitudinal acceleration
- Peak slip ratio-front
- Peak slip ratio-rear
- Area under rear brake command at 1.2, 1.4, 1.6, 1.8, and 2.0 seconds
- Area under front brake command at 1.2, 1.4, 1.6, 1.8, and 2.0 seconds
- Area under front brake command multiplied by time
- Area under front brake command
- Area under rear brake command multiplied by time
- Area under rear brake command

Dependent, true/false measures included the occurrence of:

- Collision, defined as overlap of the footprints of the subject vehicle and other vehicle(s)
- Capsize, defined as
    - Roll Rate $\geq$ 60.0 degrees/sec
    - Pitch Angle $\geq$ 6.5 degrees
    - Yaw Rate $\geq$ 33.0 degrees/sec

Note that a large number of candidate models (e.g., 40) were considered in order to not exclude any variables that could potentially influence the outcome. As a result of the large number of “Multiple Comparisons” (Ref 5) that were tested, some models may fit better or worse than would be expected due to chance. Therefore the reported confidence intervals for the best fitting model coefficients may tend to over state the statistical significance of these terms. Correcting the reported confidence intervals for Multiple Comparisons was outside the planned scope of this project.

F. SIMULATOR VALIDATION

A variety of experimental procedures can be used to "assess the risk of real world crashes." These can include vehicle operation on a closed course, over-the-road studies, or the use of a driving simulator. In general, the risk of a real world crash involves driver (rider), vehicle, and environmental factors; separately or in combination. In this study the primary factor effecting the risk of a crash was rider behavior in response to various braking tasks. The ways in which a crash might occur are many and varied, and the pertinent ones are well known (e.g., front wheel lockup) or discussed in the report.

The "distinction between real-world and simulator results" relates to the issue of simulator validation. There is a large body of work on this topic, in general, and it has been addressed specifically over the past 15 years in the DRI simulator. Validity depends on the features and quality of the simulator, the driving or riding tasks of interest, and the purpose of the study, among other things. The DRI simulator is a highly refined, research grade, large scale, moving base device. It has high resolution graphics and a very low throughput time delay. The motorcycle configuration is particularly high fidelity in terms of its cab (controls, etc.) features, the motion cue environment, and the visual image. In those regards, as a motorcycle simulator it has no peer and is unique in the world.

The automobile (car cab) version of the simulator has been validated in various ways over its more than 15 year period of operation. Basically, a simulator is a tool to study operator (rider, driver) behavior in terms of control response, operator/vehicle response and performance, and subjective opinion or assessment. Glance behavior and other psychophysical measures can also be useful in some studies. Various comparisons of operator response and performance between simulator and actual vehicle operation have been made over the years with good results. The best agreement occurs when a differential effect is being studied such as the effect of a change in a task parameter which results in a change in operator behavior. Absolute comparisons can also be made. To cite one example, (Ref 6) driver describing functions for directional control were measured for a down-the-road regulation task in both the simulator and a variable stability research vehicle. The 2 setups had similar vehicle dynamics and the same disturbance inputs were used in both cases. The driver describing function results showed similar steering control gains and stability margins, with the main differences being in the on-the-average driver time delay. The driver time delay measured in the driving simulator was about 0.2 seconds larger than in the actual vehicle. This could be attributed in part to the visual image generator lag (about 70 ms). Also, the fact that the simulator was run fixed base (no motion cueing) in that study resulted in an additional lag increment of about 100 ms which is consistent with previously reported effects of motion vs. no motion in simulator studies (e.g., Ref 7). Of course, this additional 100ms delay would not be applicable to the current study as full motion cues were used.

Another direct comparison can be made in rider braking response behavior between this study and recent braking studies with actual contemporary motorcycles. Comparison with these yet-to-be published full scale test results show that, where comparisons could be made, riders use similar front/rear braking combinations and levels of control effort in high level braking tasks in both the simulator and with actual vehicles. Subjectively, the riders found the brake control feel characteristics and the simulated braking tasks to be acceptably realistic in the riding simulator.

Section III
RESULTS

As stated in Section I the objective of this study was to gain a better understanding of how non-expert motorcycle riders use conventional brake systems in emergency braking situations. Example questions that were to be answered included:

- Which brake do riders use when faced with an emergency situation requiring braking – front, rear, or both?

- Are there rider braking behaviors than can be identified and used to predict the outcome of a possible collision event?

- Do rider factors such as age, experience, preferred motorcycle type, rider training etc. influence braking behavior?

The first question was addressed by analyzing the calculated front/rear braking distribution for both typical and emergency events.

The second question was addressed by considering possible outcomes of the potential collision event to be a collision, no collision, or loss of directional control; and performing a series of logistic regressions between event outcome and braking parameters.

Relationship between rider factors, event outcome and braking behavior were studied using logistic and linear regression, and principal components analysis.

A. FRONT/REAR BRAKE USE AND RELATIONSHIP TO RIDER FACTORS

1. Front/Rear Brake Use

Figure 8 shows a distribution plot of relative front/rear brake used by all riders for all scenarios completed. A value of 50 means both brakes were used evenly, a value of 100 means only the front brake was used, and a value of 0 means only the rear brake was used.

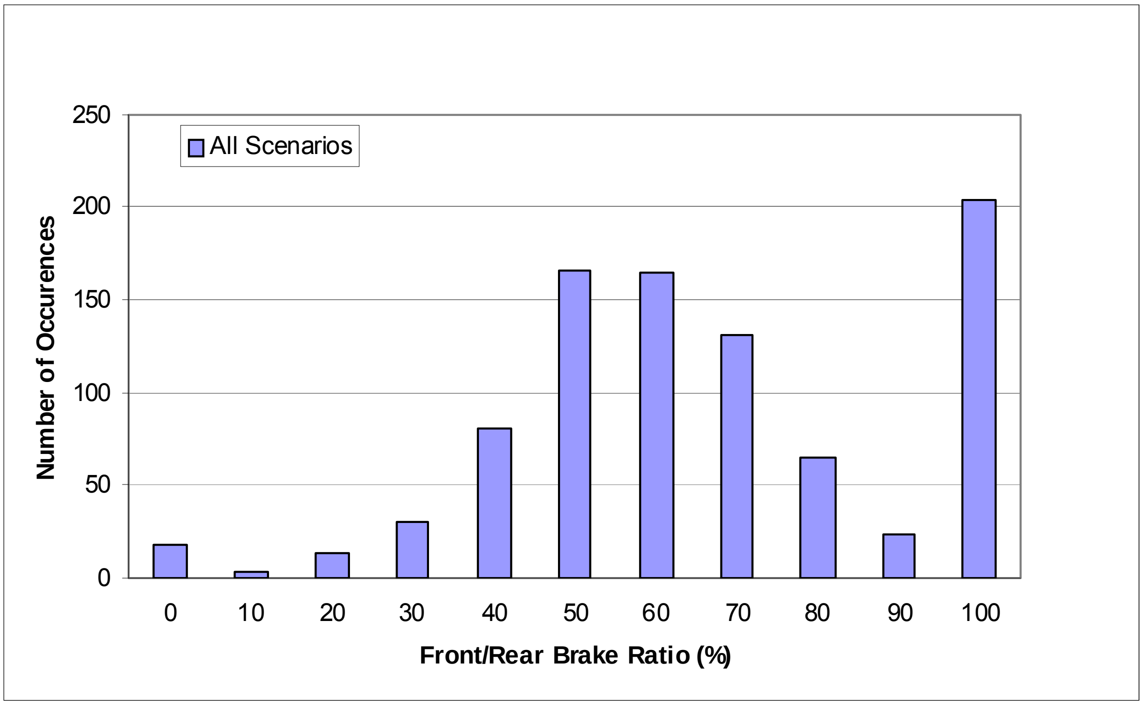


Figure 8. Distribution of Front/Rear Braking for
All Participants and All Braking Scenarios

Figure 8 shows a relatively normal distribution around 50-60% front/rear brake use, meaning that the rider is using both brakes to equal effect. But there are a large number of cases where only the front brake was used, and a few cases where only the rear brake was used. There were 6 riders who used only the front brakes for all or nearly all stopping scenarios. These 6 riders account for approximately one-half of the front brake only cases. Five of these 6 riders were classified sport-touring. There were 21 cases where only the rear brake was used. Thirteen different riders used rear only for at least one scenario, 11 of these riders were classified cruiser, and 2 sport-touring. Of the 21 rear only cases, 19 were classified as normal braking scenarios.

The scenarios with the highest incidence of collisions were used as a subset of the data to study front/rear braking behavior in emergency situations. Table 4 shows the number of collisions for scenarios where at least one collision occurred. It can be seen that the majority of the collisions occurred for scenarios EB-1, EB-2 and UB-4.

Both of the emergency braking maneuvers (EB-1 and EB-2) were designed with the possibility of collision, and to require a relatively high level of braking to avoid it. However, the EB-1 scenario triggers did not function consistently for all participants, so participants experienced the scenario with various levels of braking required. The analysis of emergency events focused on scenarios EB-2 and UB-4. Both scenarios had an initial speed of 64 km/h (40 mph), but the required braking level for EB-2 was approximately 35% higher than that for UB-4.

Both scenarios occur in a city/suburban section of the roadway where the posted speed limit is 40 mph. In scenario UB-4 the subject vehicle (motorcycle) approaches an intersection showing a red light in the direction of travel. Cross traffic is moving through the intersection. When the subject motorcycle gets close to intersection the light changes to green. Cross traffic stops except one vehicle, the collision partner, runs the red light. The motion of the collision partner is based on the speed of the subject motorcycle such that braking at an average of 0.5 g braking is required to avoid a collision. The timing assumes a one second rider reaction time.

Table 4. Number of Collisions by Braking Scenario

Scenario	Description	Number of Collisions
EB-2	Tractor-Trailer combination pulls out slowly from cross street on participant's right. Participant's path is blocked. Timing of event requires a 0.7 g[2] stop to avoid hitting the Other Vehicle.	30
UB-4	Subject Motorcycle approaches intersection with red light. Cross traffic is moving through the intersection. When Subject Motorcycle gets close to intersection light changes to green. Cross traffic stops except one vehicle runs the light. Timing of maneuver requires 0.5 g braking to avoid collision	22
EB-1	Participant is instructed to enter left lane. Traffic vehicle comes from behind and occupies Subject Motorcycle 1 o'clock position on roadway, same speed as Subject Motorcycle. At intersection, oncoming Other Vehicle turns left in front of Subject Motorcycle and stops, blocking intersection.	14
NB-2b	Other Vehicle 200 ft ahead of Subject Motorcycle in same lane. Other Vehicle signals right, brakes and executes right turn. Timing of event requires 0.1 g braking by Subject Motorcycle to avoid closing within 150 ft	1
NB-8	Other Vehicle (visible) on cross street perpendicular to participant's path stops at stop sign and then crosses Subject Motorcycle lane. Timing is based on Subject Vehicle speed such that 0.2 g braking is needed.	1
UB-1	Other Vehicle passes the Subject Motorcycle on the left and enters the Subject Vehicle lane 100 ft ahead of it. The Other Vehicle maintains the speed of the Subject Motorcycle for 1 minute then slows. Second Other Vehicle (Other Vehicle 2) in left lane at Subject Motorcycle speed - 10 mph. When Subject Motorcycle is in Other Vehicle 2 right rear blind spot Other Vehicle 2 begins to change lanes right without signaling	1

In scenario EB-2 the subject motorcycle approaches an intersection showing a green light in the direction of travel. The rider's view of the cross street

[2] Timing of triggered scenarios where a particular level of braking was required allowed for 1.0 second of reaction time

to the right is partially obstructed by a building. As the rider gets close to intersection a tractor-trailer moves from behind the building on the cross street to the rider’s right and stops at the intersection. As the subject motorcycle is about to enter the intersection the tractor-trailer pulls out suddenly into the intersection and stops, blocking the intersection. The motion of the tractor-trailer is based on the speed of the subject motorcycle such that braking at an average of 0.7 g is necessary to avoid a collision. The timing assumes a one second rider reaction time. When the subject motorcycle gets very close to the tractor-trailer, the tractor-trailer begins to move ahead slowly, allowing the possibility for the rider to steer around it to the right, if he has braked sufficiently up to that point.

Figures 9 and 10 show distribution plots of relative front/rear brake used by all riders for scenarios EB-2 and UB-4 respectively. In these emergency braking scenarios, most riders used more front brake than rear, and a number used only the front brake. Other than those using only front brakes, most riders used between 60 and 70% front brakes. There were no cases below 30% front brake use, and notably, no cases of rear brake only use in these 2 emergency scenarios.

Of the 10 cases for EB-2 where only the front brake was used, 7 were for riders classified sport-touring. Ten of the 14 cases for UB-4 where only the front brake was used were for riders classified sport-touring.

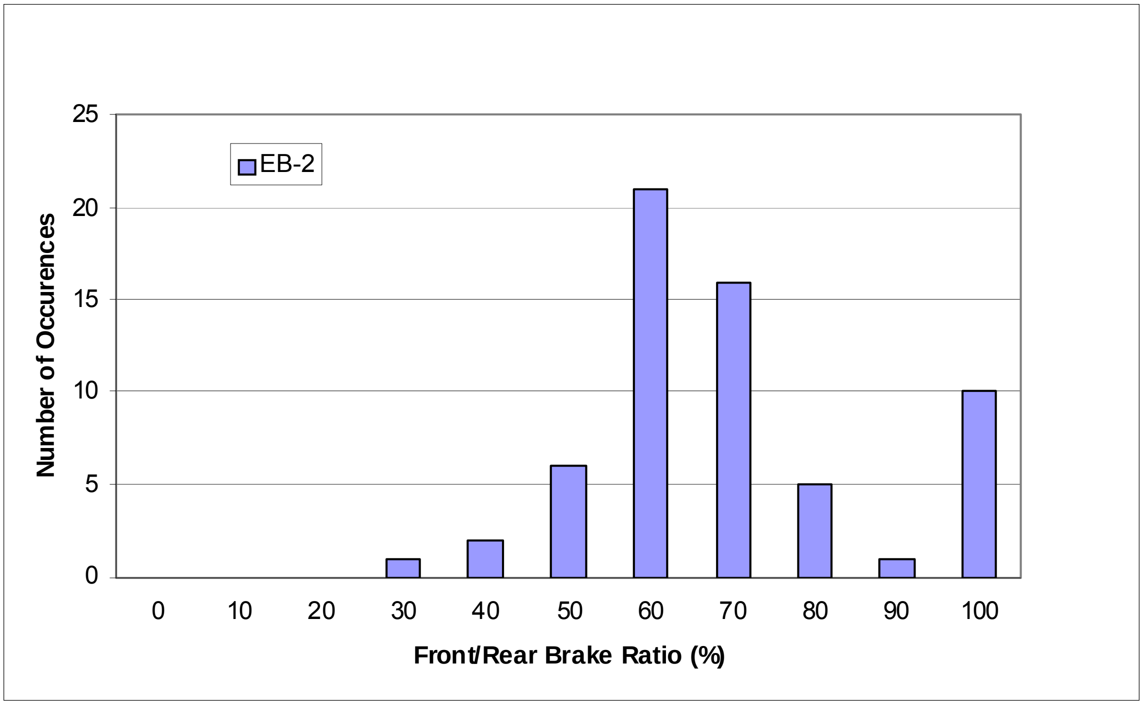


Figure 9. Distribution of Front/Rear Braking for All Participants Scenario EB-2

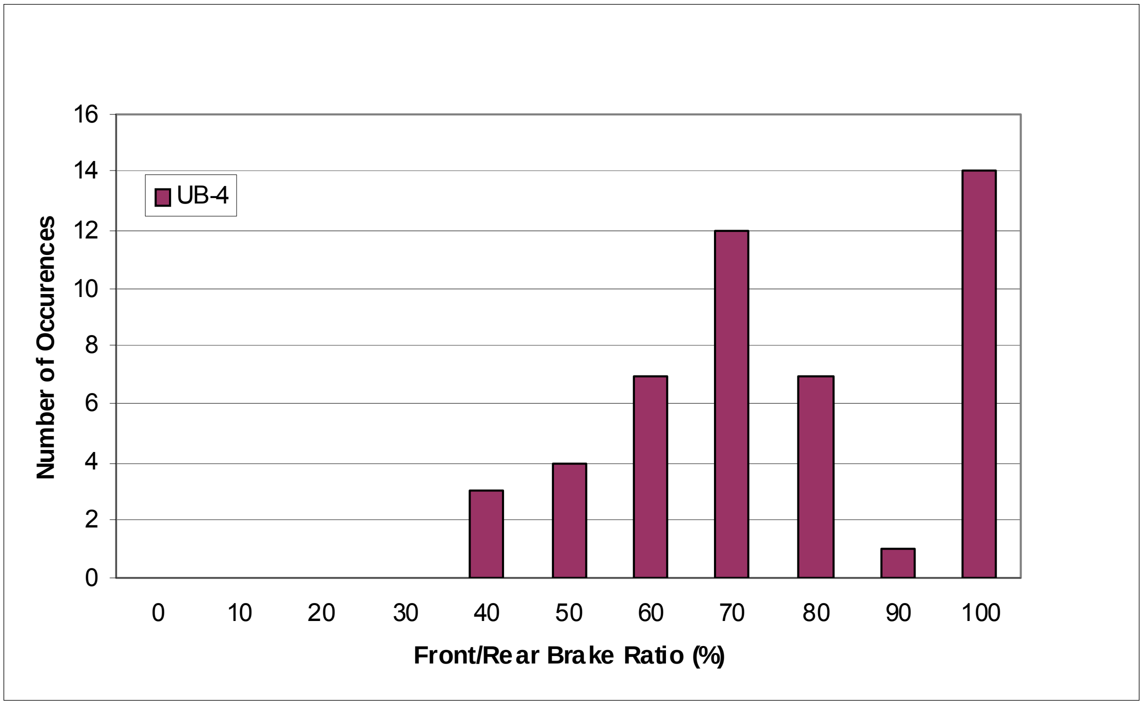


Figure 10. Distribution of Front/Rear Braking for All Participants, Scenario UB-4

2. Relationship of Front/Rear Brake Usage to Participant Factors

Front/rear brake distribution for scenarios EB-2 and UB-4 as a function of type of motorcycle normally ridden is shown in Fig 11. There is no apparent difference, \ and statistical results confirmed this.

Front/rear brake distribution as functions of recent riding experience are shown for scenarios EB-2 and UB-4 in Figs 12-13 Again, there is some scatter, but no particular trend with experience. Most riders used a combination of front and rear brake.

Figure 14 shows, for scenarios EB-2 and UB-4, the result of a logistic regression for the probability of collision as a function of front/rear brake command distribution. The collision results were poorly correlated with front/rear brake distribution, indicating that front/rear brake distribution is not a good candidate for predicting collision.

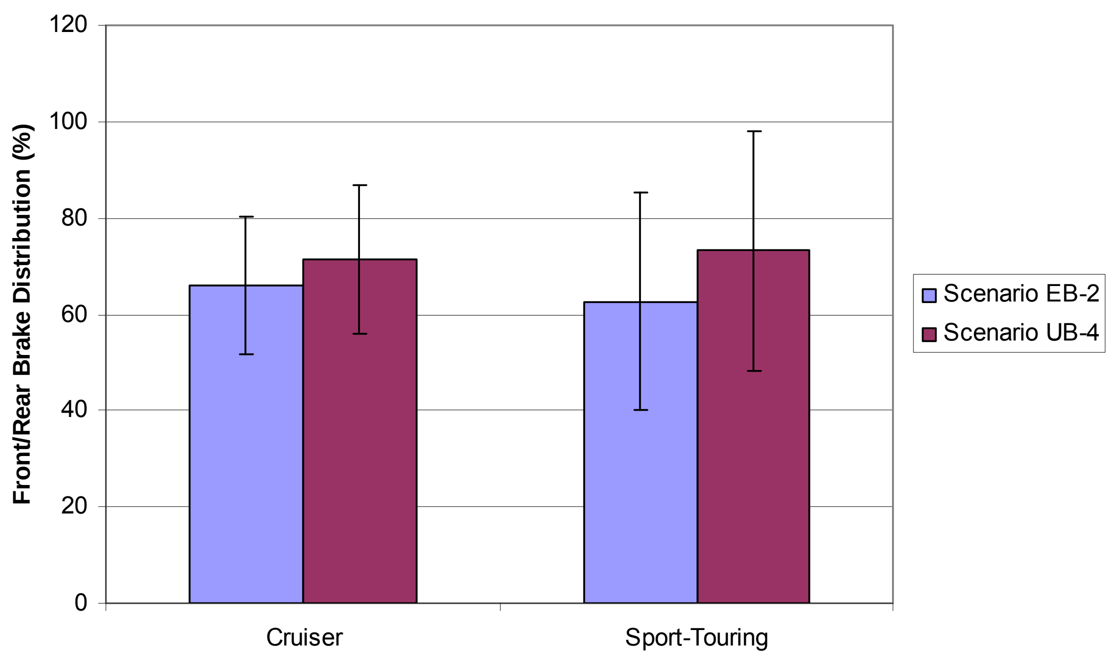


Figure 11 Front/Rear Brake Distribution as a Function of Rider Type

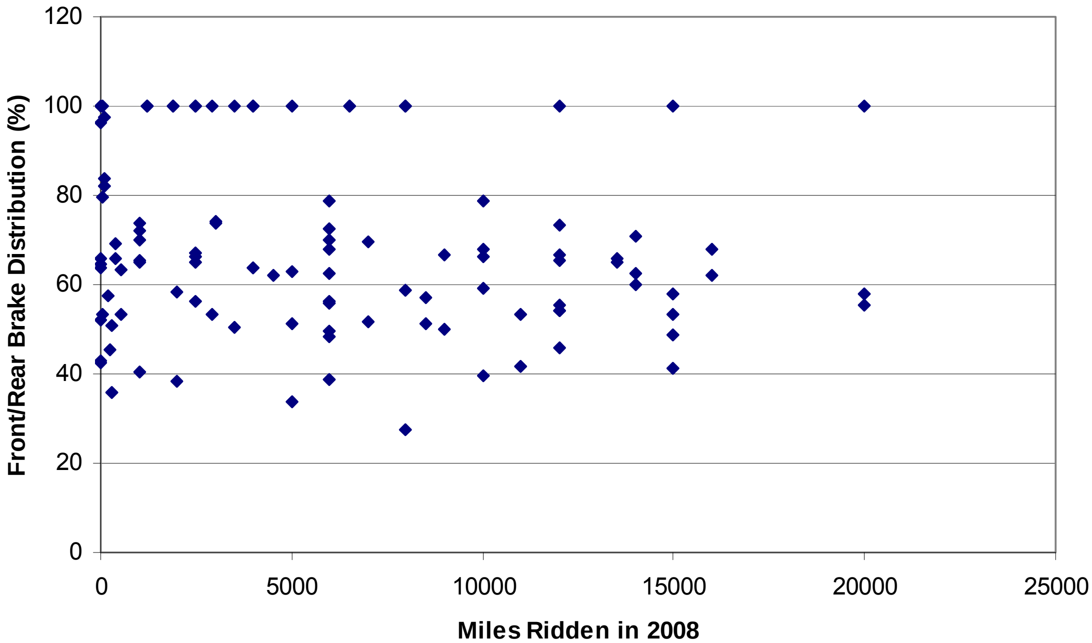
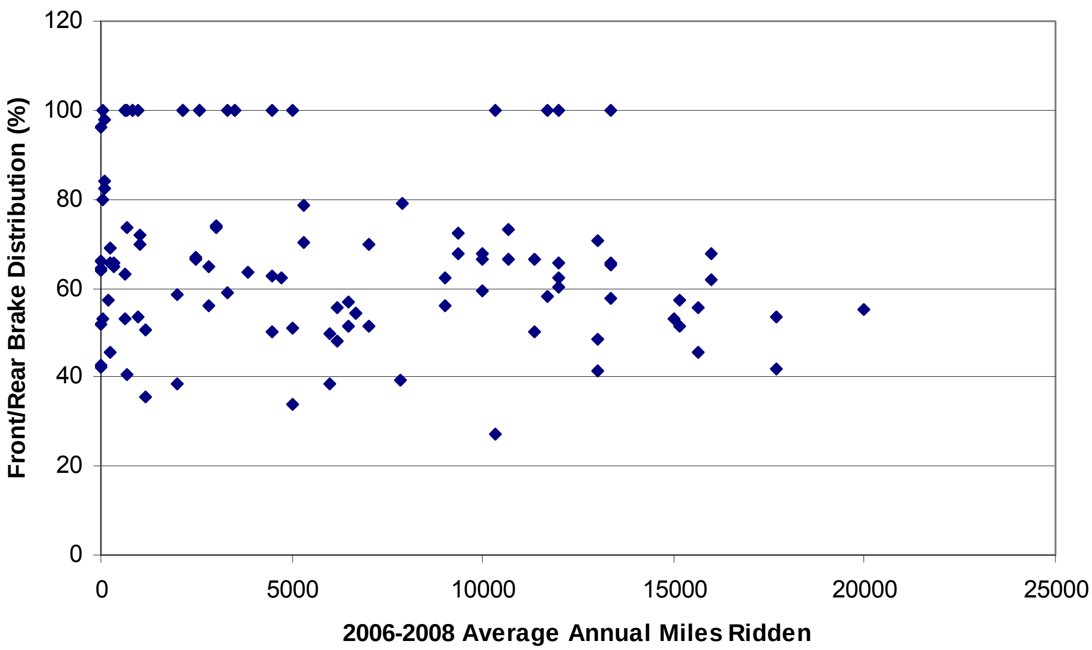


Figure 12. Front/Rear Brake Distribution as a Function of
Miles Ridden in 2008, Scenarios EB-2 and UB-4

Figure 13. Front/Rear Brake Distribution as a Function of Average Miles



Ridden in 2006-2008, Scenarios EB-2 and UB-4

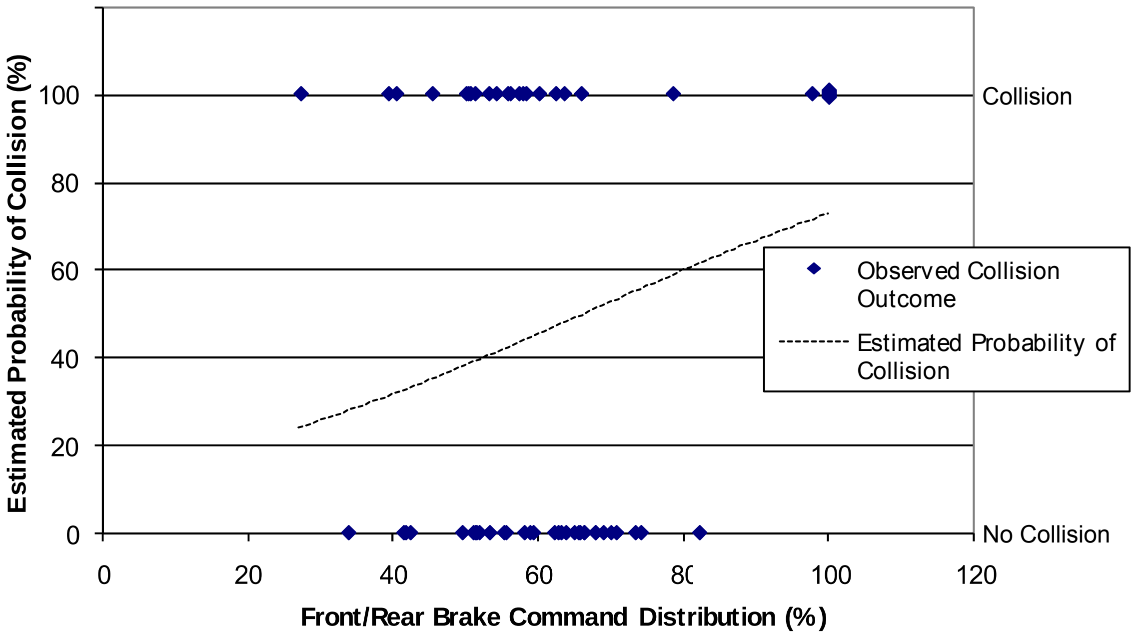


Figure 14. Logistic Regression Result for Estimated Probability of Collision as a Function of Front/Rear Brake Command Distribution for Scenario EB-2

B. BRAKING BEHAVIOR RELATED TO BRAKING EVENT OUTCOMES

The results of the previous section indicate that all riders who participated in this study used a combination of front and rear brake during emergency braking, and that most of the riders used a larger percentage of front brake. There were no apparent patterns of front/rear brake usage related to rider factors such as age, type of bike typically ridden or years of experience. In addition, the relative front/rear brake distribution used appeared to be unrelated to probability of collision. This section presents results that are addressed at identifying rider braking behaviors than might be used to predict the possibility of collision for emergency braking events. The focus is on the previously identified critical events EB-2 and UB-4 (see Table 4). The data were analyzed in terms of possible scenario outcome. For these scenarios there are two types of possible outcome, collision, or capsize resulting from loss of lateral-directional control. In each case the outcome can be either true or false, i.e., either a collision occurs or it doesn't; either capsize occurs or it doesn't.

As described in Section II E, logistic regression was used to analyze event outcome in terms of rider braking behavior factors.

The complete results for all regressions are given in Appendix E.

1. Probability of Collision

Tables 5 and 6 present the summary results of all logistic regressions comparing collision outcomes to braking variables including those related to rider braking behavior. The tables show only those results where the coefficients of the regressed variables were statistically significant. Values less than 0.05 were considered statistically significant. The first column shows the variables used in the model. These include both individual terms, and interaction terms for multiple variable regressions. The interaction terms are shown as the product of terms, e.g., "Area under front brake command at 2.0 seconds X Area under rear brake command at 2.0 seconds." The second column shows the percent of correct predictions that would result from applying the equation. The remaining columns are indicators of how well the models fit the experimental data. The Cox & Snell and Nagelkerke R^2 terms are analogs of the R^2 measure in ordinary least squares regression and indicate variability accounted for by each tabulated model. Cox & Snell R^2 provides a value based on a comparison of the model with only the constant term against the model with all the terms entered. Note that this measure does not have maximum value of 1. The Nagelkerke R^2 adapts Cox & Snell R^2, allowing it to vary between 0 to 1. The Hosmer & Lemeshow value indicates 'Goodness of Fit' of the experimental data to the models. The coefficients that result from the regressions were calculated, but are not shown in these tables.

Table 5. Summary of Logistic Correlation Results for Scenario EB-2 Collisions

Predictor Variables in Model	Overall % Correct	Cox & Snell R^2	Nagelkerke R^2	Hosmer and Lemeshow
Area under rear brake command at 2.0 seconds; Area under front brake command at 2.0 seconds	95.1	0.644	0.859	0.684
Area under front brake command multiplied by time; Area under front brake command ; Area under rear brake command	91.9	0.621	0.828	0.381
Area under rear brake command at 1.8 seconds; Area under front brake command at 1.8seconds	91.9	0.615	0.820	0.862
Area under rear brake command at 1.8 seconds X Area under front brake command at 1.8seconds	91.9	0.600	0.801	0.540
Area under rear brake command X Area under front brake command; Area under rear brake command X Area under front brake command multiplied by time	91.9	0.602	0.804	0.407
Area under rear brake command at 2.0 seconds X Area under front brake command at 2.0 seconds	91.8	0.629	0.839	0.981
Area under rear brake command at 1.6 seconds X Area under front brake command at 1.6 seconds	90.3	0.546	0.728	0.367
Area under longitudinal acceleration multiplied by time; Area under longitudinal acceleration	88.7	0.559	0.746	0.009
Area under rear brake command at 1.6 seconds; Area under front brake command at 1.6 seconds	88.7	0.548	0.731	0.362
Area under rear brake command X Area under front brake command	85.5	.547	.730	0.788
Area under rear brake command; Area under front brake command	85.5	0.533	0.712	0.549
Average longitudinal acceleration	83.9	0.499	0.665	0.699
Area under rear brake command at 2.0 seconds	83.6	0.503	0.671	0.655
Area under rear brake command multiplied by time; Area under rear brake command	82.3	0.487	0.649	0.911
Area under rear brake command at 1.4 seconds	80.6	0.430	0.573	0.765
Area under rear brake command at 1.6 seconds	80.6	0.457	0.610	0.476
Area under rear brake command at 1.8 seconds	80.6	0.478	0.638	0.102
Area under rear brake command at 1.4 seconds; Area under front brake command at 1.4 seconds	80.6	0.497	0.662	0.778
Average rear command (g)	79.2	0.377	0.510	0.563
Area under rear brake command at 1.2 seconds	79.0	0.387	0.516	0.040
Area under front brake command at 2.0 seconds	78.7	0.376	0.502	0.730
Area under front brake command at 1.8 seconds	77.4	0.397	0.530	0.993
Rear brake reaction time	77.4	0.327	0.442	0.878
Average front command (g)	75.8	0.362	0.482	0.234
Peak rear brake command (g)	75.5	0.293	0.397	0.826
Time of peak rear brake command	75.5	0.334	0.453	0.664
Area under front brake command multiplied by time; Area under front brake command	74.2	0.373	0.498	0.822

Predictor Variables in Model	Overall % Correct	Cox & Snell R^2	Nagelkerke R^2	Hosmer and Lemeshow
Area under front brake command at 1.6 seconds	74.2	0.376	0.502	0.907
Peak longitudinal acceleration	74.2	0.376	0.502	0.208
Average throttle	72.6	0.185	0.247	0.295
Time of peak front brake command	71.0	0.125	0.167	0.761
Area under front brake command at 1.4 seconds	69.4	0.355	0.474	0.243
Area under front brake command at 1.2 seconds	66.1	0.273	0.365	0.393
Peak front brake command (g)	66.1	0.199	0.266	0.705
Average front brake command (g) at 80% of initial speed	63.9	0.113	0.150	0.532

Table 6. Summary of Logistic Correlation Results for Scenario UB-4 Collisions

Predictor Variables in Model	Overall % Correct	Cox & Snell R^2	Nagelkerke R^2	Hosmer and Lemeshow
Area under longitudinal acceleration	86.3	0.592	0.795	0.645
Area under front brake command at 2.0 seconds	86.0	0.436	0.584	0.003
Average longitudinal acceleration	85.4	0.393	0.532	0.027
Area under front brake command	84.3	0.532	0.714	0.885
Peak longitudinal acceleration	79.2	0.359	0.485	0.640
Area under front brake command at 1.8 seconds	78.0	0.343	0.459	0.232
Front brake reaction time	77.1	0.357	0..483	0.276
Peak front brake command (g)	77.1	0.275	0.372	0.026
Time of peak front brake command	77.1	0.199	0.270	0.099
Area under rear brake command	76.5	0.351	0.471	0.814
Area under rear brake command at 2.0 seconds	76.0	0.309	0.414	0.724
Average front brake command (g)	75.0	0.247	0.334	0.376
Time of peak rear brake command	74.3	0.167	0.239	0.779
Area under front brake command at 1.6 seconds	74.0	0.271	0.364	0.001
Front to rear brake distribution	72.9	0.090	0.121	0.277
Area under front brake command at 1.4 seconds	66.7	0.218	0.293	0.480
Area under rear brake command at 1.2 seconds	66.7	0.098	0.132	0.209
Area under front brake command at 1.2 seconds	64.7	0.156	0.210	0.037

The approximately 40 logistic regressions performed for collision using EB-2 data produced 6 models having a predictive capability greater than 85%. Of these, 4 models had a predictive capability greater than 90% and Hosmer and Lemeshow “goodness of fit” values greater than 0.5. All of these involved the area under both the front and rear brake command curves or longitudinal acceleration. The highest predictive capability and R^2 was achieved for models comprising the area under front brake command at 2.0 seconds, area under rear brake command at 2.0 seconds, and a constant. These variables represent the area under the front and rear commanded g curves at 2 seconds after the event trigger. The model fit values are given in Table 7.

Table 7. Summary of Logistic Correlation Results for Scenario EB-2 Models Having Greater Than 85% Correct Prediction of Collision, Hosmer and Lemeshow Values Greater than 0.5

Predictor Variables in Model	**Significance**	**Overall % Correct**	**Cox & Snell R^2**	**Nagelkerke R^2**	**Hosmer and Lemeshow**
Area under rear brake command at 2.0 seconds;	.008	95.1	0.644	0.859	0.684
Area under front brake command at 2.0 seconds	.014				
Constant	.009				
Area under rear brake command at 2.0 seconds X Area under front brake command at 2.0 seconds	.004	91.8	0.629	0.839	0.981
Constant	.007				
Area under rear brake command at 1.8 seconds;	.002	91.9	0.615	0.820	0.862
Area under front brake command at 1.8seconds	.008				
Constant	.004				
Area under rear brake command at 1.8 seconds multiplied by Area under front brake command at 1.8seconds	.001	91.9	0.600	0.801	0.540
Constant	.002				

The regressions performed for collision using UB-4 data produced 12 models having a predictive capability greater than 75%. Of these, 5 models had Hosmer and Lemeshow “goodness of fit” values greater than 0.5. These involved longitudinal acceleration terms and area under the front brake command. The best fit involving a command variable was achieved for a model comprising the total front brake command and a constant. The model fit values are given in Table 8.

Table 8. Summary of Logistic Correlation Results for Scenario UB-4 Models Having Greater Than 75% Correct Prediction of Collision, Hosmer and Lemeshow Values Greater than 0.5

Predictor Variables in Model	Significance	Overall % Correct	Cox & Snell R^2	Nagelkerke R^2	Hosmer and Lemeshow
Area under longitudinal acceleration	.000	86.3	0.592	0.795	0.645
Constant	.001				
Area under front brake command	.000	84.3	0.532	0.714	0.885
Constant	.001				
Peak longitudinal acceleration	.000	79.2	0.359	0.485	0.640
Constant	.002				
Area under rear brake command	.000	76.5	0.351	0.471	0.814
Constant	.009				
Area under rear brake command at 2.0 seconds	.001	76.0	0.309	0.414	0.724
Constant	.033				

2. Probability of Capsize

Logistic regression analysis was performed relating occurrence of capsize to braking variables, including those related to rider braking behavior. Tables 9 and 10 present the summary results of all logistic regressions comparing capsize outcomes to braking variables. The tables show only those results where the coefficients of the regressed variables were statistically significant. Values less than 0.05 are considered statistically significant. In general the correlations are not very strong and for EB-2 contain more factors related to rear brake control, whereas those for UB-4 are more related to front brake control behavior. An exception for EB-2 is the model comprising the peak slip ratios of the front and rear wheels, which shows reasonably good correlation, goodness-of-fit and predictive capability.

Table 9. Summary of Logistic Correlation Results for
Scenario EB-2 Capsize

Predictor Variables in Model	**Significance**	**Overall % Correct**	**Cox & Snell R^2**	**Nagelkerke R^2**	**Hosmer and Lemeshow**
Peak slip ratio-front	.028	91.9	0.446	0.759	0.994
Peak slip ratio-rear	.002				
Peak slip ratio-front X Peak slip ratio-rear	.022				
Constant	.005				
Duration of rear brake command	.001	86.8	0.320	0.536	0.638
Constant	.007				
Average rear brake command (g) at 80% of initial speed	.023	84.0	0.115	0.189	0.648
Constant	.002				
Peak slip ratio-rear	.011	83.9	0.109	0.186	0.526
Constant	.000				
Rate of rear brake command leading to peak value	.029	83.0	0.098	0.164	0.885
Constant	.000				
Peak rear brake command	.058	83.0	0.086	0.143	0.531
Constant	.011				

Table 10. Summary of Logistic Correlation Results for Scenario UB-4 Capsize

Predictor Variables in Model	Significance	Overall % Correct	Cox & Snell R^2	Nagelkerke R^2	Hosmer and Lemeshow
Mean square of front brake command	.003	91.7	0.225	0.364	0.049
Constant	.000				
Peak slip ratio-front	.025	89.6	0.251	0.406	0.570
Constant	.000				
Average front brake command	.011	89.6	0.162	0.262	0.044
Constant	.001				
Peak front brake command	.010	89.6	0.155	0.250	0.142
Constant	.000				
Peak longitudinal acceleration	.027	85.4	0.127	0.205	0.161
Constant	.004				
Duration of front brake command	.006	83.3	0.218	0.352	0.948
Constant	.092				
Average front brake command (g) at 80% of initial speed	.025	83.3	0.153	0.245	0.402
Constant	.002				
Peak slip ratio-rear	.045	81.2	0.079	0.128	0.411
Constant	.000				

C. RIDER FACTORS RELATED TO BRAKING BEHAVIOR AND EVENT OUTCOME

This section presents possible relationships between rider factors and rider braking behaviors and/or event outcomes. The focus is on the previously identified critical events EB-2 and UB-4, exceptions are noted.

1. Single Variable Regression and Comparisons

Single variable regressions used the following rider factors, obtained from the riding experience questionnaires:

- Rider category – cruiser or sport-touring
- Age
- Years riding
- Total miles ridden in 2008
- Group miles ridden in 2008
- Commute miles ridden in 2008
- Average yearly miles ridden for 2006-2008
- Aggressiveness rating
- Skill rating
- Riding frequency rating
- Completion of basic riders course
- Completion of advanced riders course

In general, all of the measures listed in Section II B4 were correlated with the various rider factors, and the results are summarized in Appendix E. In some cases statistical significance was found but most measures were poorly correlated with rider factors. In spite of this, the nature of the data and data scatter in the plots are of interest, and some examples are presented below.

Reaction time is generally observed to vary with age in the general population. Figures 15-18 show the variation in minimum braking reaction time as a function of rider age and rider experience (age related) for scenarios EB-2 and

UB-4 in this study. Interestingly, the data show some scatter but no age effect. The EB-2 values are lower with less scatter, as might be expected. These results show that for these emergency braking situations, and in terms of making an effective control response, older riders react just as quickly as younger less experienced riders.

Mixed results are shown in Fig 19, in terms of number of collisions.

Peak front brake command and ratio of brake application are shown as a function of motorcycle normally ridden in Figs 20 and 21. Again, for a given scenario there is little apparent difference. Peak brake command is plotted in Figs 22 and 23 as a function of recent riding experience for scenarios EB-1 and UB-4. There is considerable scatter among the riders, but no apparent trend with experience. Plots of rate of application vs experience in Figs 24 and 25 show similar results.

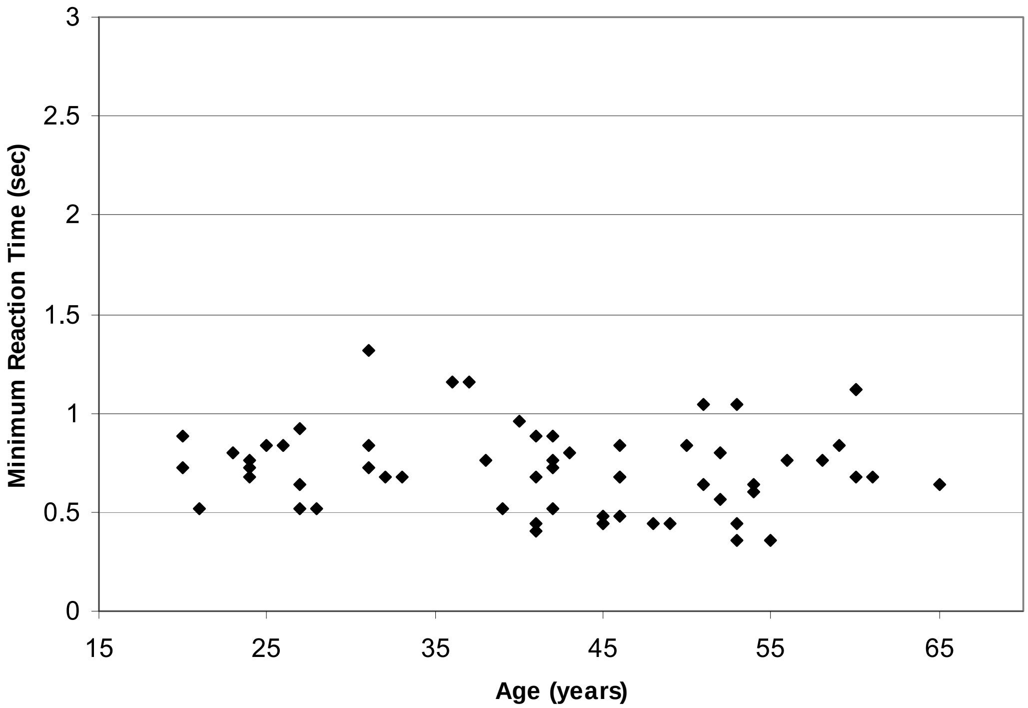


Figure 15. Minimum Reaction Time as a Function of Rider Age for Scenario EB-2

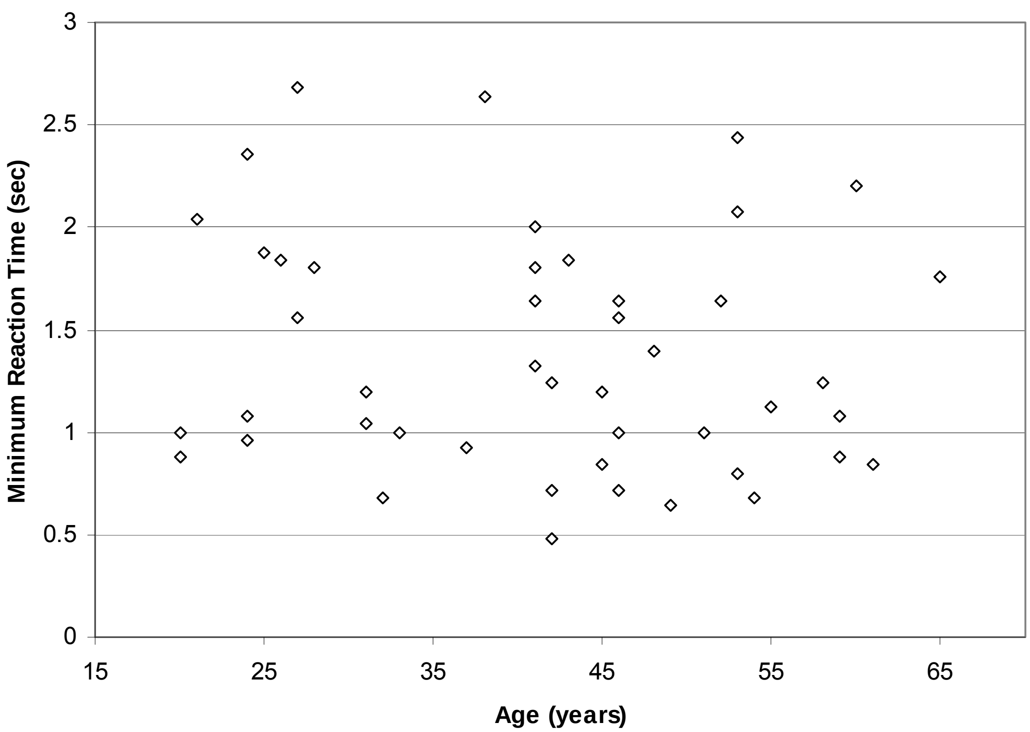


Figure 16. Minimum Reaction Time as a Function of Rider Age for Scenario UB-4

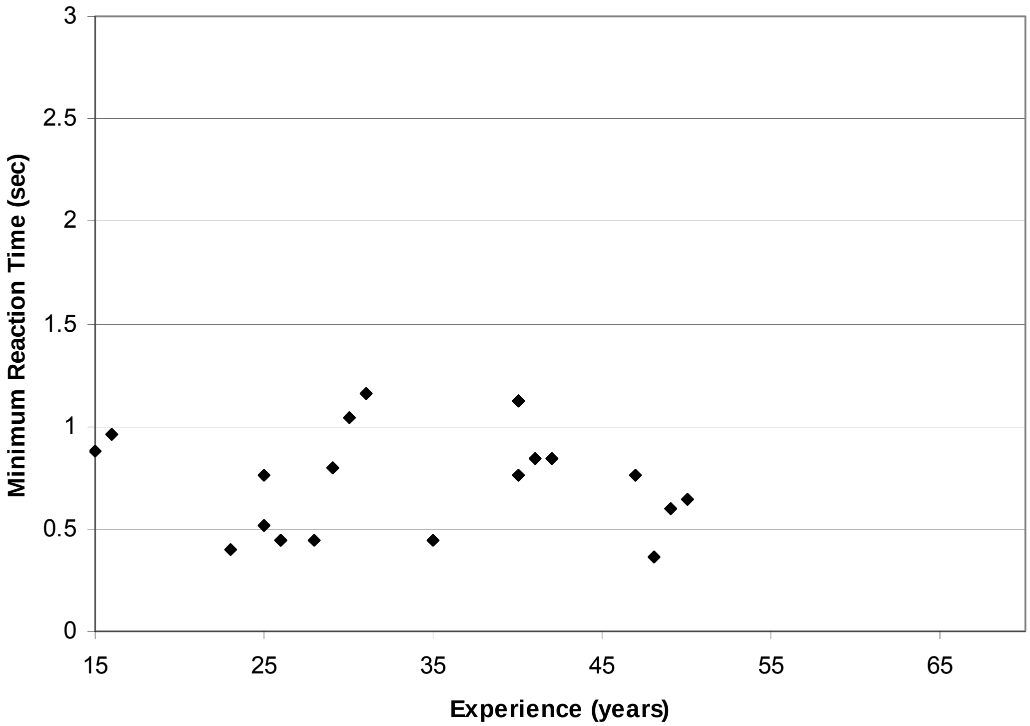


Figure 17. Minimum Reaction Time as a Function of Rider Experience for Scenario EB-2

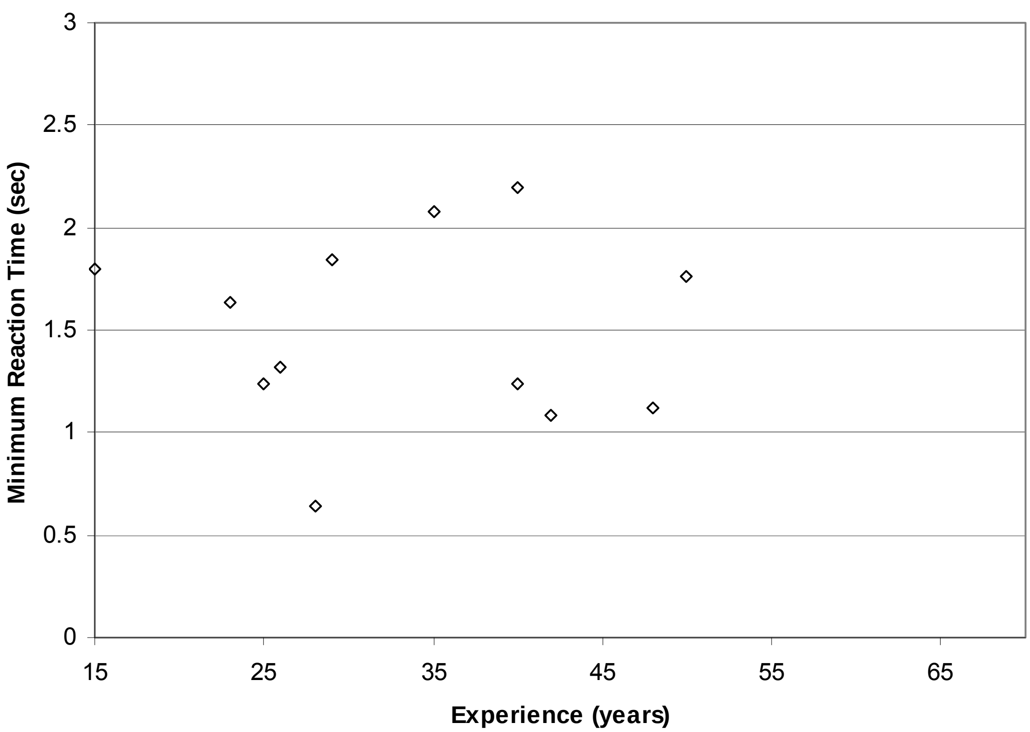


Figure 18. Minimum Reaction Time as a Function of Rider Experience for Scenario UB-4

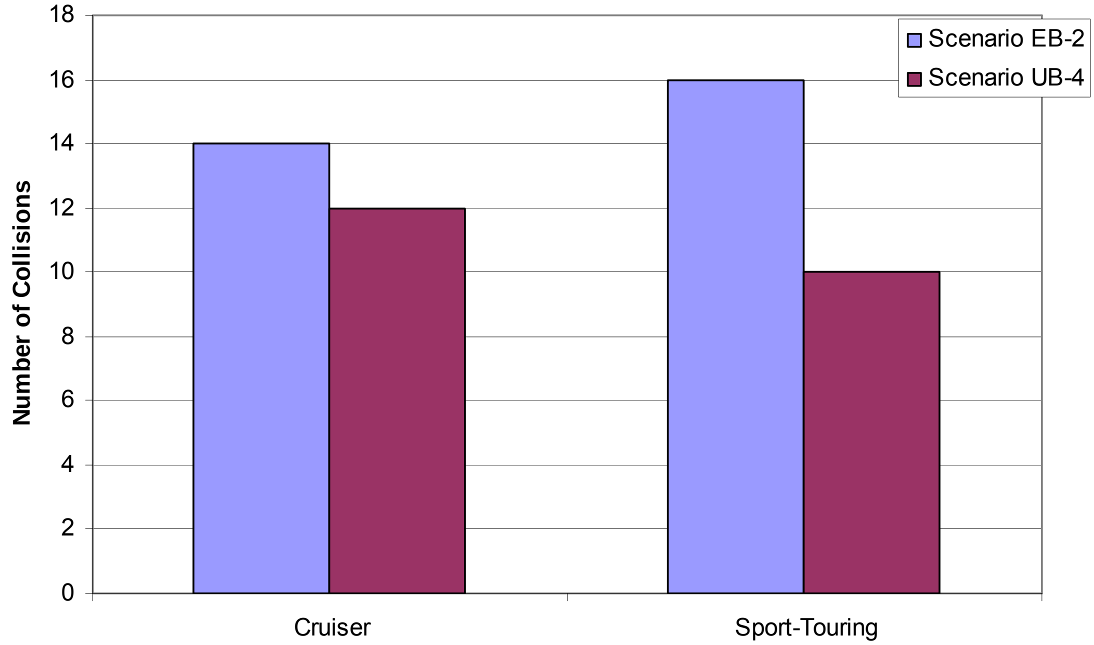
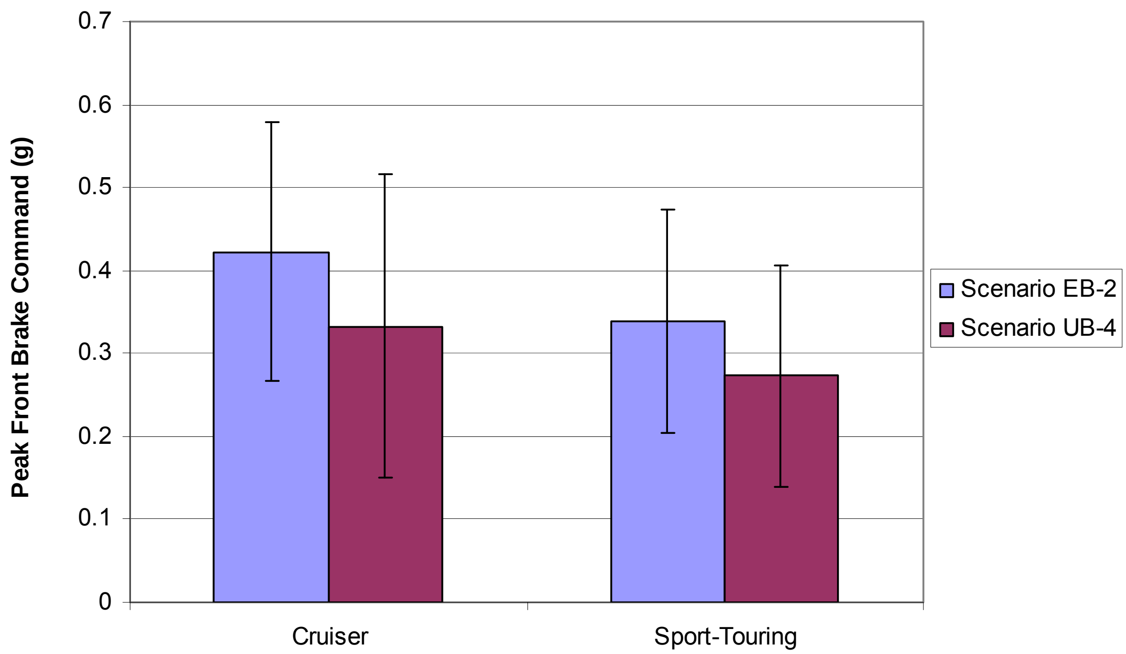


Figure 19 Number of Collisions as a Function of Rider Type

Figure 20. Peak Front Brake Command as a Function of Rider Type



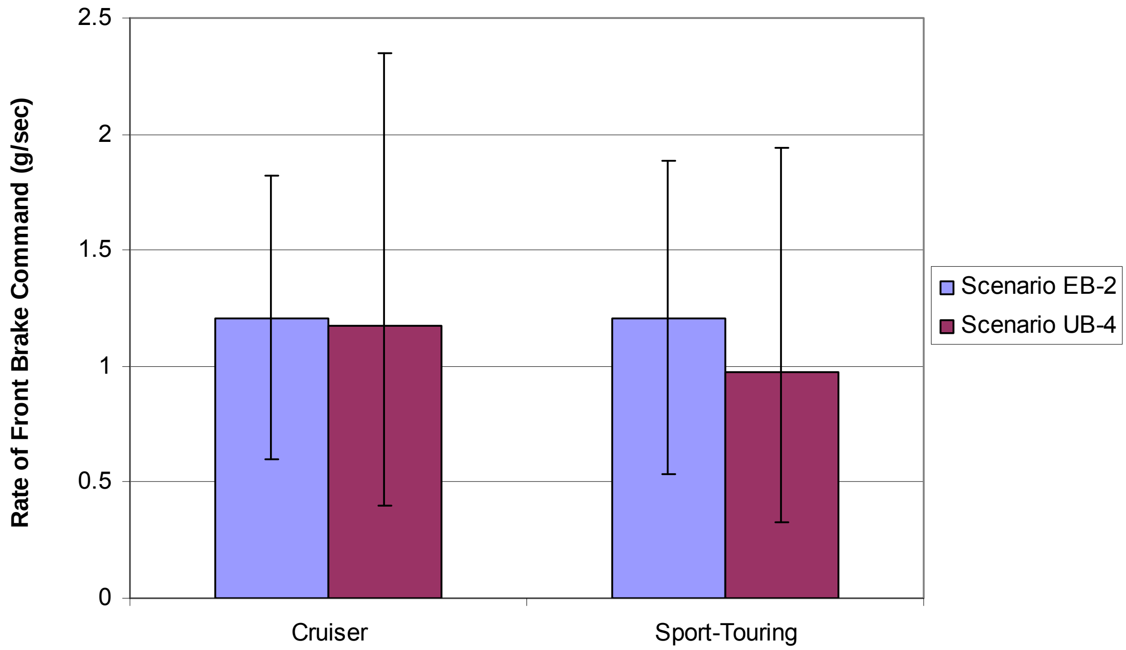


Figure 21. Rate of Front Brake Command as a Function of Rider Type

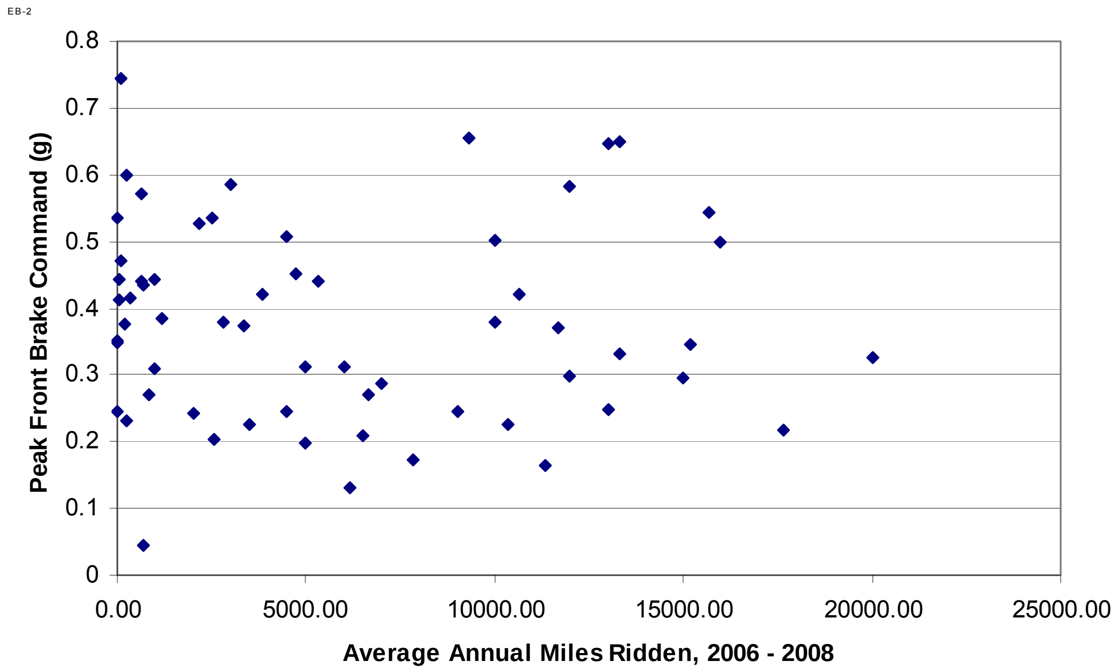


Figure 22. Peak Front Brake Command for Scenario EB-1 as a Function of Average Annual Miles Ridden in 2006-2008

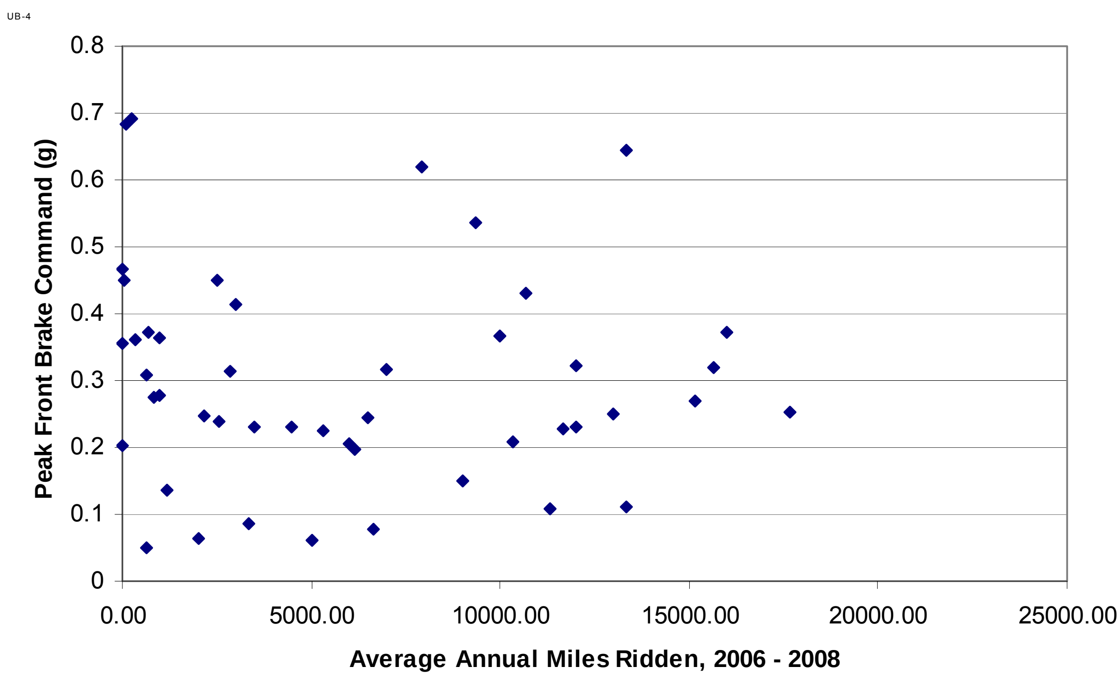


Figure 23. Peak Front Brake Command for Scenario UB-4 as a Function of Average Annual Miles Ridden in 2006-2008

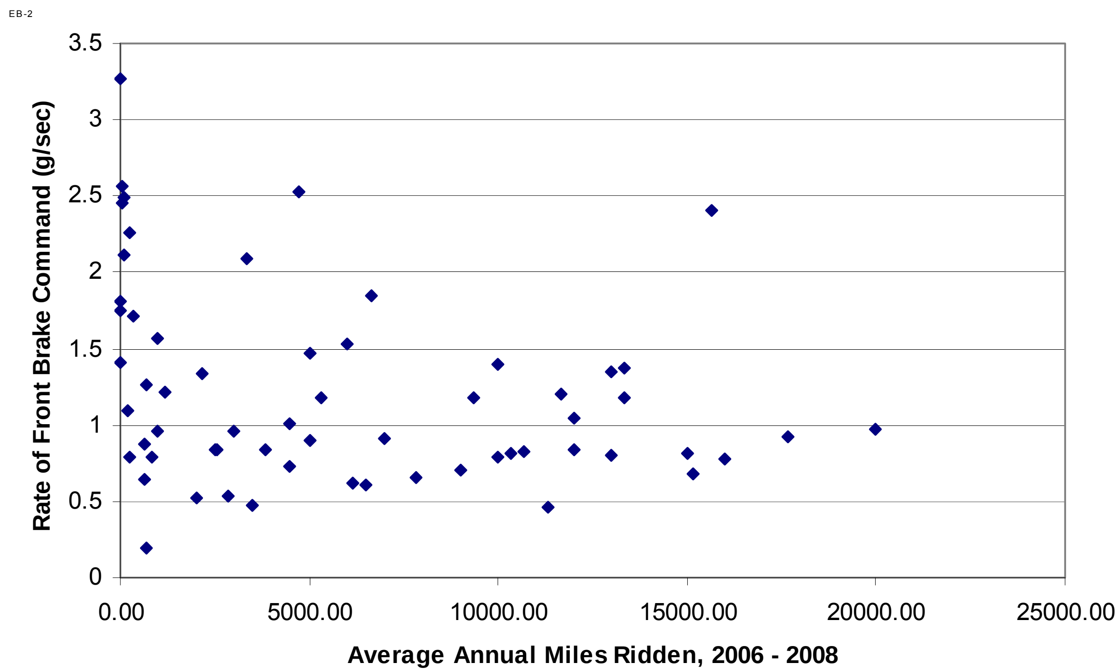


Figure 24. Rate of Front Brake Command for Scenario EB-1 as a Function of Average Annual Miles Ridden in 2006-2008

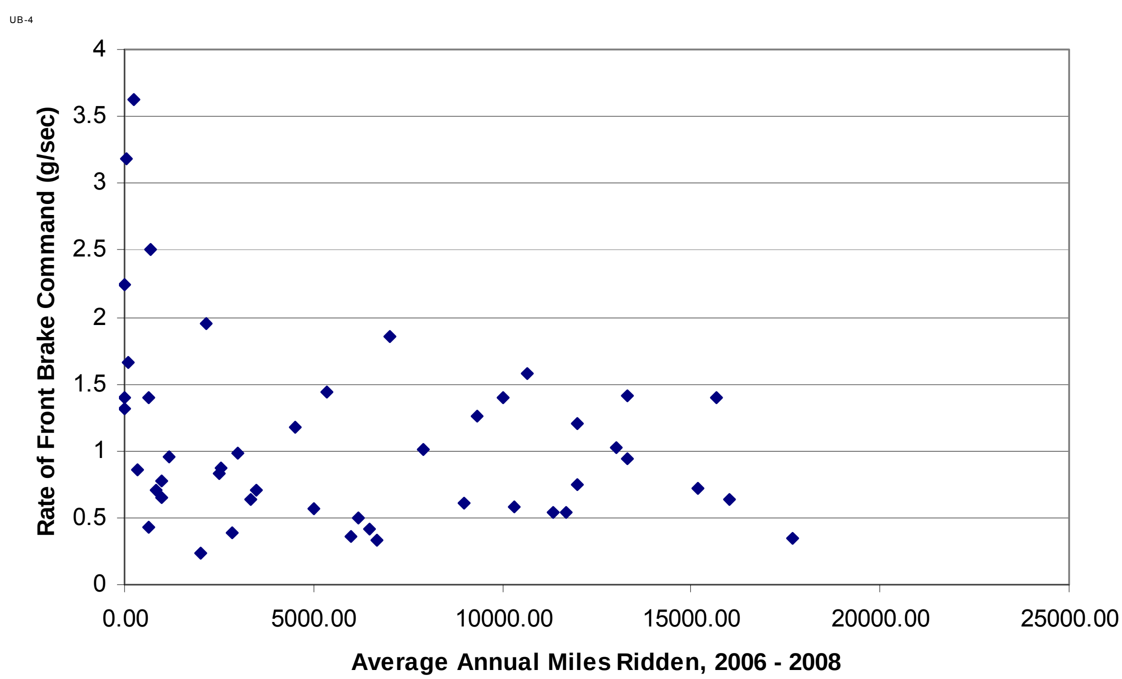


Figure 25. Rate of Front Brake Command for Scenario UB-4 as a Function of Average Annual Miles Ridden in 2006-2008

2. Relationship Between Individual Rider Factors and Scenario Outcome

Logistic regressions were performed to determine if any relationship existed between actual or predicted scenario outcome and rider factors, or PCA rider factor components. The individual rider factors and PCA rider factor components were logistically correlated with:

- Collision in Scenario EB-2
- Collision in Scenario UB-4
- Combinations of collision groups:
  - Riders who had no collisions over all scenarios
  - Riders who had one or more collision over all scenarios
  - Riders who had 2 or more collisions over all scenarios
  - Riders who had 3 or more collisions over all scenarios
- Capsize in all runs
- Capsize in Scenario EB-2
- Capsize in Scenario UB-4
- Predicted collision based on logistic regression model of AF20 and AR20, these being defined respectively, as the area under front and rear brake commanded g curves at 2.0 sec (g-sec) . Groups having:
  - 10% vs. 90 % estimated probability of collision
  - 5% vs. 95 % estimated probability of collision
  - 0% vs. 100 % estimated probability of collision

Some of these correlations proved significant and others did not. The complete results of these regressions are given in Appendix E.

The results of logistic correlations between individual rider factors and actual or predicted scenario outcomes are summarized in Table 11. The more detailed results of regressions indicating statistical significance are given in Table 12.

Table 11. Results of Logistic Regression of
Individual Rider Factors and Scenario Outcome

Regression	**Result**
Rider factors with EB-2 Collisions	No statistically significant rider factors
Rider factors with UB-4 Collisions	No statistically significant rider factors
Rider factors with Collision Group (0 vs. ≥1 collision)	Statistical significance for years riding and age
Rider factors with Collision Group (≤1 vs. ≥2 collision)	No statistically significant rider factors
Rider factors with Collision Group (≤1 vs. ≥3 collision)	No statistically significant rider factors
Rider factors with Collision Group (0 vs. ≥3 collision)	No statistically significant rider factors
Rider factors with all capsize	No statistically significant rider factors
Rider factors with EB-2 capsize	No statistically significant rider factors
Rider factors with UB-4 capsize	No statistically significant rider factors
Rider factors with predicted collision based on AF20, AR20 90% chance of collision 10% chance of collision	No statistically significant rider factors
Rider factors with predicted collision based on AF20, AR20 95% chance of collision 5% chance of collision	No statistically significant rider factors
Rider factors with predicted collision based on AF20, AR20 100% chance of collision 0% chance of collision	Statistical significance for years riding

Table 12. Detailed Results of Logistic Regression of Individual Rider Factors and Scenario Outcome for Cases Indicating Statistical Significance

Dependent Variables Entered into Model	Independent Variables (Rider Factors)	Sig.	Overall Percentage Correct	Cox & Snell R Square	Nagelkerke R Square
Collision Group (0 vs. ≥1 collision)	YearsRiding	015	66.0	.130	.180
	Constant	.003			
	Age	.027	64.0	.107	.148
	Constant	.009			
Predicted collision based on AF, AF: 100% chance of collision 0% chance of collision	YearsRiding	.059	65.4	.146	.195
	Constant	.076			

The results of logistic correlations between PCA rider factor components (see Table 3) and actual or predicted scenario outcomes are summarized in Table 13 based on the full set of results in Appendix E. No statistically significant results were found.

Table 13. Results of Logistic Regression of PCA Rider Factor Components and Scenario Outcome

Regression	Result
PCA Rider Components with EB-2 Collision Groups (≤1 vs. ≥2 collision)	No statistically significant PCA rider factor components
PCA Rider Components with EB-2 Collision Groups (≤2 vs. ≥3)	No statistically significant PCA rider factor components
PCA Rider Components with EB-2 Collision Groups (0 vs. ≥3 collision)	No statistically significant PCA rider factor components
PCA Rider Components with EB-2 Capsize	No statistically significant PCA rider factor components
PCA Rider Components with UB-4 Capsize	No statistically significant PCA rider factor components

3. Relationship Between Rider Factors and Braking Behavior Variables

Linear regressions were performed to determine if any relationship existed between key braking behavior variables and individual rider factors, or PCA rider factor components. The braking behavior variables of interest were previously identified by correlation of braking behavior variables with scenario outcome. For scenarios EB-2 and UB-4, the individual rider factors and PCA rider factor components were linearly correlated with:

- AF20- the area under the front brake force curve, calculated in terms of commanded front brake deceleration

- AR20- the area under the rear brake force curve, calculated in terms of commanded rear brake deceleration

The results of linear correlations between individual rider factors and key braking behavior variables are summarized in Table 14. The more detailed results of regressions indicating statistical significance are given in Table 15. The complete results of these regressions are given in Appendix E.

Table 14. Results of Linear Regression of Individual Rider Factors and Key Braking Behavior Variables and Subjective Ratings

Regression	**Result**
Rider factor with EB-2 Braking Measures (AF20)	No statistically significant rider factors
Rider factor with EB-2 Braking Measures (AR20)	Statistical significance for Aggressiveness Rating
Rider factor with UB-4 Braking Measures (AF20)	Statistical significance for Aggressiveness Rating
Rider factor with UB-4 Braking Measures (AR20)	Statistical significance for Aggressiveness Rating

Table 15. Detailed Results of Linear Regression of Individual Rider Factors and Key Braking Behavior Variables for Cases Indicating Statistical Significance

Dependent Variables Entered into Model	Independent Variables (Rider Factors)	Predictors		Model		
		Pearson R	Pearson R Sig.	Sig.	R	Adjusted R Square
AR20 from EB-2	Aggressiveness Rating	.310	.015	.030	.310	.077
	(Constant)			.821		
AF20 from EB-2	Aggressiveness Rating	.300	.018	.037	.300	.070
	(Constant)			.788		
AR20 from UB-4	Aggressiveness Rating	.310	.015	.030	.310	.077
	(Constant)			.821		

The results of linear correlations between PCA rider factor components and key braking behavior variables are summarized in Table 16 The complete results of these regressions are given in Appendix E.

Table 16. Results of Linear Regression of PCA Rider Factor Components and Key Braking Behavior Variables

Regression	**Result**
Rider factor with EB-2 Braking Measures (AF20)	No statistically significant PCA rider factor components
Rider factor with EB-2 Braking Measures (AR20)	No statistically significant PCA rider factor components
Rider factor with UB-4 Braking Measures (AF20)	No statistically significant PCA rider factor components
Rider factor with UB-4 Braking Measures (AR20)	No statistically significant PCA rider factor components

Section IV
DISCUSSION AND CONCLUSIONS

A. DATA TREATMENT AND INTERPRETATION

Scenarios EB-2 and UB-4 had the highest number of cases of collision with the opposing vehicle, and were therefore conducive to study of rider's emergency braking behavior. These two scenarios were both designed such that, allowing for a nominal 1 second reaction time, collision could be avoided if a sufficient predetermined constant deceleration was achieved. Constant deceleration was assumed to allow a simple calculation to be used to time the event; it was not necessary for the rider to achieve constant deceleration to avoid a collision.

To enable comparisons of front and rear rider braking behavior, the applied lever and pedal brake force data were multiplied by their corresponding gains (g/force) to yield a term whose units related directly to acceleration (g). In the linear braking region, the brake force data can then be considered as the rider's deceleration command to the motorcycle. Typically, rear brakes require a larger pedal force input to achieve a given level of deceleration than do the front brakes. If the brake force data were used in terms of force, the rider-intended contribution of the rear brake would seem higher than it should be. By converting the applied lever and pedal brake force data to "commanded g", the contributions of the front and rear could be compared and analyzed on an equal basis.

B. FRONT AND REAR BRAKE USAGE

A key goal of this study was to gain a better understanding of how motorcycle riders use their brakes in an emergency. A specific research question was "Which brake do riders use when faced with an emergency situation requiring braking – front, rear, or both?"

Relative front-to rear-brake proportioning used by each rider was calculated by dividing the average value, in g, of front brake command by the total of the average front and average rear brake commands for each scenario.

In the emergency braking scenarios analyzed in this study (EB-2 and UB-4) most riders used a combination of front and rear brake. There were not any EB-2 or UB-4 cases where the rider used just the rear brake, though there were a number of cases where just the front brake was used. Over all scenarios, including all levels of braking needed, there were some cases where the rider used just the rear brake, though many more where just the front brake was used. The majority of the riders used a front brake bias, and there were a few riders who essentially, never used the rear brake.

C. BRAKING EVENT OUTCOMES RELATED TO BRAKING CONTROL BEHAVIOR

Another of the goals of this study was to determine if there were rider braking behaviors than could be identified and used to predict the outcome of a possible collision event. A series of logistic regressions were performed comparing various braking measures, including rider braking behavior factors, with scenario outcomes. These analyses focused on scenarios EB-2 and UB-4, where the possible outcomes were collision/no collision and capsize/no capsize. The results indicate that the combination of timing and magnitude of rider's brake inputs are important, and that how a rider brakes in the initial portion of the braking is very important in determining the outcome of the event.

When collision was considered as the dependent variable for both the EB-2 and UB-4 scenarios, the logistic models with acceleration terms tended to have the highest predictive capability and correlation. (Note that the brake commands were interpreted in terms of commanded acceleration.) This is to be expected, since if an adequate level of braking was achieved, the motorcycle either stopped before colliding with the opposing vehicle or was going slow enough to allow the rider to maneuver around it.

The more interesting result is that the best regression results were obtained from models where time was a factor in the acceleration term, either directly as in “area under the brake command multiplied by time”, or where the acceleration value was summed over a specific time, such as “area under the brake command at 2.0 seconds”. For acceleration terms, including brake commands interpreted in terms of acceleration, the area under the acceleration vs time curve represents the change in speed over that time. In that respect, a term like “area under the brake command at 2.0 seconds” can be interpreted as meaning the commanded change (reduction) in speed over the first 2.0 seconds of the emergency event. This implies that the contribution to collision avoidance of the combination of magnitude and timing of the braking is more important than that of the individual factors.

The best results for predicting collision in scenario EB-2 were obtained with a logistic regression model with the independent variables:

- Area under the front brake command at 2.0 seconds
- Area under the rear brake command at 2.0 seconds

This result is interesting in that both front and rear brake terms were significant, and the timing is approximately halfway through the nominal event.

Scenario EB-2 was designed such that:

- Initial speed = 64 km/h (40 mph)
- Reaction time = 1 sec
- Brake level = 0.6 g

Under these conditions the total time of the scenario is approximately 4 seconds. The average minimum reaction time for this scenario was 0.74 seconds. Minimum reaction time was the time between when the truck first started to move and either the front or rear brake was actuated.

Table 17 summarizes the logistic regression results with the independent variables;

- Area under the rear brake command at (t)
- Area under the rear brake command at (t)

for scenario EB-2.

Table 17. Effect of Braking Time

Time	**% correct**	**R^2**
1.4	80.6	.662
1.6	88.7	.731
1.8	91.9	.820
2.0	95.1	.859
Entire event	85.5	.712

As time from the beginning of the event increases, the predictive capability of the logistic model with these 2 terms gets better and correlation with data increases and, for the time values considered, the correlation is best at 2.0 seconds. An interesting result is that the outcome predicted at 2 seconds is more likely to be correct than the prediction for the entire event, i.e., the speed reduction at 2 seconds is a better predictor of collision than the total speed reduction. This is probably because there were some cases where the rider slowed enough to maneuver around the opposing vehicle, so he neither stopped nor collided. These results suggests that the speed reduction achieved at some point during the event may be the best indicator of collision. From a rider behavior perspective, this indicates that how a rider brakes in the initial portion of the braking is very important in determining the outcome of the event.

The best results for relating a command variable with collision in scenario UB-4 were obtained with a logistic regression model with a single independent variable, “area under the front brake command at 2.0 seconds.” In general the results for UB-4 were not as predictive or well correlated as those for EB-2, and 2 of the 3 more promising models included only front brake terms.

Logistic regression methods were also used to analyze the possibility of the motorcycle capsizing during scenarios EB-2 and UB-4. For motorcycles, capsize may occur during braking as a result of “locking” either the front or rear wheel. In general, tires are capable of producing a combination of lateral and longitudinal forces. As more force is developed in either axis, usually there is a reduced capacity to produce force in the other. For a motorcycle, this is of interest because as large longitudinal forces are produced by braking, there may be less lateral force available to help steer or stabilize the motorcycle.

While the correlations between collision probability and braking control behavior for both EB-2 and UB-4 were not particularly strong, they do indicate some generally interesting trends. Scenario EB-2 was the more demanding of the scenarios, nominally requiring 0.6 g braking. Five of the 6 statistically significant factors related to capsize were for the rear brake. It may be that for this maneuver, with a relatively high level of braking, simulated motorcycle weight transfer reduced the normal load on the rear wheel, with a corresponding reduction in both lateral and longitudinal tire force capability. Use of the rear brake might further reduce the lateral force capability of the rear tire, increasing the possibility of capsize. For scenario UB-4, 6 of the 8 statistically significant factors related to capsize were for the front brake. At lower braking levels managing the rear brake may have been less important.

D. RIDER FACTORS

An effort was made to identify possible relationships between rider characteristics or factors and rider braking behaviors and/or event outcomes. Logistic regressions were performed to determine if any relationship existed between actual or predicted scenario outcome and rider factors, or PCA rider factor components. A few cases produced statistically significant results, but with poor correlation.

Linear regressions were also performed to determine if any relationship existed between key braking behavior variables and individual rider factors, or PCA rider factor components. The rider’s Aggressiveness Rating was found to be statistically significant in a few cases, but the correlation was poor.

The absence of correlation between individual rider factors and braking behavior or event outcome is in itself an interesting result. Conclusions that might be drawn from this include:

- Cruiser riders and sport touring riders have similar braking behavior, and neither is more or less likely to use only the rear brake in an emergency.

- Rider factors such as age, years experience, recent riding experience, etc are not good indicators of probability of collision in a path conflict emergency

E. IMPROVEMENTS FOR FUTURE STUDIES

Based on the experience of preparing and running the study and analyzing the data, there are several areas where improvements might be made for future, similar projects.

An area of improvement for future studies is in simulation of the low speed vehicle dynamics. While the scenarios were designed to occur at speeds where the realism of the vehicle dynamics was sufficient, the overall level of realism in the riding task would be improved with realistic low speed dynamics. DRI has several candidate solutions to this difficulty, but time did not allow full development of these for this study.

The scenarios were initially tested using in-house motorcycle riders who may not be typical of the general riding population. Difficulties were encountered with several scenarios when typical riders were used. Root-cause study of the difficulties revealed that they were related to simulated motorcycle speed at an initial trigger point, and variations in speed between the initial trigger point and subsequent scenario actions. Because of this, for some scenarios, the braking required was not the same for all participants. These scenarios were not used in the analyses. To avoid this occurring in future studies, the method of triggering all critical scenarios need to ensure that timing is consistent, and the scenarios need to be tested for off-nominal initial conditions.

For future studies it may be desirable to include an additional interview/screening step in the recruitment process. Some participants adapted to the motorcycle simulator quite easily, while others required some coaching. An additional screening step, aimed at assessing the riding skill/experience of the participants could give researchers a better opportunity to assess their suitability for the simulator. Note that for the current study there were several candidate participants who could not adapt to the riding simulator, and these did not participate past the warmup.

Future studies might also benefit from a more systematic assessment of personality type. This could possibly be accomplished by use of established psychological surveys intended to establish personality type(s) that may be relevant to risk taking and an aggressive riding style.

F. RIDING SIMULATOR AS A RESEARCH TOOL

This study demonstrated the viability of using a research grade riding simulator to study behavior of ordinary riders in realistic but potentially dangerous maneuvers in a safe, repeatable and efficient manner. A key element of this is that the riding simulator must be of high fidelity, and present a realistic representation of a real motorcycle that is compelling to the rider. Careful attention must be paid to realistically modelling the motorcycle dynamics, feel properties and other physical representation.

G. POSSIBLE FOLLOW-ON STUDIES

Twenty-three of the 62 rider who completed the emergency braking scenario EB-2 were successful at avoiding a collision and capsize. No strong relationship between rider factors and braking performance was found in this study. Analysis of the brake behavior data showed that the 23 successful riders used more brakes earlier in the scenario, than the unsuccessful riders. To accomplish this, the successful riders may have recognized the threat earlier, or been more willing to apply and modulate the brakes harder than the others, or both. This raises the question of what might be done to improve the success rate. Areas to explore in that regard include studies of the effectiveness of technological solutions, such as ABS, as well as that of focused training, e.g., for threat recognition or limit braking. These topics lend themselves to study in the motorcycle simulator.

With respect to ABS, an appropriate ABS system could be implemented in the simulator, and emergency braking situations studied with and without ABS, and with a rider participant group divided between those accustomed to ABS and those not accustomed to ABS, or with no motorcycle ABS experience. Possible research question could include (referring to Table 18):

- Are riders who are accustomed to ABS and riding an ABS equipped motorcycle more likely to brake aggressively than equivalent riders who are not accustomed to ABS, riding a motorcycle not equipped with ABS? (group A compared to group D)

- Are riders who are accustomed to ABS less likely to brake aggressively when riding a motorcycle that is not equipped with ABS ? (group A compared to group C)

- Are riders who are not accustomed to ABS and riding an ABS equipped motorcycle more likely to brake aggressively than when riding a motorcycle not equipped with ABS? (group B compared to group D)

- Are riders who are accustomed to ABS and riding a motorcycle not equipped with ABS more likely to brake aggressively than riders who are not accustomed to ABS and riding an ABS equipped motorcycle (group C compared to group B)

- Over all riders how does ABS affect the likelihood of a collision or capsize in emergency braking maneuvers?

Table 18. Possible Evaluation Matrix for ABS Study

Simulated Motorcycle	Motorcycle Typically Ridden	
	ABS Equipped	Not ABS equipped
ABS Equipped	A	B
Not ABS equipped	C	D

With respect to training there are several possible research questions:

- Are riders who have completed training aimed specifically at addressing braking skills more likely to avoid a collision or capsize in an emergency braking maneuver than equivalent that have not completed such training?

- Are riders who have completed training aimed specifically at threat recognition more likely to avoid a collision or capsize in an emergency braking maneuver than equivalent that have not completed such training?

REFERENCES

1. Hurt, H.H. Jr., Ouellet, J.V. & Thom D.R. (1981b). *Motorcycle Accident Cause Factors and Identification of Countermeasures*. (DOT HS 805 862). Washington, DC: National Highway Traffic Safety Administration.

2. Anon, 2007 Statistical Annual, published by the Motorcycle Industry Council.

3. National Agenda for Motorcycle Safety DOT HS 809 156, November 2000.

4. Erdfelder, E., Faul, F., & Buchner, A. (1996). GPOWER: A general power analysis program. Behavior Research Methods, Instruments, & Computers, 28, 1-11.

5. Miller, R.G., *Simultaneous Statistical Inference 2nd Ed*. Springer Verlag New York, 1981

6. Weir, D.H. and K.C. Chao, "Review of Control Theory Models for Directional and Speed Control," Workshop on Modelling Driver Behavior in Automotive Environments, Ispra, Italy, May 2005.

7. Stapleford, R.L., R.A. Peters, and F.R. Alex, Experiments and a Model for Pilot Dynamics with Visual and Motion Inputs, NASA CR-1325, 1969.

APPENDIX A

DESCRIPTION OF SCENARIOS

Road	Order	Scenario	Type	Scene	Description
1	1	NB-8	Normal braking	City/suburban Speed limit 40 mph Stop sign on cross street	Vehicle (visible) on cross street perpendicular to participant's path stops at stop sign and then crosses SV lane. Timing is based on SV speed such that 0.2 g braking is needed.
1	2	UB-2	Urgent braking	City/suburban Speed Limit 40 mph Controlled intersection	Participant is instructed to enter left lane. OV comes from behind and occupies SV 1 o'clock position on roadway, same speed as SV. At intersection, oncoming OV2 turns left in front of SV slowly completing the left turn. Timed for 0.5 g
1	3	T-3	Traffic	City/suburban Speed limit 40 mph Uncontrolled intersection	At intersection oncoming OV signals left turn and stops in own lane.
1	4	NB-2b	Normal braking	City/suburban Speed limit 40 mph Uncontrolled intersection	OV 200 ft ahead of SV in SV lane. OV signals right, brakes and executes right turn. Timing of event requires 0.1 g braking by SV to avoid closing within 150 ft
1	5	T-4b	Normal braking	City/suburban Speed Limit 40 mph Stop sign on cross street	Right cross street OV (visible) stops at stop sign and waits for SV to pass.
1	6	NB-1	Normal braking	City/suburban Speed Limit 40 mph Uncontrolled intersection	At intersection oncoming OV begins to turn left in front of SV but stops before entering SV lane.
1	7	UB-5	Urgent braking	City/suburban Speed limit 40 mph Controlled intersection	Traffic light turns yellow then red. Timing is based on SV speed such that 0.6 g braking is needed. When SV reaches 25 mph the light changes to green
1	8	NB-10	Normal braking	Highway Speed limit 65 mph	OV passes the SV on the left and enters the SV lane 200 ft ahead of it. The OV maintains the speed of the SV for 2 minutes then begins to gradually and continuously slow. Participant may elect to pass OV.

Road	Order	Scenario	Type	Scene	Description
1	9	T-2	Traffic	Highway Speed limit 65 mph	OV passes the SV on the left at SV speed +5 mph, with right turn signal on.
1	10	NB-11a	Normal braking	Highway Speed limit 65 mph	OV passes the SV on the left and enters the SV lane 150 ft ahead of it. The OV then changes speed such that the distance between the OV and SV varies sinusoidally between 100 and 200 feet at a frequency of .2 Hz, regardless of the SV speed or lane position.
1	11	NB-11b	Normal braking	Highway Speed limit 65 mph	OV passes the SV on the left and enters the SV lane 150 ft ahead of it. The OV then changes speed such that the distance between the OV and SV varies sinusoidally between 100 and 200 feet at a frequency of .2 Hz, regardless of the SV speed or lane position.
1	12	NB-11c	Normal braking	Highway Speed limit 65 mph	OV passes the SV on the left and enters the SV lane 150 ft ahead of it. The OV then changes speed such that the distance between the OV and SV varies sinusoidally between 100 and 200 feet at a frequency of .2 Hz, regardless of the SV speed or lane position.
1	13	NB-9	Normal braking	Highway Speed limit 65 mph	SV comes upon a group of OV at SV speed – 5 mph. When SV is within 150 ft OVS brake at 0.2 g. If SV closes to within 100 ft OVs accelerate at .3 g to SV speed +5. If not OVs track SV speed.
1	14	UB-1	Urgent braking	Highway Speed limit 65 mph	OV passes the SV on the left and enters the SV lane 100 ft ahead of it. The OV maintains the speed of the SV for 1 minute then slows. Second OV (OV2) in left lane at SV speed - 10mph. When SV is in OV2 RR blind spot OV2 begins to change lanes right without signaling.

Road	Order	Scenario	Type	Scene	Description
1	15	T-1	Traffic	Highway Speed limit 65 mph	OV passes the SV on the left. When the rear of the OV is level with the front of the SV the OV maintains the speed of the SV. After one minute the OV accelerates away in the left lane.
1	16	EB-1	Emergency	Highway Speed limit 65 mph	Participant is instructed to enter left lane. Traffic vehicle comes from behind and occupies SV 1 o'clock position on roadway, same speed as SV. At intersection, oncoming OV turns left in front of SV and stops, blocking intersection.
2	1	T-5	Traffic	Highway Speed limit 65 mph	Traffic light turns yellow then red. Timing is based on SV speed such that 0.2 g.
2	2	NB-13	Normal braking	Highway Speed limit 65 mph Controlled intersection	Traffic light turns yellow then red. Timing is based on SV speed such that 0.2 g braking is needed. When SV reaches 30 mph the light changes to green
2	3	T-7	Traffic	Highway Speed limit 65 mph Controlled intersection (green)	At intersection oncoming OV signals and makes left turn in front of SV. Timed such that at SV speed there is a 2 second margin.
2	4	NB-4	Normal braking	Highway Speed limit 65 mph	OV passes the SV on the left and enters the SV lane 100 ft ahead of it. The OV maintains the speed of the SV for 1 minute then slows and exits to the right.
2	5	UB-3	Urgent braking	Highway Speed limit 65 mph	SV comes upon a group of OV at SV speed - 5 mph. When SV is within 150 ft OVS brake at 0.8 g. When SV reaches 30 mph all vehicles maintain speed for 3 sec than increase to 55 mph at 0.4 g
2	6	NB-3	Normal braking	Highway Speed limit 65 mph Uncontrolled intersection	OV passes the SV on the left and enters the SV lane 200 ft ahead of it. The OV maintains the speed of the SV for 30 sec then signals, slows and exits to the right.

Road	Order	Scenario	Type	Scene	Description
2	7	T-4a	Traffic	City/suburban Speed Limit 40 mph Stop sign on cross street	Right cross street OV (visible) stops at stop sign and waits for SV to pass.
2	8	NB-12	Normal braking	City/suburban Speed Limit 40 mph Uncontrolled intersection	Left cross street OV begins to cross in front of SV but stops before entering SV lane.
2	9	UB-4	Urgent braking	City/suburban Speed limit 40 mph Controlled intersection	SV approaches intersection with red light. Cross traffic is moving through the intersection. When SV gets close to intersection light changes to green. Cross traffic stops except one vehicle runs the light. Timing of maneuver requires 0.5 g braking to avoid crash.
2	10	NB-2a	Normal braking	City/suburban Speed limit 40 mph Controlled intersection	OV 200 ft ahead of SV in SV lane. OV signals right, brakes and executes right turn. Uncontrolled intersection. Timing of even required 0.1 g braking by SV to avoid closing within 150 ft.
2	11	UB-5a	Urgent braking	City/suburban Speed limit 40 mph Controlled intersection	OVs in both lanes ahead of SV. OVs both brake at 0.6 g as intersection is approached. When SV reaches 25 mph OVs accelerate
2	12	NB-6	Normal braking	City/suburban Speed limit 40 mph Controlled intersection	Traffic light turns yellow then red. Timing is based on SV speed such that 0.2 g braking is needed. When SV reaches 25 mph the light changes to green
2	13	T-6	Traffic	City/suburban Speed limit 40 mph Controlled intersection	At intersection oncoming OV signals left turn and stops in own lane.
2	14	EB-2	Emergency	City/suburban Speed limit 40 mph Controlled intersection	Tractor-Trailer combination pulls out slowly from cross street on participant’s right. Participant’s path is blocked. Timing of event requires a 0.7 g stop to avoid hitting the OV, allowing 1-2 second of reaction time.

APPENDIX B

PARTICIPANT DOCUMENTS

INTRODUCTION TO THE RIDING EVALUATION STUDY

The objective of this project is to study how motorcycle riders behave in various riding situations. This Introduction includes:

- Typical Evaluation Session description
- Safety Precautions with the Motorcycle Simulator
- What to do in case of an unusual situation

Please read and fill out the attached documents:

- General Information and Health Questionnaire
- Informed Consent Form
- Applied Research Participant Confidentiality Agreement

On the day of your simulator experience you will be asked to fill out a Daily Health Questionnaire

This study will use the DRI Driving Simulator at our facility in Torrance. This is an interactive, rider-in-the-loop, moving base riding simulator useful for studies of rider behavior and the effects of vehicle and roadway parameters. As the rider you will sit on a modified motorcycle "cab" with instrumented controls and displays. You will see a computer generated graphics roadway scenes with a 150 deg field of view. Simulator motion is provided by a hexapod motion system under the cab. The riding simulator is similar to a flight simulator with a moving cab, or a ride at a theme park, such as Disneyland. So, the risks you will experience are similar to those of an office environment, combined with some aspects of an amusement-park-like ride. You will not be riding an actual motorcycle. The motion system helps to simulate motion sensations similar to those you would experience when riding a real motorcycle.

Riding tasks in the simulator will involve various roadways and maneuvers. You will be asked to follow, and maneuver around other vehicles and simulated objects on the roadway. The simulator computer will record certain aspects of each run, such as your speed, path, and steering actions.

Typical Evaluation Session

Riding in the simulator will involve various roadways and maneuvers. A brief description of these is given below, and a DRI staff member will give you instructions at the beginning of each set. If you have any questions at any time during the experiment or if you are unclear about the task to be performed please ask the DRI staff member.

At the beginning of the riding session, you will do a practice run. The main purpose of this is to acquaint you, or re-acquaint you, with the simulator itself and the characteristics of the simulated motorcycle. During the practice run you will experience the platform and cab motions normally associated with braking and turning maneuvers. These will be explained to you. In that way, you will know what "normal" platform motions are, and be able to distinguish those from possible unusual motions (which may indicate a simulator problem).

After the practice runs and a short break, the evaluations will begin. Each test run will last about 10 to 25 minutes, depending on the scenario. During the run you will so a number of riding and braking tasks. It is important that you be alert and comfortable throughout the session. There will be a short break in the waiting room after each run. If you feel you need a longer break, or rest at any time, please inform the DRI staff member.

Most of the maneuvers will be performed along a 2-lane road or multi-lane highway. For these, the task is to ride in the manner instructed by the DRI staff member. You may need to maneuver to avoid slower moving vehicles, or other path obstructions.

Safety Precautions with the Motorcycle Simulator

DRI knows that it is important to ensure the safety and well being of all study participants. Toward that end we want to make you aware of a number of safety precautions and procedures have been implemented. Important among these are hardware and software safety interlocks built into the simulator. In addition are precautions you can take as follows:

In general, if you think there is a problem with the simulator or the procedures, say "STOP" in a loud voice over the intercom. The operator will immediately shut down the simulator.

The motorcycle simulator has 2 motion devices in addition to the main motion of the simulator platform. One is a secondary motorcycle roll motion system and the other is a steering actuator. To provide a sense of realism, the secondary roll mechanism rolls the motorcycle with respect to the platform floor. Because there is relative motion between the motorcycle and the platform parts of your body could become trapped between the two. To avoid this keep all parts of your body away from the underside of the motorcycle. Also keep all parts of your body away from the roll motion mechanism located behind the motorcycle and near the steering head. This can be accomplished by being seated on the seat and keeping your feet on the foot pegs or foot rests.

To provide realistic steering feel an electric torque-producing motor is attached to the handlebars of the motorcycle. Because there can be relative motion between the handlebars and the rest of the motorcycle you must keep your hands and arms away from the steering mechanism, including the handlebars and triple clamps except during experimental runs. If the steering appears to be moving in any unusual way during an experimental run, remove your hands from the hand grips, stay away from the handlebars and inform a DRI staff member immediately.

Under very rare circumstances the motion platform or the roll motion system might experience sudden unexpected motion as a result of system failure. To avoid falling off the motorcycle cab and possibly falling from the platform, you will be wearing a safety harness while on the simulator. This harness can be adjusted to fit you comfortably, and will be attached to the rear of the motorcycle mount. Enough slack will be provided to allow you to move naturally on the motorcycle, but the attachment will be adjusted so as not to allow your head to strike the forward part of the motorcycle. Do not remove or unhook the harness, or dismount the motorcycle until instructed to do so by the DRI staff person.

As part of both the riding experience and a safety precaution you will be required to wear an approved motorcycle helmet. To be effective this helmet must be properly sized and adjusted. Several helmets are available, so please choose the size that fits you best and adjust the strap to ensure a secure fit. If you have any questions regarding the helmet size or adjustment ask the DRI staff person.

The helmet is equipped with an intercom system through which you can communicate with a DRI staff person. The microphone and headphone levels will be adjusted prior to beginning any runs. If at any time during the run you feel uncomfortable or wish to end the run tell the staff person at once and the experiment can be stopped. Just say "STOP."

Mounted on top of the fuel tank is a large red Emergency Stop button. To effect an emergency stop forcefully push down on the Emergency Stop button. When it is pushed down the simulator will immediately go into abort mode:

- The motion system will be depressurized and the platform will slowly return to its bottom position.

- Power to the steering actuator will be turned off.

- Pressure to the motorcycle roll motion will be turned off, but the motorcycle cab may still be able to roll slowly.

Do not hesitate to use the Emergency Stop should there be a serious emergency, such as sudden and large unexpected motion of the platform, cab roll motion or steering. However, the Emergency Stop is only to be used in case of a large motion emergency, and not for example to stop a run due to discomfort, fatigue, etc. In less serious cases if you want to stop the correct procedure is to let the DRI staff person know that you wish to stop the experiment by saying "STOP" in a loud voice, and they will shut the simulator off, immediately.

WHAT TO DO IN CASE OF:

Unusual motion or injury

If the motion system or the steering system makes unusual or apparently uncontrolled sustained motions at any time, or if you are in any way injured, inform the DRI staff person immediately by saying "STOP" and explaining the problem. If you feel that there is an immediate danger, forcefully push the Emergency Stop button to stop all simulator motion. Remain calm, stay on the motorcycle with your safety harness on, and wait while the simulator returns to its bottom position. Wait for further instructions from a DRI staff person either through the intercom or by speaking to them directly. The DRI staff person will assist you and help you off the motorcycle and platform.

Motion discomfort

If at any time during the study you begin to feel uncomfortable or feel the onset of motion sickness inform the DRI staff person immediately.

Apparent malfunction of some part of the simulator

Inform the research assistant immediately of your concern, and say "STOP" over the intercom.

Intercom failure

If the intercom should stop working at any time, including non-emergencies sit up and wave your hands above your head to inform the DRI staff person of the situation.

Dynamic Research, Inc.

Subject no.:

GENERAL INFORMATION AND HEALTH QUESTIONNAIRE

This questionnaire is intended to help us determine your suitability to participate in this study. The information you provide will be kept strictly confidential by the research team within DRI.

Name ________________________________ Date ____________________

Address ______________________________ Phone - Home ____________

______________________________ Work ____________

Email Address (optional) ______________________________

Emergency Contact ________________________ Their Phone ____________

PERSONAL INFORMATION:

Height ______________ Weight ________________ Sex ______

Age ________________ Birthdate (MM/DD/YY) ______________

Occupation ____________________ Employer ____________________

HEALTH INFORMATION:

1. How would you rate your general health?

   ❑ Excellent ❑ Good ❑ Fair ❑ Poor

   Note: If your answer is fair or poor, you should not participate.

2. Do you wear glasses or corrective lenses for riding? Yes ❑ No ❑
3. Do you have any uncorrected visual impairment? Yes ❑ No ❑
4. What is your level of night vision?

   ❑ Excellent ❑ Good ❑ Fair ❑ Poor
5. Are you color blind? ❑ Yes No ❑
6. Do you have any hearing impairment? ❑ Yes ❑ No
7. Do you have a heart condition? ❑ Yes ❑ No

8. Do you currently have back/neck pain or have you received treatment for back/neck problems within the last 3 years? ❑ Yes ❑ No

9. Have you had or do you have any disorders that would impair your current riding ability? If yes, describe ❑ Yes ❑ No

____

10. Do you have any physical disability that might affect your ability to ride a motorcycle or to participate in the evaluation? If yes, describe ❑ Yes ❑ No

____

11. Have you had any seizures or loss of consciousness within the last 6 months? If yes, describe ❑ Yes ❑ No

____

12. Do you smoke?

❑ No ❑ Occasionally ❑ Regularly

13. Do you consider yourself to be susceptible to motion sickness, such as car sickness or sea sickness?

❑ No ❑ Seldom ❑ Occasionally ❑ Often ❑ Always

14. Are you currently taking any medications or drugs that might interfere with your ability to ride a motorcycle or drive a car? If yes, describe:

____

GENERAL INFORMATION AND HEALTH QUESTIONNAIRE (cont.)

RIDING INFORMATION:

1. Do you have a valid California motorcycle license? ❑Yes ❑No
2. Has your license ever been suspended or revoked? Yes ❑o ❑
3. How many years have you been riding? _______
4. On average, how many miles do you ride in a year? ___________
5. On the first line below, list the kind of motorcycle you ride most frequently. On the remaining lines, list other motorcycles that you ride frequently (at least monthly).

Year	Make	Model	Yrs owned/ridden
____	______________	_________________________	_________________
____	______________	_________________________	_________________
____	______________	_________________________	_________________
____	______________	_________________________	_________________

6. List other motorcycles you have owned or ridden frequently in the last 15 years.

Year	Make	Model	Yrs owned/ridden
____	______________	_________________________	_________________
____	______________	_________________________	_________________
____	______________	_________________________	_________________
____	______________	_________________________	_________________

7. What is your shoe size? ______________

8. How often do you brake with your right foot? Alway❑
   - ❑ Usually
   - ❑ Sometimes
   - ❑ Never

9. Is your riding currently restricted for any reason? ❑Yes ❑No
   Is this voluntary? ❑Yes ❑No
   Was it suggested by another party? ❑Yes ❑No

10. Do you experience any riding difficulties or have any particular problem areas (e.g., braking, turning, etc.)? ❑Yes ❑No
    If yes, how do you compensate (e.g., ride slower, don't ride at night, etc.)?
    ____
    ____

GENERAL INFORMATION AND HEALTH QUESTIONNAIRE (cont.)

YOUR AVAILABILITY:

Please list the hours of each day when you would generally be available to participate.

Monday________________________________

Tuesday _______________________________

Wednesday ____________________________

Thursday ______________________________

Friday _________________________________

Saturday_______________________________

Sunday ________________________________

Signature ____ Date _______________

INFORMED CONSENT FORM

Please read and understand the following.

1. Your participation. You are being asked to volunteer as a participant in a research project whose purpose and description are contained in the document entitled "Introduction to the Riding Simulator Study." Please read that description now, if you have not done so. Your participation will involve 1 session with the riding simulator lasting approximately 75 minutes.

2. Risks in the Study. There are some risks to which you may expose yourself in volunteering for this research study. The evaluations will be accomplished in the DRI Driving Simulator Laboratory at its facility in Torrance. The “riding simulator” version of the driving simulator is similar to a video game with a moving cab, or a ride at an amusement park, such as Disneyland. You will be seated on a motorcycle “cab” mockup. There is a relative motion between the motorcycle cab and the platform. As a result, parts of your body could become trapped between the two. To avoid this keep your hand and other parts of your body away from the roll motion mechanism located behind the motorcycle and near the steering head. This can be accomplished by sitting on the seat and keeping your feet on the foot rest.

   You will experience the illusion of realistic riding motions. Because of this visual illusion, and since the riding simulator projects the road ahead on a screen, you may experience some of the symptoms of motion sickness; such as a headache, uneasiness, or other discomfort. You will not be riding an actual motorcycle. So, the risks you will experience are similar to those of an office environment, combined with some aspects of a mild amusement-park-like ride. If you feel uneasy, disoriented, or motion sick during the riding, please tell a member of the research team, so you can take a break. If you become too uncomfortable you can end your participation (see Item 9, below).

3. Precautions. The following precautions will be taken prior to and during your participation:

   - A member of the research team will be nearby watching you.
   - You will be asked to wear a safety harness on the cab any time the simulator is in operation. This harness will keep you comfortably on the cab.
   - Before and during the evaluations, you will be briefed on the procedures and what we want you to do.
   - DRI staff will be directing all activities and serving as safety observers.

4. Use of Data and Confidentiality. The data from this study will be treated anonymously, and your name will not be identified in any publically available records or reported results. Your hands and feet will be video recorded during the study for data reduction and analysis purposes only. Your face will not be recorded. If you do not agree to being video recorded please let a research team member know. The data and the results of the evaluations will be the exclusive property of DRI and its customer.

5. Benefit of the Study. While there are no direct benefits to you from this research (other than an honorarium for participation), your help with the study will contribute to our knowledge of how riders interact with various motorcycle technologies and riding situations.

6. Qualifications to Participate. You should not participate in this research if you are under 20 years of age, or if you do not have a valid driver's license with a motorcycle endorsement, or if you have taken any drug, alcoholic beverage, or medication within the last 24 hours that might interfere with your ability to ride or to operate a vehicle safely. It is your responsibility to inform a research team member of any conditions that might interfere with your ability to participate or ride safely. Such conditions would include inadequate sleep, fatigue, hunger, hangover,

headache, cold symptoms, depression, allergies, emotional upset, uncorrected visual or hearing impairment, seizures (fits), nerve or muscle disease, or other similar conditions.

7. No Smoking. There will be no smoking in the simulator or inside the DRI facility.

8. Questions. You should know that the research team will answer any questions that you may have about this project. You should not sign this consent form until you are satisfied that you understand all of the previous descriptions and conditions. If you have any questions please contact:

   John Lenkeit, Project Engineer
   Dynamic Research, Inc.
   355 Van Ness Avenue, Torrance, CA 90501
   Ph: 310-212-5211

   or another DRI staff member

9. Okay to Stop Participating. You may withdraw from participation in this study at any time you wish, now or during the session and without any penalty. Should you, for any reason, feel the need or desire to stop participating, please do not hesitate to let the safety observer or another research team member know. The DRI research team also reserves the right, for any reason, to terminate your participation in the study. You will still be paid the honorarium.

10. <u>Signature</u> of the volunteer and date:

    I have read and understand the description and scope of this research project, and I have no questions. I understand the risks outlined in Item 2, I acknowledge reading about the safety features of the riding simulator, and I satisfy all the requirements and restrictions of Item 6 (Qualifications to Participate). I hereby agree and consent to participate, and I understand that I may stop participation if I choose to do so at any time, either prior to or during the evaluation day.

    Signature ______________________________

    Date ________________________________

11. <u>Witnessing</u> signature of a member of the research team or other responsible DRI employee and date:

    Signature ______________________________

    Date _________________________________

APPLIED RESEARCH PARTICIPANT CONFIDENTIALITY AGREEMENT

As a participant in an applied research study at Dynamic Research, Inc., (DRI), I recognize that such research studies involve confidential and proprietary information and matters. This includes data, information, software, hardware, and inventions which are considered proprietary by DRI or its customers.

I agree not to divulge or discuss the details of these confidential activities, and related data, information, software, hardware, and inventions to anyone outside of DRI, either during the study period or at any time in the future. I further agree not to remove from DRI any such data, information, software, hardware, or inventions.

I hereby waive the rights to any results, findings, or consequences thereof which may result from my activities for DRI.

I agree that this research activity participation is on an at-will basis, which means that either I or DRI can terminate the employment relationship at any time, without prior notice, and for any reason or for no reason or cause.

I understand and agree to the above.

Signed________________________________

Printed________________________________

Date__________________________________

Witnessed__________________________

DAILY HEALTH QUESTIONNAIRE

Subject # _________

1. How would you describe your general health today?

   ❑ Excellent ❑ Good ❑ Fair ❑ Poor

   If your answer is fair or poor you should discuss how you feel with a project team member.

2. Has there been any change in your general health in the past few days? If yes, please describe ❑ Yes ❑ No

   ____

   ____

3. In the last 24 hours have you experienced any of the following conditions?

Unusually tired feeling	❑ Yes	❑ No
Unusual hunger	❑ Yes	❑ No
Hangover	❑ Yes	❑ No
Headache	❑ Yes	❑ No
Cold symptoms	❑ Yes	❑ No
Depression	❑ Yes	❑ No
Emotional upset	❑ Yes	❑ No
Other illness or injury	❑ Yes	❑ No

4. Have you taken any prescription or non-prescription drugs in the last 48 hours that might affect your ability to ride a motorcycle or participate in this study? If yes, please describe

   ❑ Yes ❑ No

   ____

   ____

DAILY HEALTH QUESTIONNAIRE (cont)

5. Have you consumed any alcohol (beer, wine, liquor, etc.) in the last 24 hours?
   If yes, please describe type and amount. ❑ Yes ❑No

   ____

   ____

6. Do you have a valid California driver's license with a motorcycle endorsement?
   Yes No ❑ ❑

7. Is the main motorcycle you are currently riding different than the one you were using when you completed the General Information Questionnaire? ❑Yes ❑No

There are some small risks you may be exposed to as a volunteer in this study. Remember to keep your hands away from the roll motion mechanism near the steering head and behind the seat. Stay seated on the seat with your feet on the footrests. Since the riding simulator projects the road ahead on a screen, and the cab where you sit moves around a little, you may experience some of the symptoms of motion sickness; such as a headache, uneasiness, or other discomfort. Overall, the small risks you will experience are similar to those of an office environment, combined with some aspects of an amusement-park-like ride. If you feel uneasy, disoriented, or motion sick, please tell a member of the evaluation team, so you can take a break. You can stop participating in this study at any time, by just telling a member of the team.

DAILY HEALTH QUESTIONNAIRE (cont)

I understand the purpose of this study and the possible risks involved, and I am in good health today and ready to participate.

Signature ________________________________

Date ____________________________________

Team Member (Witness) ____________________________

POST STUDY INSTRUCTIONS

1. Indicate to the participant that he/she needs to wait/rest for at least 20 min. before leaving DRI. Offer additional time to rest if the participant indicates any discomfort or fatigue. If necessary, offer to arrange alternative transportation.

2. IMPORTANT: Remind the participant that the riding in the simulator should not necessarily reflect in any way how he/she should ride back on the road. The handling of the motorcycle simulator may not be the same as their own motorcycle. The participant needs to continue to ride in a safe manner.

3. Ask if it would be okay for someone to conduct him/her at a later time to make sure everything is okay.

POSSIBLE QUESTIONS PARTICIPANTS COULD ASK, AND
ANSWERS TO BE GIVEN

1. How did I do? This study is to examine riders' behavior and preference during panic stops. There were no measures to determine how you did.

2. The simulator did not seem realistic or correct? Thank you for your feedback. We will consider your comments. Remember, this is a simulator and some difference with the real-world is to be expected.

3. Who is this study sponsor? US DOT

4. Will there be a way to see the results from this study? There will be a report to DOT but ID of participants is confidential and protected. To be determined by the DOT

5. Will there be future similar studies? If interested, we can put your name down if future studies come up.

CONFIDENTIALITY, DATA SECURITY, AND DATA DESTRUCTION

Records relating to a participants background and participation in an experimental project are kept confidential and stored in a secure manner (in a locked file or on password protected computers in an otherwise secure office area). The data are made available only to project staff members for purposes of the project. To protect each participant's confidentiality a unique identification code is assigned to each participant. All data and data forms will use this identification code, and if the data are shared with others, it is done in such a way that the participant cannot be directly identified. The data are owned by DRI in a manner consistent with the terms of a contract.

For the present project (Subcontract 8172-S-05), DRI will destroy all data that may identify an individual participant or associate them with their screening responses within the period of the project. Performance data that cannot be related to a participant's identity will be retained for archival purposes for as long as they are needed or useful.

The General Information and Health Questionnaire, the Daily Health Questionnaire, and other documents or files containing personal information about the participant are destroyed within the period of a project. General information that is not health-related (address, phone, employer, age, height, weight and occupation) is retained for archival purposes according to DRI's general retention policy.

The general DRI data retention policy of long standing is to only retain such technical documents, data, and other materials for a period in which they would be needed or useful. Data and documents are destroyed in a manner appropriate for confidential information. In the case of business records they are retained for the periods prescribed by law and regulations. Paid invoices and employee time cards are retained no longer than 7 years. In some cases a summary technical report or other document with archival value is prepared in the course of a project, and such archival document may be retained for an indefinite period in a DRI archive or the DRI Technical Library.

Riding Experience Questionnaire

1. At what age did you first ride a motorcycle on at least an occasional basis?

 ____

2. What types of motorcycle training courses have you completed? (Check all that apply)

 ☐ Basic Rider Course

 ☐ Advanced Rider Course

 ☐ Other Rider Training Courses (please list them)

 ____

 ☐ I have not completed any formal courses

3. Have you ever held a competition license for motorcycle events? If yes, please list the licenses or types of events.

 ☐ Yes ☐ No

 ____

 ____

4. What types of motorcycles have you **owned or ridden** on a regular basis? (check all that apply)

☐ Sport Bike	☐ Chopper
☐ Sport Touring	☐ Dual Purpose
☐ Cruiser	☐ Off-Road
☐ Touring	☐ Competition
☐ Standard	☐ Vintage

5. What motorcycle(s) do you ride most often?

Manufacturer	Model	Year	% Riding this Motorcycle

6. Approximately how many miles have you ridden during the last 3 years?

	Commuting	Touring	Cruising	Recreational
2008				
2007				
2006				

7. What percentage of your riding is on:

Weekdays ________ %

Weekends ________ %

100

8. What percentage of your riding is:

By yourself ________ %

In groups ________ %

100

9. What percentage of your riding is:

Rural ________%

Suburban ________%

City ________%

100

10. Do you belong to any riding clubs? (if yes, please specify)

☐ Yes ☐ No

____

____

12. The motorcycle simulator can be set up as either a cruiser or sport touring. Which best suits your experience and type of riding?

Cruiser ________

Sport Touring ________

12. How would you rank your preference for riding the type(s) of motorcycle listed below? (Please check boxes that apply)

	Prefer least								Prefer most	
	1	2	3	4	5	6	7	8	9	10	No Interest
Sport bike											
Cruiser											
Touring											
Dual Purpose											
Sport Touring											
Standard											
Off-Road											
Chopper											
Vintage											

13. Do you have experience with off road motorcycles? (If yes, please describe)

☐ Yes ☐ No

Post Ride Questionnaire

1. In an emergency braking situation (similar to the one you saw in the simulator), what do you typically do?

   ☐ Brake ☐ Accelerate

   ☐ Steer ☐ Use the horn

   ☐ Brake and Steer ☐ Other (please specify) ________________

2. Have you ever had a critical accident avoidance experience in real world riding? (If yes, please describe)

   Yes ☐ No ☐

   ____
   _

   ____
   _

3. What types of brake systems are the motorcycles you typically ride equipped with? (Check all that apply)

   ☐ Conventional (separate front and rear brake controls)

   ☐ Combined or Linked Brake System (either control operates both front and rear brake)

   ☐ ABS

4. How do you rate your overall riding skill and recent experience?

Recent Experience:

- Daily Riding
- Weekly Riding
- Monthly Riding
- Occasionally
- Rarely

Overall Riding Skill:

- Expert
- Typical
- Novice

5. How do you rate your riding style?

- Aggressive
- Moderate
- Conservative

APPENDIX C

RUN PROCEDURE DOCUMENTS, PARTICIPANT INSTRUCTIONS, AND QUESTIONNAIRES FOR USE IN THE MOTORCYCLE BRAKING STUDY

June 2009

The following are run procedure documents, participant instructions, and questionnaires for use in the Motorcycle Braking simulator study, May 2009

The following items are to be discussed with the participants before they participate in the riding simulator evaluation. Instructions in *italic* are to be given to the participants.

1. Give the participant a copy of the pre-test documentation package, and ask him to fill it out. Answer any questions the participant has while filling it out. Review the completed form. If any of the conditions listed on the daily questionnaire indicate that the participant would not be suitable to test in the simulator, thank the participant for his willingness to participate but tell him that he is being excused, and that the reason will be kept confidential. If the form is acceptable, sign and file it.

2. Review the "INTRODUCTION TO THE RIDING EVALUATION STUDY", and "WHAT TO DO IN CASE OF" forms.

3. How the evaluation will be conducted:

[In the Subject Room]

BEFORE ENTERING THE TESTING AREA
I will need you to empty your pockets and leave all personal items in one of the lockers in the break room. Please remember to bring the locker key with you. Drinks, snacks, cell phones, and all personal items are not allowed in the testing area.

ABOUT THE STUDY
"Today's evaluation will consist of a single session. The entire study should take approximately 2.5 hours, including paperwork, a break, and a questionnaire.

ABOUT THE ROAD
When you are asked to ride the simulator, you will be riding on a 4 lane road with 2 lanes going in each direction, in the daytime, and the weather will be clear. At times you will be riding through city/suburban roads and your speed limit will be 40 mph. Other times you will be riding through highway and your speed limit will be 65 mph. Please make sure to follow posted speed limits at all times and follow the rules of

the road. You will mostly be riding in the ***right lane*** *but will occasionally be asked to ride in the left lane. When you hear instructions to ride on the left lane, please do so, otherwise,* ***I expect you to stay in the right lane****.*
Before starting the actual study, you will be doing a warm-up run to familiarize yourself with the simulator and the road.

ABOUT THE BIKE

The motorcycle simulator has many moving parts. Please keep all parts of your body away from the underside of the motorcycle. Also keep all parts of your body away from the roll motion mechanism located behind the motorcycle and near the steering head. Do this by keeping your feet on the foot pegs or foot rests. Also keep your hands and arms away from the steering mechanism, including the handlebars and triple clamps except during the ride. While riding please make sure use both hands and use smooth steering and accelerating inputs.

ABOUT THE HELMET

As part of both the riding experience and safety precaution, you will be wearing an approved motorcycle helmet with intercom system built in. Before starting we will first adjust the microphone and headphone levels. If you feel uncomfortable or you want to take a break at any time, please let me know right away. The helmet is equipped with an intercom system through which you can communicate with me during the study. If the intercom should stop working at any time, including non-emergencies, sit up and wave your hand above your head to inform the DRI staff person of the situation.

ABOUT THE SAFETY HARNESS

To avoid falling off the motorcycle cab and possibly falling from the platform, you will be wearing a safety harness while on the simulator. Before getting started we will take a moment to adjust it to fit you comfortably. Do not remove or unlock the harness, or dismount the motorcycle until instructed to do so by the DRI staff person.

After we have completed the riding portion of this study I will have you fill out a questionnaire before dismissing you. [Demonstrate all parts to Participant]

In General, if you think there is a problem with the simulator or the procedures, say "STOP" in a loud voice over the intercom. The operator will immediately shut down the simulator.

Mounted on top of the fuel tank is a large red Emergency Stop or E-Stop button. To effect an emergency stop, forcefully push down on the Emergency Stop Button. When it is pushed the simulator will immediately abort, depressurize and the platform will slowly return to its bottom position. Power to the steering actuator and pressure to the motorcycle roll motion will be turned off.

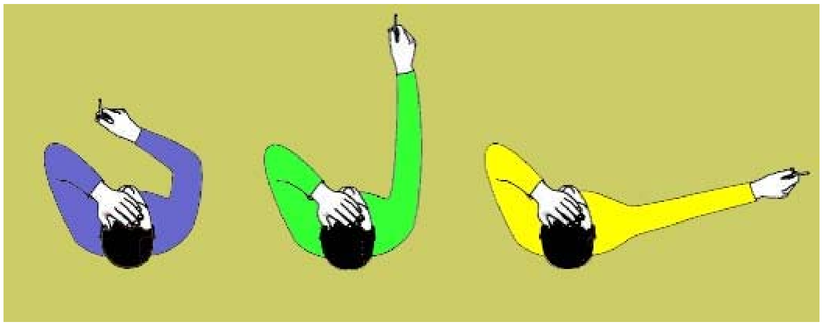
<u>EYE TESTS & DYNAMOMETER TEST</u>

Before we get started, we will need to complete a quick eye test (acuity test) and check your peripheral vision.

Acuity Test

- With their glasses/contacts on have the participant stand 20 feet away from the eye chart (At the "do not remove" tape on the floor)
- Have the participant read each line of letters, starting from the top until they can no longer read the letters (until they miss 2 or more letters on a line)
- Write down their acuity (expressed as a fraction, stated on the left side of the chart)
- 20/20 is considered normal. Write down their acuity.

Peripheral Test (Visual Field Test)



Take a pen in your hand and hold your outstretched arm in front of your face. Cover the eye that is opposite the outstretched hand with your free hand. Look straight ahead. Keep looking straight ahead while slowly moving the pen in outward with your arm still outstretched. Please do the same with the other arm.

The participant's arm should be at an angle of 90 degrees from the starting point of movement.

Do you have any questions before we enter the testing area? Would you like to use the restroom before we start? Our next break is in about 45 minutes.

DYNAMOMETER

We will be measuring your right hand grip force with this dynamometer. Simply hold it in your right hand and squeeze once as hard as you can. (demonstrate to participant)

4. Questionnaire:

   After you have completed the study, review the questionnaire. Describe what is being asked exactly, so that each participant will answer with the same considerations. This makes the data more consistent and more meaningful. Explain how to complete the rating scales.

The following items are to be performed as the participant enters the simulator room and proceeds to the cab.

1. Assist the participant onto the motorcycle.

2. Have the participant adjust the harness.

3. Assist participant with the harness.

4. Assist participant with helmet, gloves, and make sure their intercom mic is in working condition.

The following items are to be described and performed with the participants after getting on the cab.

1. Review safety features:
   - Stay seated until the platform is completely lowered and I am able to assist you with dismounting the motorcycle.
   - Keep the safety harness on at all times.
   - If you feel any discomfort, you should inform me (the research assistant) immediately.
   - Use small, smooth steering inputs and corrections.

Miscellaneous pre-test tasks to be performed by the SimOp:

1. Inform the business office that testing is in progress. If testing is being performed at night, please let the business office know you will be there after hours.

INSTRUCTIONS – WARM UP

The following instructions are to be given to the participants while in the riding simulator. Instructions in *italic* are for the research assistant.

The purpose of the warm is to get you familiar with the feel of the bike. Once you are comfortable with riding, we will start the main study.

[In the Cab Area]

You will first ride a five minute warm-up road. This time is intended to familiarize you with operating the motorcycle simulator. Generally, you will ***use small smooth steering inputs and corrections to control the motorcycle****.*

The warm-up road will be similar to the road you will be riding during the actual study without any other traffic. The speed you are riding at will appear on the screen in miles per hour. Please note that when your speed is less than 30 mph, you will have minimal to no control over the steering of the bike but you will still be in control of the acceleration and braking. This motorcycle has an automatic transmission, so there is no need to shift gears.

If you feel uncomfortable in any way or you want to take a break at any time, please let me know right away. The helmet you are wearing is equipped with an intercom system through which you can communicate with me during the study.

Please keep all parts of your body away from the underside of the motorcycle. Also keep all parts of your body away from the roll motion mechanism located behind the motorcycle and near the steering head. Do this by keeping your feet on the foot pegs or foot rests. Also keep your hands and arms away from the steering mechanism, including the handlebars and triple clamps except during the run (riding portion of the study).

You will be wearing a safety harness while in the simulator. Please do not remove the harness until the platform has been completely lowered and I am able to help you safely dismount from the motorcycle.

When you come to the end of the warm-up session, you do not need to come to a complete stop, but please slow down when instructed to. At that point I will warn you and the simulation operator will bring you to a full stop.

Do you have any questions?
Okay, we're ready to begin the warm-up. When you hear the starting sounds of the motorcycle you can begin riding.

***Wait until the participant can keep their speed steady and stay in their lane before asking them to do a couple of lane changes to the right and left, first at 40 mph then at 60 mph. When they seem comfortable and before the end of the warm up, have them slow to 20 and then speed back up to 40.**

***Make sure that they are using the correct pegs:**

- ***sport bike riders* should be using the *rear pegs***
- ***cruiser riders* should be using the *front pegs***

INSTRUCTIONS (ROAD 1 & 2)

Now that you are more comfortable with the vehicle and with riding, on the actual simulated roadway, we can begin the main study.

You will be riding on a 4 lane road with 2 lanes going in each direction, in the daytime, and the weather will be clear. At times you will be riding through city/suburban roads and your speed limit will be 40 mph. Other times you will be riding through highway and your speed limit will be 65 mph. Please make sure to follow posted speed limits at all times and follow the rules of the road, including traffic lights. The speed you are riding at will appear on the screen in miles per hour. Please note that when your speed is less than 30 mph, you will have minimal to no control over the steering of the bike but you will still be in control of the acceleration and braking. You will mostly be riding in the right lane but will occasionally be asked to ride in the left lane. When you hear instructions to ride in the left lane, please do so, otherwise, I expect you to stay in the right lane.

If you feel uncomfortable in any way or you want to take a break at any time, please let me know right away. The helmet is equipped with an intercom system through which you can communicate with me during the study.

You will be wearing a safety harness while in the simulator. Please do not remove the harness until the platform has been lowered and I am able to help you safely dismount from the motorcycle.

Please keep all parts of your body away from the underside of the motorcycle. Also keep all parts of your body away from the roll motion mechanism located behind the motorcycle and near the steering head. Do this by keeping your feet on the foot pegs or foot rests. Also keep your hands and arms away from the steering mechanism, including the handlebars and triple clamps except during the run (riding portion of the study).

When you come to the end of the warm-up session, you do not need to come to a complete stop, but please slow down when instructed to. At that point I will warn you and the simulation operator will bring you to a full stop.

Do you have any questions? Ok, we are ready to start. When you hear the starting sounds of the motorcycle you can begin riding.

***Make sure that you are recording**

[After end of Run #1]

We will be taking a 10 minute break. Please take this time to use the restroom, have a quick snack or something to drink, or just relax before we start up again. I will come back to get you when we are ready to begin again. Restrooms are located up stairs or down stairs on the left. When you return, just remember to come back through the door on the purple wall.

***Make sure that you are recording**

SSQ - POST EXPOSURE SYMPTOM CHECKLIST

Date: Subject#: Study: MC Braking (167-2)

Please circle how much each symptom below is affecting you right now.

#	Symptom	Severity			
1.	General discomfort	None	Slight	Moderate	Severe
2.	Fatigue	None	Slight	Moderate	Severe
3.	Headache	None	Slight	Moderate	Severe
4.	Eyestrain	None	Slight	Moderate	Severe
5.	Difficulty focusing	None	Slight	Moderate	Severe
6.	Increased salivation	None	Slight	Moderate	Severe
7.	Sweating	None	Slight	Moderate	Severe
8.	Nausea	None	Slight	Moderate	Severe
9.	Difficulty concentrating	None	Slight	Moderate	Severe
10.	Fullness of the head	None	Slight	Moderate	Severe
11.	Blurred vision	None	Slight	Moderate	Severe
12.	Dizziness (eyes open)	None	Slight	Moderate	Severe
13.	Dizziness (eyes closed)	None	Slight	Moderate	Severe
14.	Vertigo*	None	Slight	Moderate	Severe
15.	Stomach awareness**	None	Slight	Moderate	Severe
16.	Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

POSSIBLE QUESTIONS PARTICIPANTS COULD ASK, AND ANSWERS TO BE GIVEN

1. How did I do? This study is to examine riders' behavior riding style while on a motorcycle. There were no measures to determine how you did.

2. The simulator did not seem realistic or correct? Thank you for your feedback. We will consider your comments. Remember, this is a simulator and some difference with the real-world is to be expected.

3. Who is this study sponsor? US Department for Transportation.

4. Will there be a way to see the results from this study? There will be a report to our customer but ID of SS is confidential and protected. To be determined by the customer.

5. Will there be future similar studies? If interested, we can put your name down if future studies come up.

POST STUDY INSTRUCTIONS

1. Indicate to the participant that he/she needs to wait/rest for at least 20 min. before leaving DRI. Offer additional time to rest if the participant indicates any discomfort or fatigue. If necessary, offer to arrange alternative transportation.

2. IMPORTANT: Remind the participant that the riding in the simulator should not necessarily reflect in any way how he should ride back on the road. The handling of the riding simulator may not be the same as their own motorcycle. The participant needs to continue to ride in a safe manner.

3. Ask if it would be okay for someone to contact him/her at a later time to make sure everything is okay.

APPENDIX D

RIDER FACTORS

Approximately 100 motorcycle riders expressed an interest in participating in this study. As described in Section II, the recruitment goals were to have a participant age range evenly distributed between 20 and 60 years of age, with various types of riding experience and training, and evenly divided between those who primarily rider cruisers and those who ride primarily sport-touring or sportbikes. Seventy-two candidates were invited to participate, and completed the initial processing, including the orientation. Of these, 68 completed the warmup runs and most or all of the scenarios, and had usable data. As described in Section II B, two roadways were used, so for the purpose of counterbalancing the experiment, the participants were split into two groups, those who rode Roadway 1 first, and those who rode Roadway 2 first. A table listing these participant's participant number, and age is given in Table D1. Figure D1 shows the age distribution for the two motorcycle configuration groups. All participants were male.

Table D1. Participants Summary by Motorcycle Type

Cruiser	
Participant Number	Age
382	41
828	51
1151	31
1152	45
1153	32
1155	43
1156	49
1157	59
1158	51
1159	27
1160	60
1161	58
1162	60
1163	45
1164	50
1169	41
1172	55
1173	41
1174	31
1175	40
1176	56
1179	51
1180	27
1183	42
1186	52
1187	75
1194	45
1200	46
1203	24
1204	38
1205	53
1206	31
1207	54
1209	21

Sport-Touring	
Participant Number	Age
516	65
887	42
943	54
947	31
1137	20
1138	24
1139	23
1140	28
1142	32
1143	41
1145	39
1146	36
1147	23
1148	27
1149	53
1150	37
1166	53
1167	33
1177	24
1181	26
1182	22
1185	25
1188	59
1190	48
1191	20
1192	61
1193	60
1195	52
1197	42
1198	46
1199	46
1201	42
1202	46
1208	45

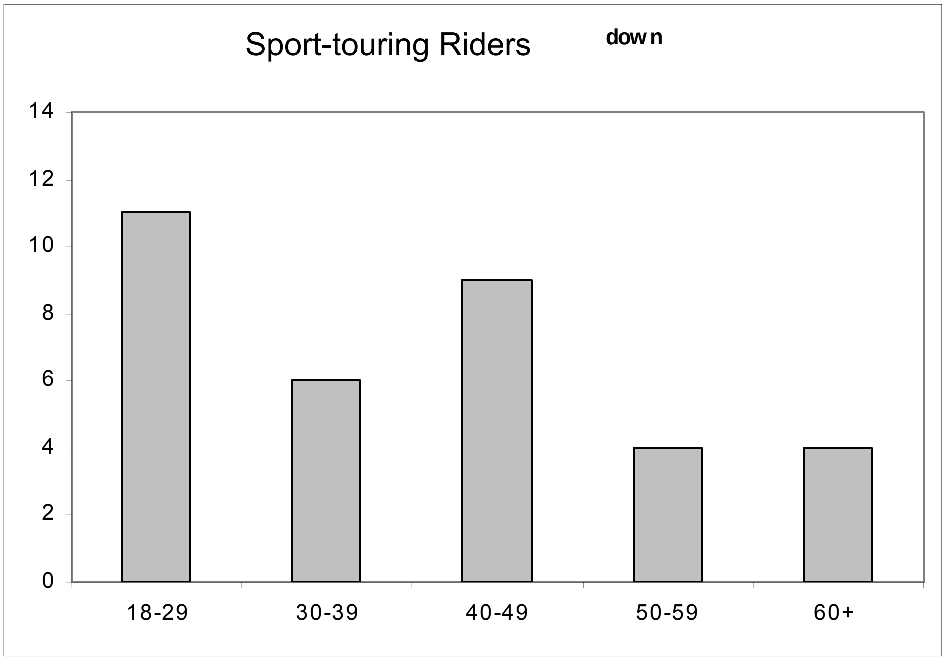


Figure D1. Participant Age Breakdown

1. Riding Experience Questionnaire Results

As described in Section III C of the technical report, all participants completed a questionnaire related to their riding experience. The questions are repeated here along with the tabulated responses. Note that responses to questions 9 and 11 are not given here. Regarding question 9, there was confusion regarding definitions of the various riding locales, and the results of question 11 were used to determine which cab setup to use.

Question 1: At what age did you first ride a motorcycle on at least an occasional basis (see Fig D2)?

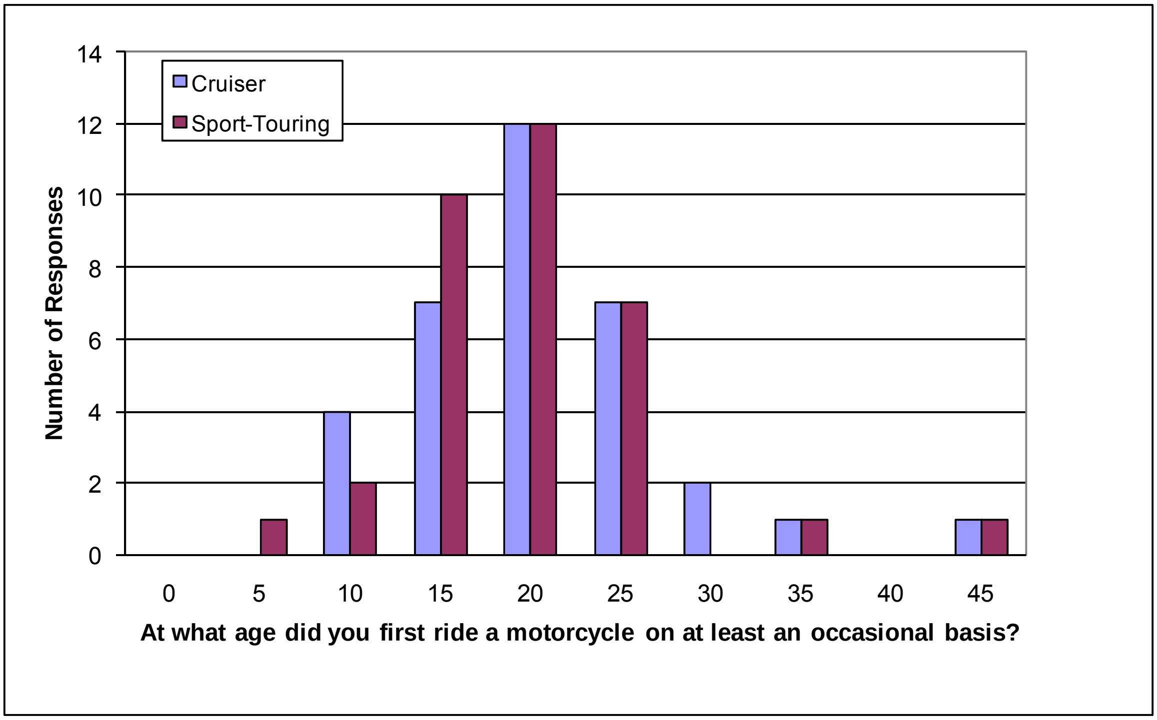


Figure D2. Age Motorcycle Riding Began

Question 2: What types of motorcycle training courses have you completed (see Table D2)?

Table D2. Response to Rider Training Questions

	Cruiser	Sport-Touring	Total
Basic Rider Course	23	22	45
Advanced Rider Course	4	7	11
No formal training	11	6	17
Other formal training	0	7	7

Question 3: Have you ever held a competition license for motorcycle events (see Table 4)? If yes, please list the licenses or types of events.

Table 4. Response to Competition License Questions

	Cruiser	Sport-Touring	Total
Competition license	2	3	5

Question 4: What types of motorcycles have you owned or ridden on a regular basis? (check all that apply). Results are in Fig D3.

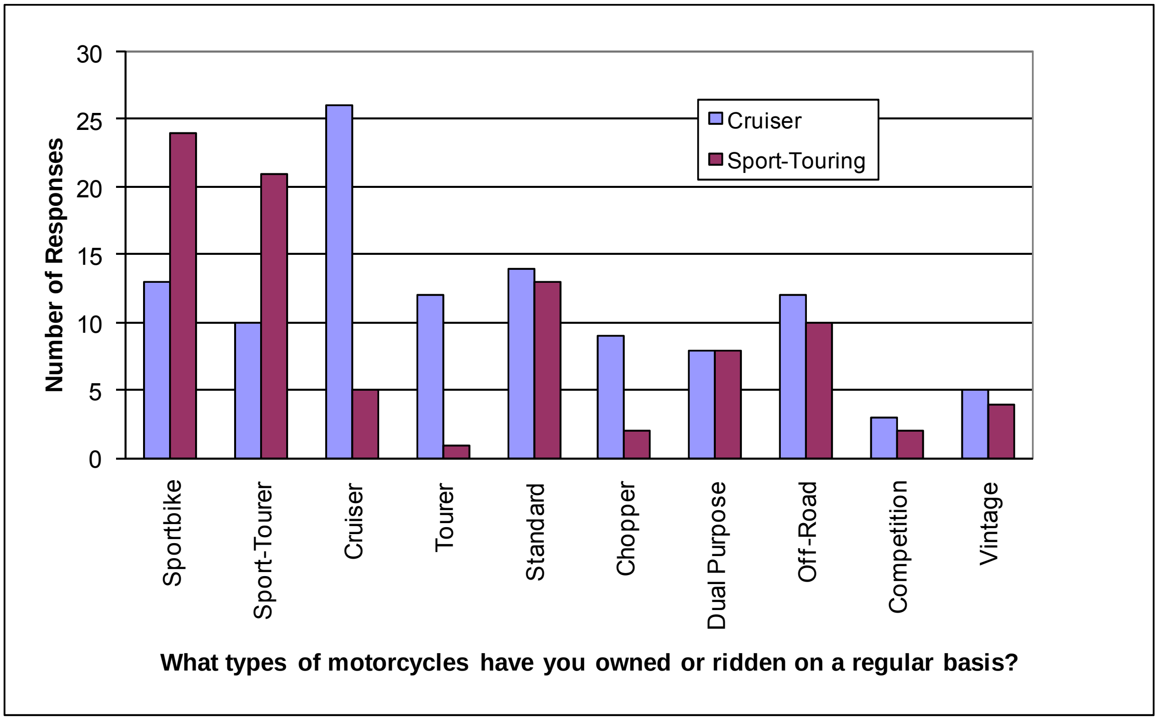


Figure D3. Types of Motorcycles Owned

Question 5:

What motorcycle(s) do you ride most often?

Ride Category	Motorcycle 1	Motorcycle 2
Cruiser	Yamaha Zuma 2008 (100%)	
Cruiser	Kawasaki 1100 LTD 1985 100	
Cruiser	Honda Shadow 2003 (100%)	
Cruiser	Harley FLSRSE 2008 (90%)	Harley FLHS 89/FXDBSE 09 (5/5%)
Cruiser	Harley FXDWG 2008 (100%)	
Cruiser	Harley Davidson Softail Chopper Springer 1994 (100%)	Kawasaki KX250K 2007 (100%)
Cruiser	Honda VF750C1997 (99.9%)	
Cruiser	Harley FXDWGI 2006 (75%)	Honda CBR600F4I 2006 (25%)
Cruiser	H-D Sportster XLIZ00 2005 (95%)	H-D Road King FLUR 2008 (5%)
Cruiser	Yamaha Virago 1996 (100%)	
Cruiser	Harley Davidson Street Glide 2006 (100%)	
Cruiser	HD FLTR (touring model) 2002 (100%)	
Cruiser	Harley Davidson Fat Bob 2009 (100%)	Harley Davidson Street Glide 2007
Cruiser	Harley Davidson FLSTC 2008 (100%)	
Cruiser	Harley Davidson Sportster 2003 (99.9%)	
Cruiser	Harley Davidson Dyna 2009 (60%)	Ducati ST4S 2003 (40%)
Cruiser	Honda CB750 71 (100%)	
Cruiser	Honda VTX 1300 2007 (100%)	
Cruiser	Harley Davidson Sportster 2002 (85%)	
Cruiser	HD Ultra Classic 2009 (100%)	
Cruiser	HD Road King 2006 (100%)	
Cruiser	Honda ST1300 2004 (90%)	Honda Magna 1989 (10%)
Cruiser	Yamaha R6 2006 (50%)	Honda Shadow 2006

Ride Category	Motorcycle 1	Motorcycle 2
		(40%)
Cruiser	Yamaha X5400 82 (85%)	Yamaha Virago 750 87
Cruiser	Harley Davidson Ft 1971 (90%)	
Cruiser	British	
Cruiser	Harley Davidson FLH 1979 (50%)	
Cruiser	Harley Sportster 1987 (100%)	
Cruiser	Honda CBR1000 2007 (60%)	Honda Shadow 750 2007 (40%)
Cruiser	Harley Heritage classic 2003 (60%)	Yamaha Sports 1989 (30) vespa 10
Cruiser	Honda VT1100 2005	
Cruiser	Honda CBR1000 RR 2008 (20%)	Honda VTX 1800 2007 (20%)
Cruiser	Harley FLSTC 1997 (100%)	
Cruiser	Suzuki SV1000S 2003 (95%)	Kawasaki EX250 1997 (5%)
Sport Touring	Honda 500 1980 (100%)	
Sport Touring	BMW K1300S 2009 (90%)	BMW K1200S 2006 (10%)
Sport Touring	H-D Sportster 1974 (50%)	Bultaco Pursang 1973 (50%)
Sport Touring	Honda CBR 600 2003 (100%)	
Sport Touring	Yamaha YZF 600R 2001 (70%)	Honda Rieber 250 1999 (30%)
Sport Touring	Yamaha RG 2007 (90%)	Honda CBR600rr 2003 (10%)
Sport Touring	Suzuki DR650 2007 (85%)	Honda CR 250 1999 (13%)
Sport Touring	Honda CRF 450X 2005 (100%)	
Sport Touring	Kawasaki Ninja 250 2007 (100%)	
Sport Touring	BMW KIZ00S 2006 (80%)	Moto Guzzi V11Sport 2003 (15%)
Sport Touring	Yamaha FZ1 2003 (100%)	
Sport Touring	Harley Davidson Softail Spring 2005 (95%)	Honda TRX 300 2006 (5%)
Sport Touring	Honda CBR 600rr 2008 (100%)	

Ride Category	Motorcycle 1	Motorcycle 2
Sport Touring	Buell XB12's Lightning 2007 (33%)	Honda CBR600 rr 2006 (33%)
Sport Touring	Cagiva Gran Canyon 2009 (95%)	Ossa MAR 1972 (4%)
Sport Touring	Kawasaki KLR 650 2003 (90%)	
Sport Touring	Honda ST1300A 2007 (100%)	
Sport Touring	Yamaha Sport 2006 (90%)	
Sport Touring	Honda CBR 600F4 1996 (50%)	Kawasaki Ninja 500R 1998 (50%)
Sport Touring	Suzuki Bandit 1200 2003 (90%)	
Sport Touring	Honda CBR 600 rr 2004 (100%)	
Sport Touring	Yamaha R6 2008 (100%)	
Sport Touring	Buell XB95X 2008 (98%)	YAMAHA RZ350 1985 (2%)
Sport Touring	BMW RII50RT 2003 (90%)	BMW RII50GS 2003 (5%)
Sport Touring	Suzuki GSXR 600 2007 (90%	Honda CBR-1000 2009 (5%)
Sport Touring	MotoGuzzi Norge 2007 (99%)	Honda CJ360T (2001%)
Sport Touring	Honda ST1100 98 (50%)	Honda 919/CX650 04/83 (40/10)
Sport Touring	Honda ST1300 2004 (100%)	
Sport Touring	Kawasaki Concours 14 2008 (50%)	Suzuki Vstrom 1000 2005 (50%)
Sport Touring	Honda ST1100 2002 (100%)	
Sport Touring	Pipelia RSV 1000 2001 (90%)	
Sport Touring	Yamaha IJ2 2008 (100%)	
Sport Touring	Honda VFR 800 2000 (90%)	Yamaha FJR 1300 2006 (10%)
Sport Touring	Honda VFR 800 2002 (80%)	Suzuki V-Strom 1000 2004 (20%)

Question 6: Approximately how many miles have you ridden during the last 3 years (see Figs D4 - D6)?

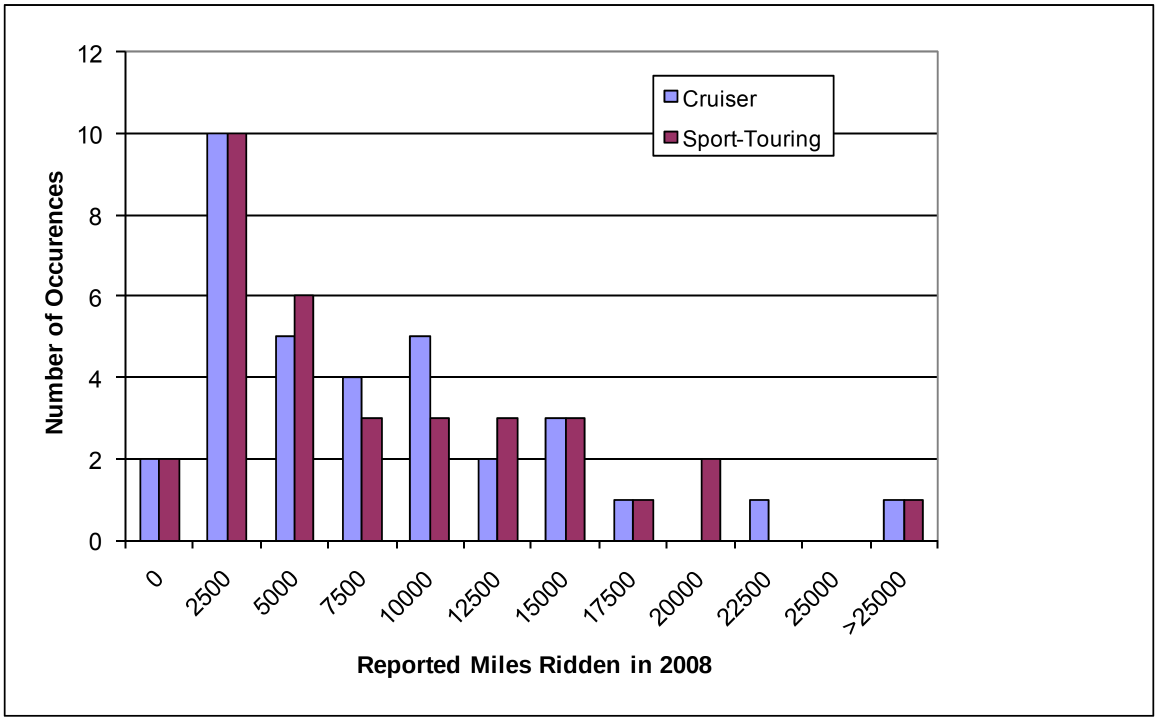


Figure D4. Reported Miles Ridden in 2008

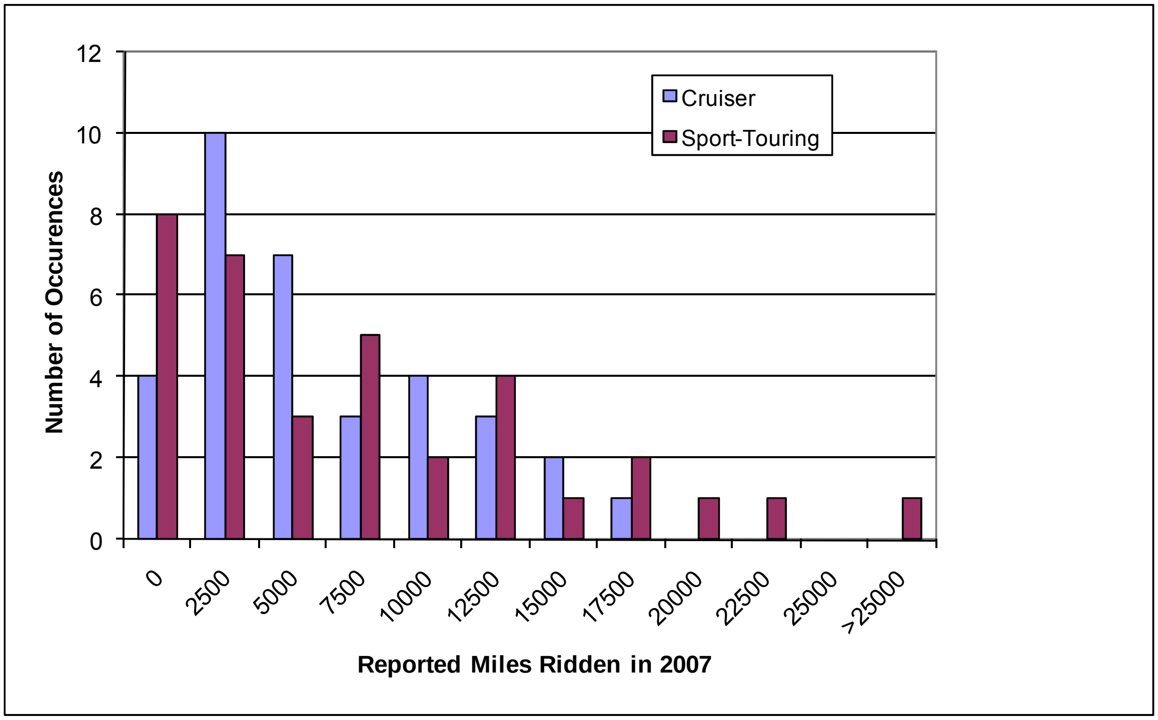


Figure D5. Reported Miles Ridden in 2007

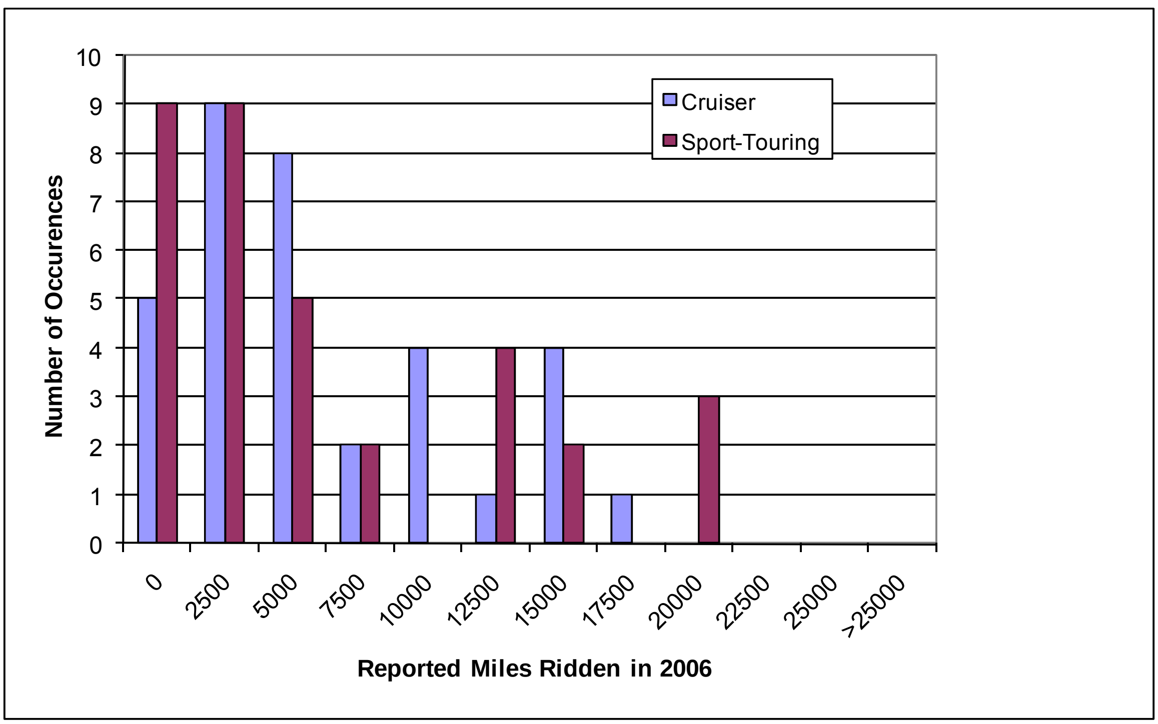


Figure D6. Reported Miles Ridden in 2006

Question 7: What percentage of your riding is on weekdays/weekends (see Figs D7 and D8)?

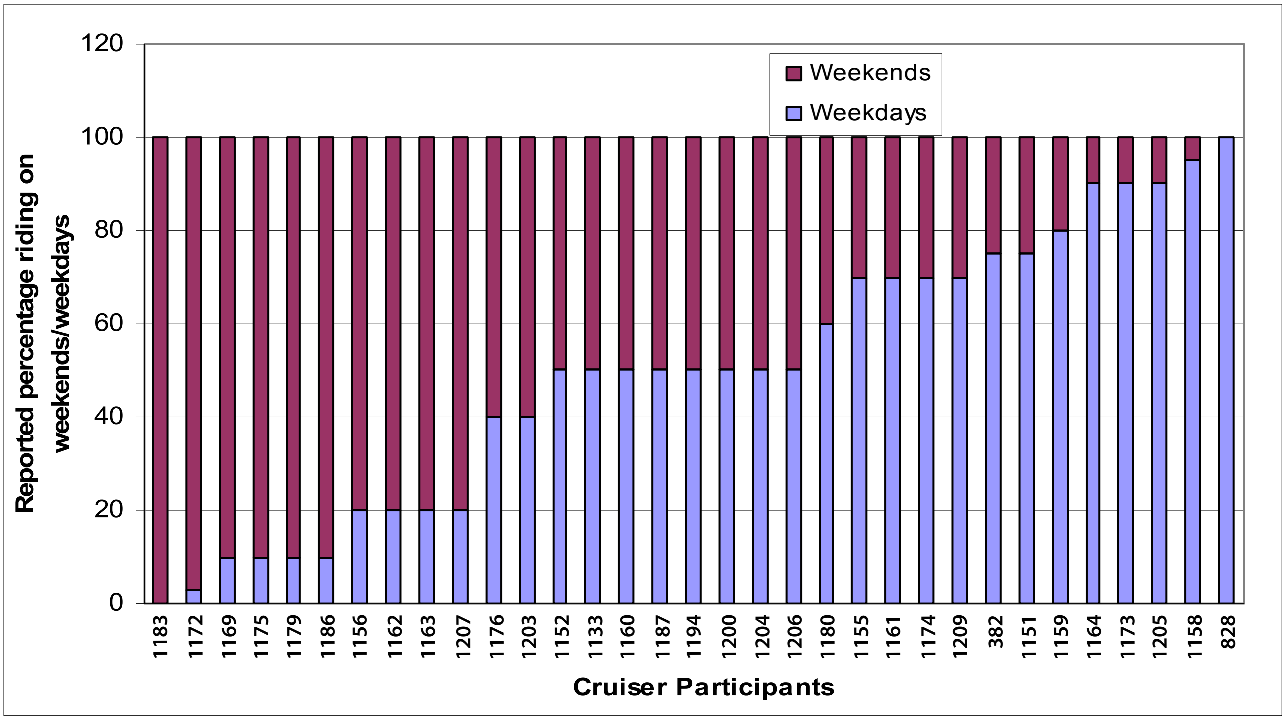


Figure D7. Percentage of Riding on Weekends and Weekdays for Sport Touring Participants

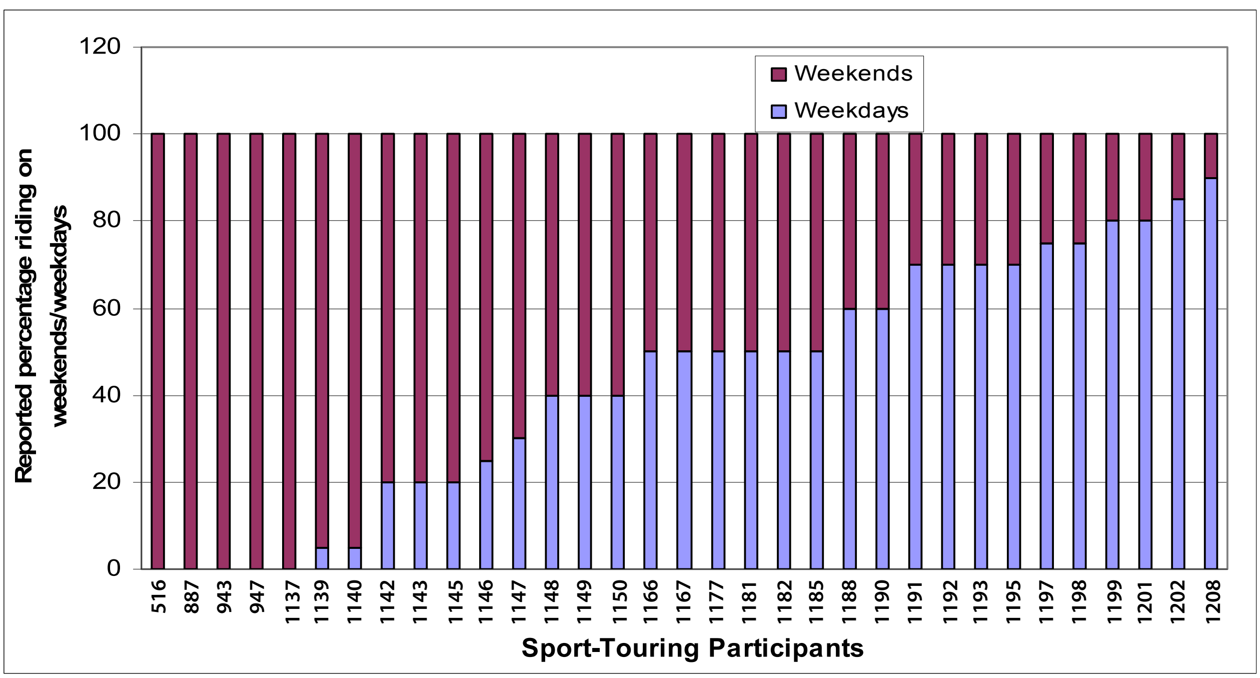


Figure D8. Percentage of Riding on Weekends and Weekdays for Cruiser Participants

Question 8: What percentage of your riding is alone/with a group (see Figs D9 and 10)?

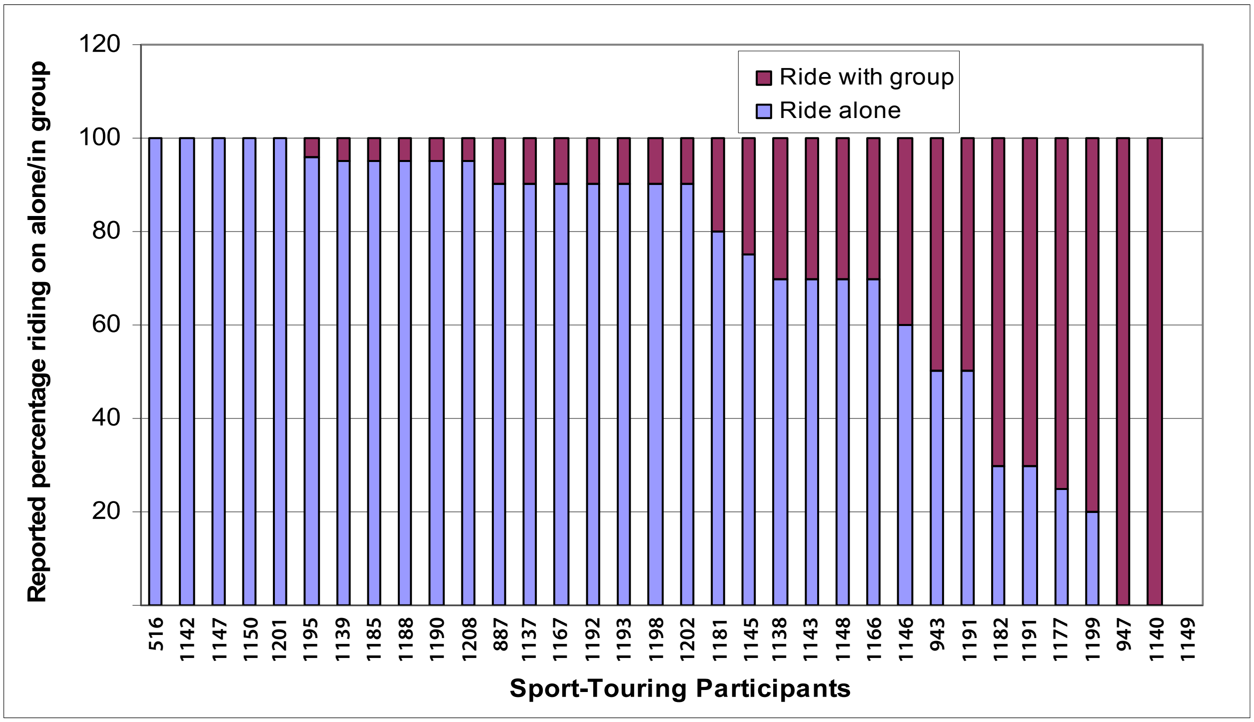


Figure D9. Percentage of Riding with a Group or Alone for Sport Touring Participants

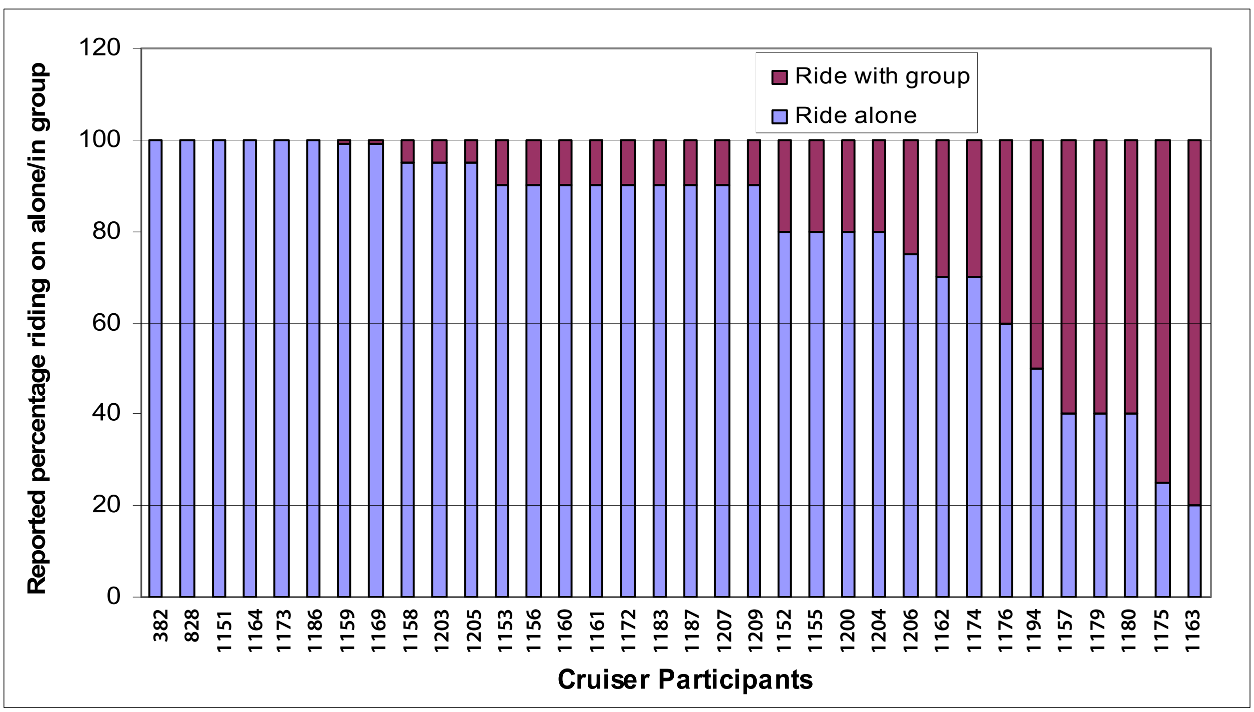


Figure D10. Percentage of Riding with a Group or Alone for Cruiser Participants

Question10: Do you belong to any riding clubs (see Table 5)?

Table 5. Response to Club Membership Question

	Cruiser	Sport-Touring	Total
Member of a club	8	14	22

Question 12: How would you rank your preference for riding the type(s) of motorcycle listed below (see Fig D11)? (Please check boxes that apply).

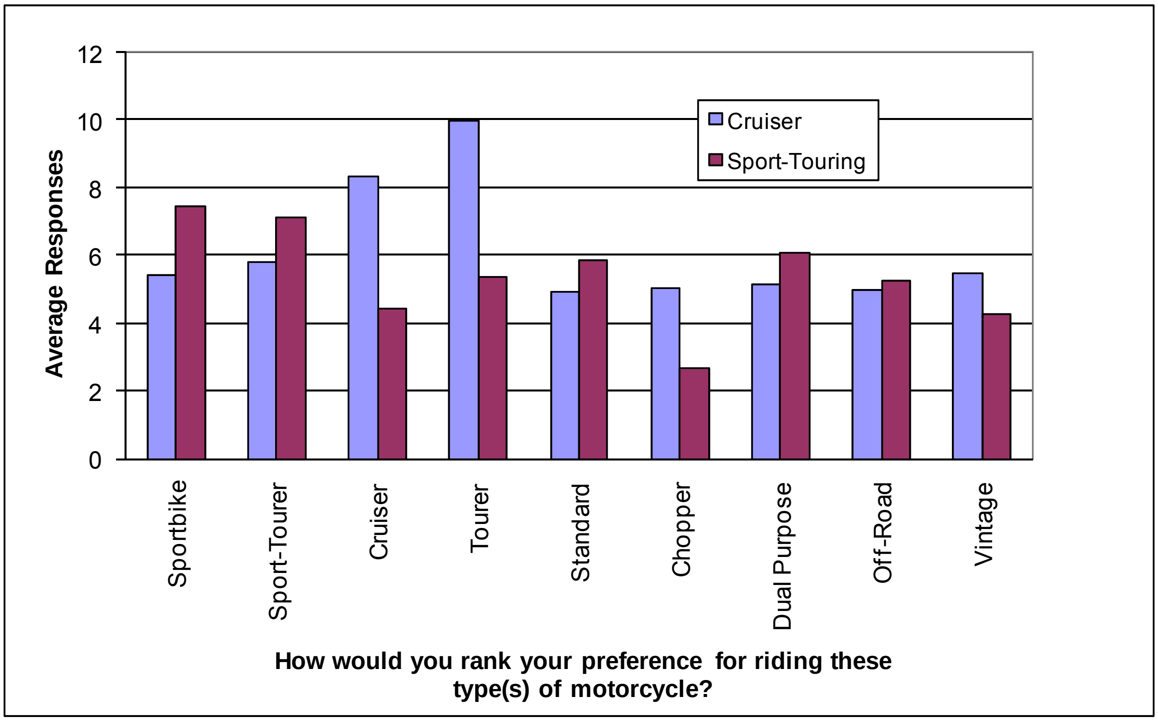


Figure D11. Motorcycle Preference

Question 13: Do you have experience with off road motorcycles (see Table 6)? (If yes, please describe).

Table 6. Response to Off Road Riding Question

	Cruiser	Sport-Touring	Total
Off-road	27	17	44

2. Post-Ride Questionnaire Results

As described in Section III C above, all participants completed a questionnaire after completing the simulator runs. The questions are repeated here along with the tabulated responses.

Question 1: In an emergency braking situation (similar to the one you saw in the simulator), what do you typically do (see Fig D12)?

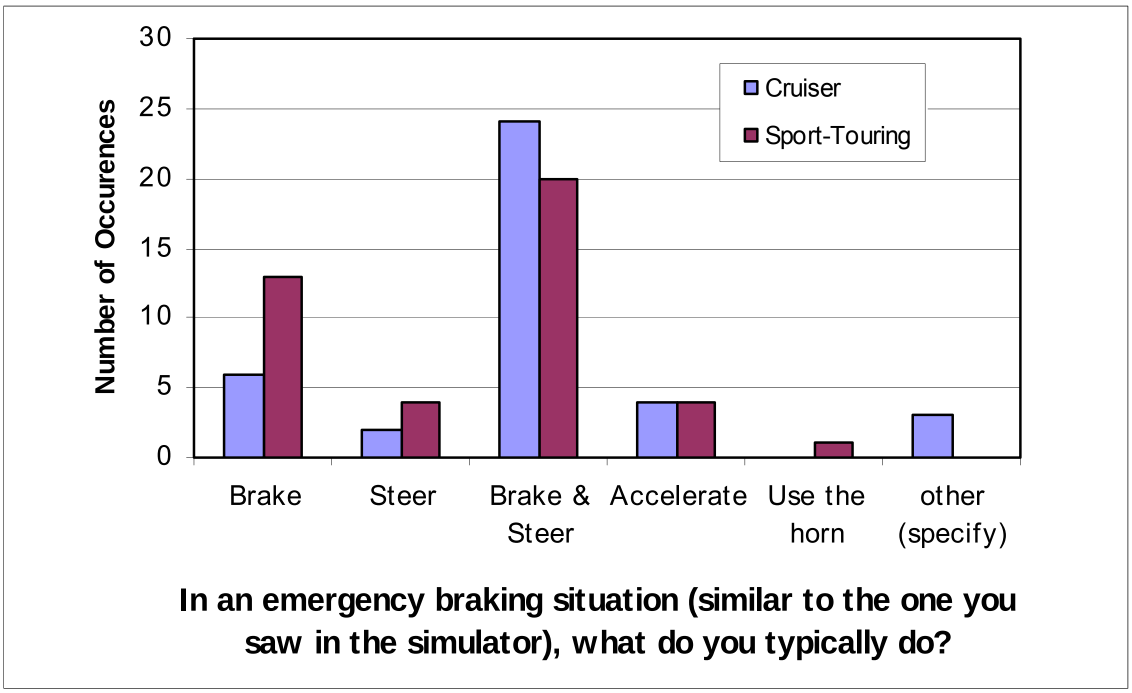


Figure D12. Response in an Emergency Brake Situation

Question 2:   Have you ever had a critical accident avoidance experience in real world riding (see Fig D13)?

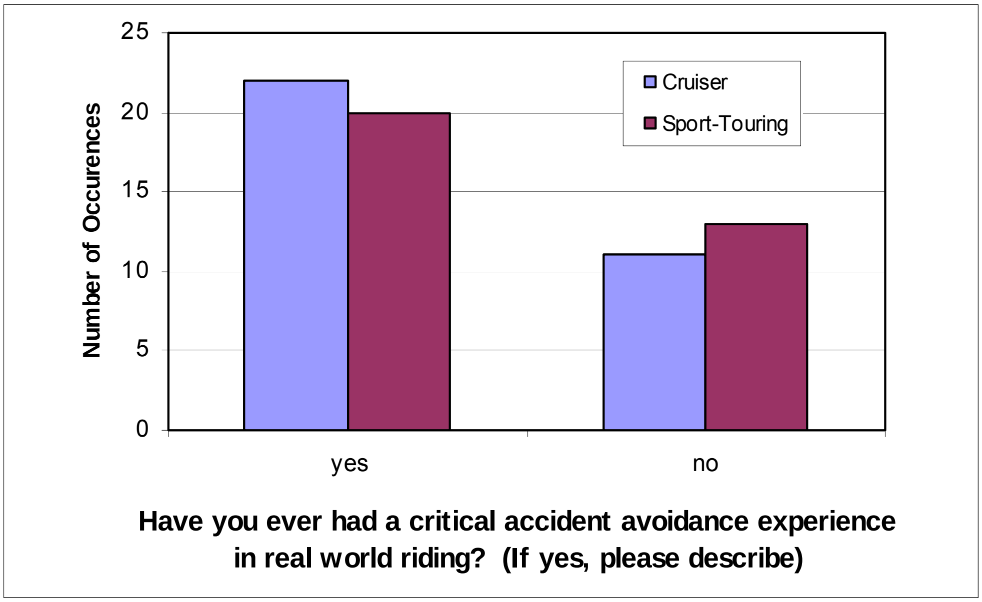


Figure D13. Critical Accident Avoidance Experience

Question 3: What types of brake systems are the motorcycles you typically ride equipped with (see Fig D14)?

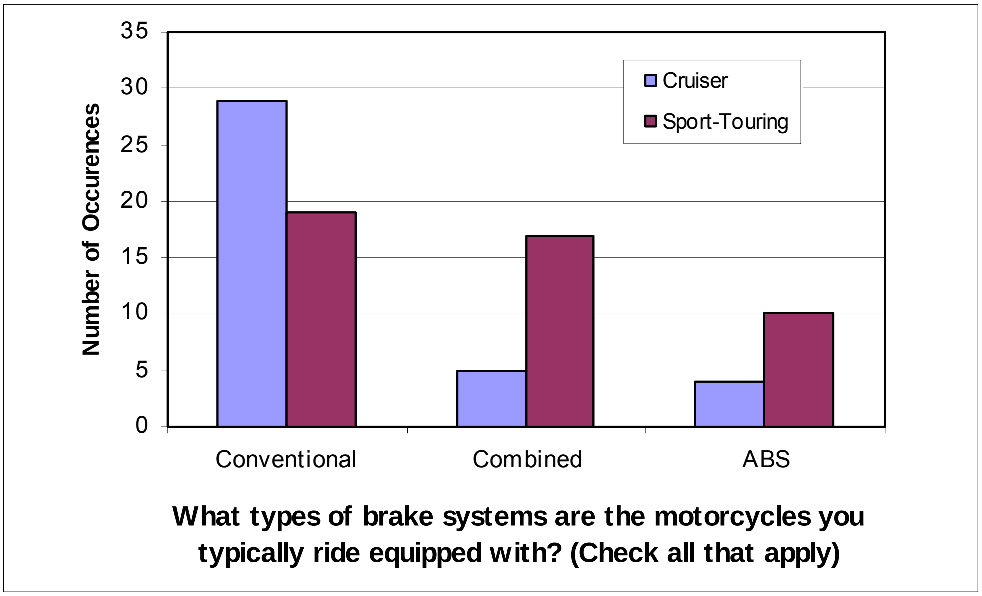
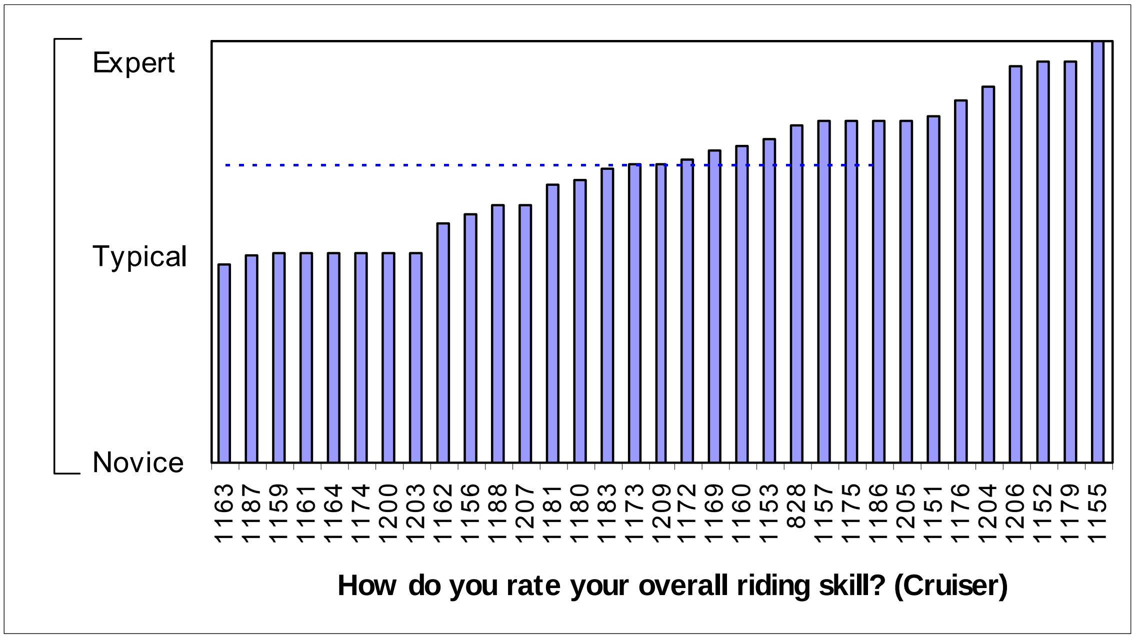


Figure D14. Brake Systems Motorcycles Typically Equipped With

Question 4: How do you rate your overall riding skill and recent experience (see Fig D15)?



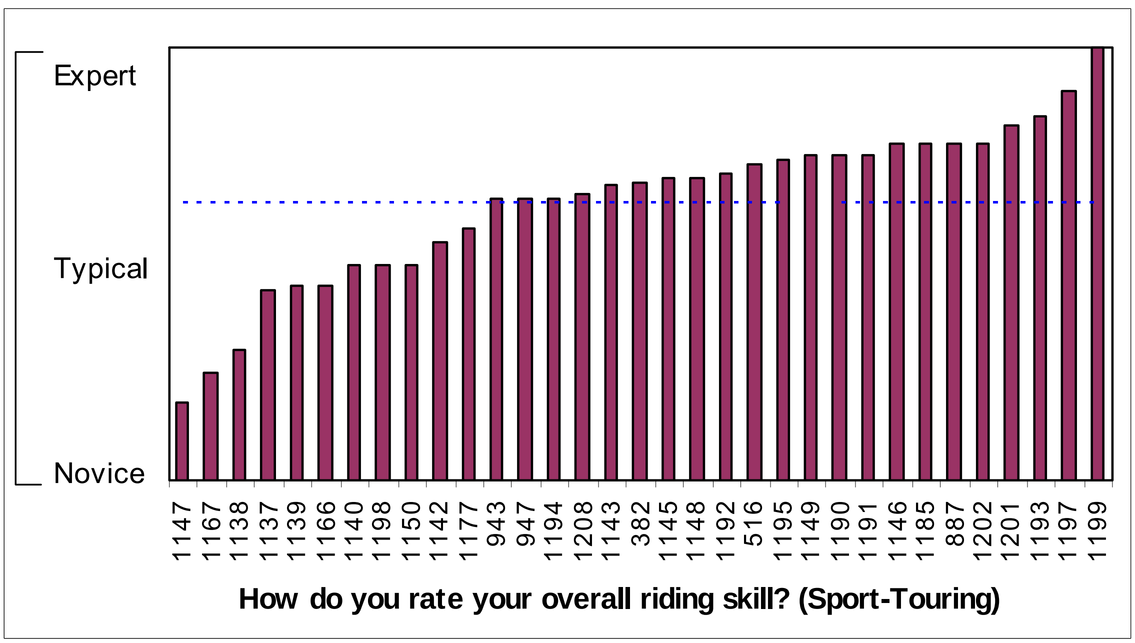
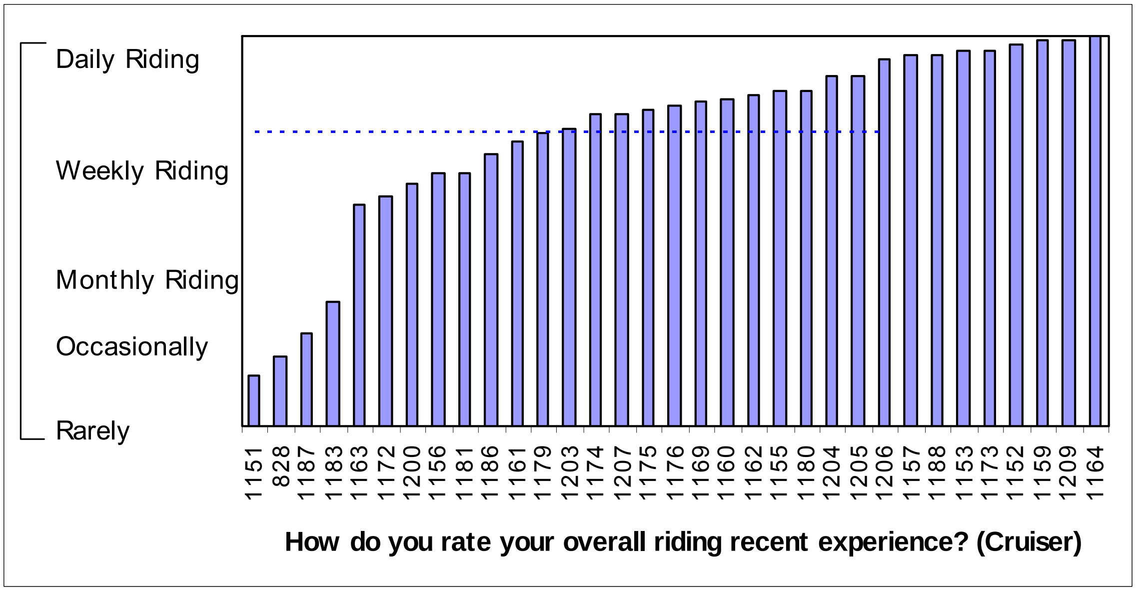


Figure D15. Overall Riding Skill



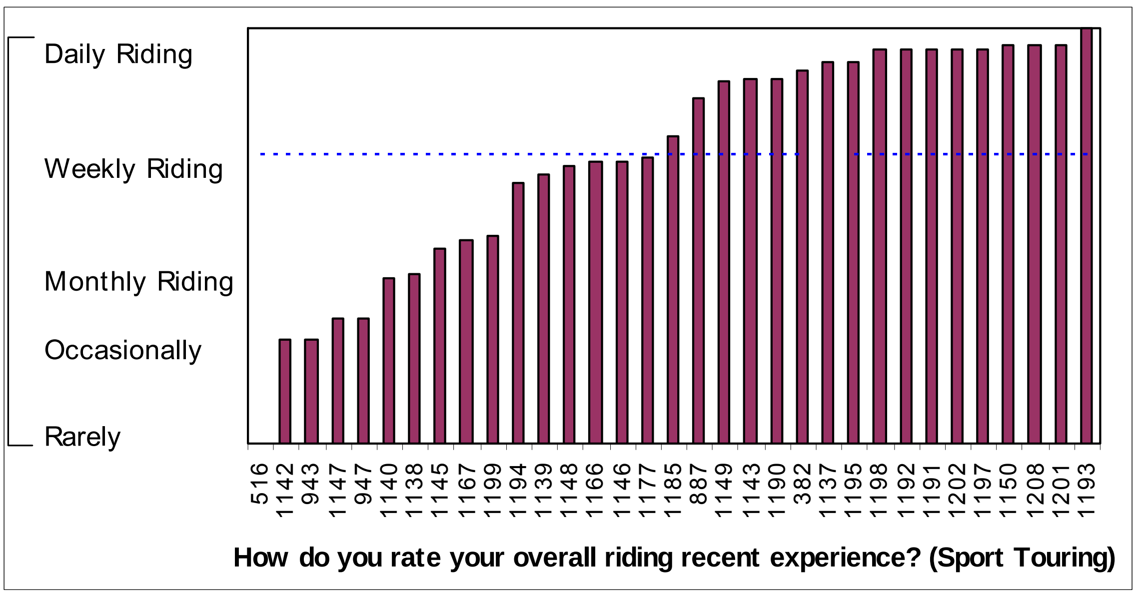
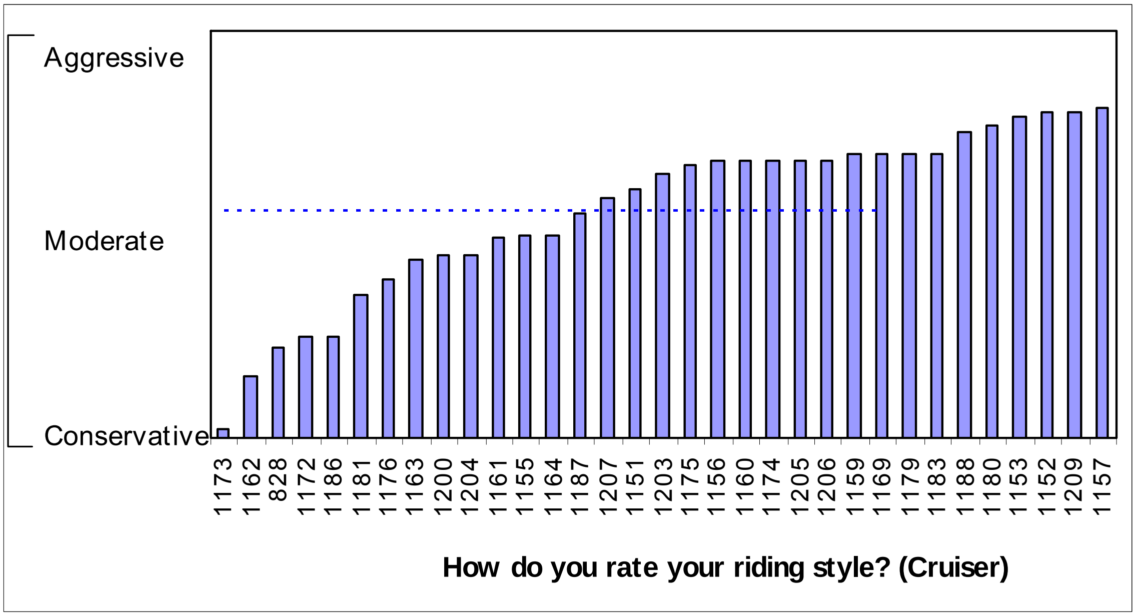


Figure D16. Overall Riding Recent Experience

Question 5: How do you rate your riding style (see Fig d17)?



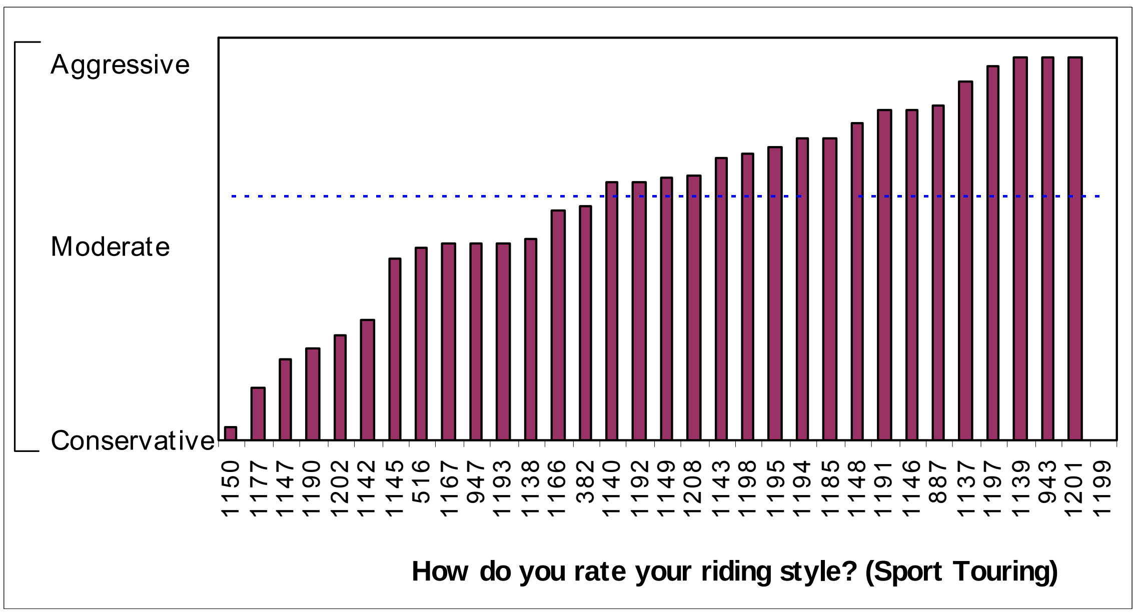


Figure D17. Riding Style

3. Visual Acuity and Hand Strength Test Results

As described in Section III C above, all participants completed a visual acuity and right hand strength test. A table giving participant's age, acuity results, peripheral vision and right hand grip strength is shown in Appendix D.

Visual and Strength Results

Participant Number	Acuity Results	Peripheral Right	Peripheral Left	Dynamometer Reading
1137	20/20	90	90	41
1139	20/25	90	90	36
1143	20/20	90	90	50
1147	20/20	90	90	21
1145	20/20	90	90	38
1146	20/25	90	90	35
516	20/40	90	90	50
1142	20/25	90	90	50
1148	20/15	90	90	40
947	20/20	90	90	45
9996	20/15	90	90	39
9981	20/15	90	90	52
1141	20/20	90	90	48
1138	20/40	85	90	44
1150	20/20	90	90	38
1140	20/15	90	90	56
943	20/25	90	90	54
1177	20/25	90	90	32
382	20/30	90	90	42
1172	20/20	90	90	53
1151	20/25	90	90	29
1152	20/20	90	90	49
1153	20/20	90	90	48
1163	20/20	90	90	38
1161	20/25	90	90	50
1175	20/13	90	90	54
1159	20/15	90	90	58
1158	20/20	90	90	30
1157	20/25	80	90	40
1156	20/20	90	90	38
1155	20/50	90	90	36
1160	20/25	90	90	36
1162	20/20	90	90	42
1173	20/25	90	90	49
1169	20/15	90	90	34
1180	20/20	90	90	42
1190	20/25	90	90	40
1174	20/25	90	90	54
1149	20/20	90	90	56
1176	20/25	90	90	50
1185	20/20	90	90	38
1181	20/20	90	90	24

Participant Number	Acuity Results	Peripheral Right	Peripheral Left	Dynamometer Reading
1186	20/25	90	90	48
828	20/15	90	90	37
1187	20/40	90	90	34
1183	20/20	90	90	36
1182	20/15	90	90	65
1164	20/15	90	90	48
1191	20/15	90	90	50
1188	20/25	70	90	48
1203	20/13	90	90	52
1184	20/20	90	90	28
887	20/13	90	90	47
1196	20/20	90	90	20
1192	20/25	90	90	24
1197	20/20	90	85	60
1198	20/15	90	90	45
1199	20/15	90	90	32
1201	20/20	90	90	42
1195	20/20	90	90	28
1194	20/25	90	90	66
1200	23/30	90	90	50
1204	20/40	90	90	30
1193	20/20	90	90	34
1166	20/15	90	90	42
1167	20/20	90	90	45
1206	20/20	90	90	45
1207	20/25	90	90	45
1208	20/15	90	90	35
1209	20/13	90	90	64
1179	20/25	90	90	54
1202	20/30	80	80	26
1205	20/25	90	90	44

APPENDIX E

LOGISTIC REGRESSION RESULTS

Terms used in the Analyses

Raw data were post processed to develop the quantitative response and performance measures listed in Table 2 of Section II E. For convenience that table is summarized here.

Mnemonic	Measure
F_ReacTime	Front brake reaction time (sec)
F_Peak_CF_g	Front Peak Control Force Overall (g commanded)
F_Peak_CF_time	Front Peak Control Force Rate Time (sec)
F_Peak_CF_dot_g	Front Peak Control Force Rate Time (sec)
F_InputDuration	Front Duration of Brake Input (sec)
F_Mean_CF_g	Front Mean Control Force (g commanded)
F_MS_Dev_CF_gsq	Front Mean Square Deviation of Control Force (g commanded^2)
F_Mean_CF_80_g	Front Mean Control Force to 80% of Speed (g commanded)
R_ReacTime	Rear Reaction Time (sec)
R_Peak_CF_g	Rear Peak Control Force Overall (g commanded)
R_Peak_CF_time	Rear Peak Control Force Rate Time (sec)
R_Peak_CF_dot_g	Rear Peak Control Force Rate Time (sec)
R_InputDuration	Rear Duration of Brake Input (sec)
R_Mean_CF_g	Rear Mean Control Force (g commanded)
R_MS_Dev_CF_gsq	Rear Mean Square Deviation of Control Force (g commanded^2)
R_Mean_CF_80_g	Rear Mean Control Force to 80% of Speed (g commanded)
MeanAx	Mean Longitudinal Acceleration (g)
PeakAx	Peak Longitudinal Acceleration (g)
PeakPitchAngle (deg)	Peak Pitch Angle (deg)
F_Peak SlipRatio	Front Peak Longitudinal Slip Ratio (0 to 1)
R_Peak SlipRatio	Rear Peak Longitudinal Slip Ratio (0 to 1)
PP_LatLaneDev	Peak to Peak Lateral Lane Deviation (m)
MS_LatLaneDev	Mean Square Lateral Lane Deviation (m^2)
PP_Phi	Peak to Peak Roll Angle (deg)
PP_Delta	Peak to Peak Steer Angle (deg)
MeanThrottle	Mean throttle (%)
InitialSpeed	Initial Speed (km/h)
Collision	Collision
CollisionSpeed	Collision Speed (km/h)
RunAborted	Run aborted
AbortSpeed	Speed when run aborted (km/h)
FrontRearDistribution	Front to rear brake distribution for means (%F commanded g)
FrontRearDistribution80	Front to rear brake distribution to 80% of initial speed (%F commanded g)

Mnemonic	Measure
axneeded	Deceleration needed so as not to hit oncoming vehicle for selected runs (g)
ATF	Front brake, area under commanded g curve multiplied by time (1st moment)
AF	Front brake, area under commanded g curve
ATR	Rear brake, area under commanded g curve multiplied by time (1st moment)
AR	Rear brake, area under commanded g curve
ATAx	Area under Ax curve multiplied by time (1st moment)
AAx	Area under Ax curve
AF_12	Area under front brake commanded g curve at 1.2 sec (g-sec) for selected runs
AF_14	Area under front brake commanded g curve at 1.4 sec (g-sec) for selected runs
AF_16	Area under front brake commanded g curve at 1.6 sec (g-sec) for selected runs
AF_18	Area under front brake commanded g curve at 1.8 sec (g-sec) for selected runs
AF_20	Area under front brake commanded g curve at 2.0 sec (g-sec) for selected runs
AR_12	Area under rear brake commanded g curve at 1.2 sec (g-sec) for selected runs
AR_14	Area under rear brake commanded g curve at 1.4 sec (g-sec) for selected runs
AR_16	Area under rear brake commanded g curve at 1.6 sec (g-sec) for selected runs
AR_18	Area under rear brake commanded g curve at 1.8 sec (g-sec) for selected runs
AR_20	Area under rear brake commanded g curve at 2.0 sec (g-sec) for selected runs

Additional variables relate to rider factors. The following table defines those variables.

Mnemonic	Rider Factor	Source
Years Riding	Response to question: "How many years have you been riding?"	General Information and Health Questionnaire
Miles for 2008	Response to question:	Riding Experience Questionnaire
Average Miles	Average miles reported for 2006, 2007, 2008	Riding Experience Questionnaire
Aggressiveness Rating	Self reported aggressiveness rating	Post Ride Questionnaire
Skill Rating	Self reported skill rating	Post Ride Questionnaire
Riding Frequency Rating	Self reported ride frequency	Post Ride Questionnaire
Group Miles 2008	Miles ridden in a group in 2008	Riding Experience Questionnaire
Commute Miles 2008	Miles commuted on a motorcycle in 2008	Riding Experience Questionnaire
Age	Age	General Information and Health Questionnaire
Ride Category Num	Preference for Cruiser or Sport touring motorcycle	Riding Experience Questionnaire
BRC	Completed MSF Basic Riders Course	Riding Experience Questionnaire
ARC	Completed MSF Basic Riders Course	Riding Experience Questionnaire
PCA_RC_Distance	PCA Component 1 (Distance) is primarily composed of measures of distance traveled recently: Miles Ridden in 2008	Principal Components Analysis (PCA)
PCA_RC_Years	PCA Component 2 (Years) is primarily composed of measures of total riding experience: Age	Principal Components Analysis (PCA)
PCA_RC_Frequency	PCA Component 3 (Frequency) is primarily composed of measures of riding frequency and type of riding: Rider Frequency Rating	Principal Components Analysis (PCA)
Total Motion Discomfort	Post Exposure Symptom Checklist Total Score	SSQ - Post Exposure Symptom Checklist
Health	Self reported rating of overall health	Daily Health Questionnaire

Logistic Regression of Braking Measures by EB-2 Collisions

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Percentage Correct	Cox & Snell R Square	Nagelkerke R Square	Hosmer and Lemeshow
F_Peak_CF_g	F_Peak_CF_g	.001	66.1	.199	.266	.705
	Constant	.002				
F_Peak_CF_time	F_Peak_CF_time	.020	71.0	.125	.167	.761
	Constant	.018				
F_Peak_CF_dot_g	F_Peak_CF_dot_g	.033	59.7	.083	.111	.118
	Constant	.060				
F_InputDuration	F_InputDuration	.069	71.0	.203	.271	.519
	Constant	.042				
F_Mean_CF_g	F_Mean_CF_g	.000	75.8	.362	.482	.234
	Constant	.000				
F_MS_Dev_CF_gsq	F_MS_Dev_CF_gsq	.047	56.5	.078	.103	.513
	Constant	.130				
F_Mean_CF_80_g	F_Mean_CF_80_g	.016	63.9	.113	.150	.532
	Constant	.024				
R_ReacTime	R_ReacTime	.001	77.4	.327	.442	.878
	Constant	.001				
R_Peak_CF_g	R_Peak_CF_g	.001	75.5	.293	.397	.826
	Constant	.002				
R_Peak_CF_time	R_Peak_CF_time	.001	75.5	.334	.453	.664
	Constant	.000				
R_Mean_CF_g	R_Mean_CF_g	.000	79.2	.377	.510	.563
	Constant	.001				
R_Mean_CF_80_g	R_Mean_CF_80_g	.037	68.0	.101	.138	.294
	Constant	.114				
MeanAx	MeanAx	.000	83.9	.499	.665	.699
	Constant	.000				
PeakAx	PeakAx	.000	74.2	.376	.502	.208
	Constant	.000				
R_PeakSlipRatio_Adj	R_PeakSlipRatio_Adj	.003	62.9	.169	.225	.510
	Constant	.017				
MeanThrottle	MeanThrottle	.004	72.6	.185	.247	.295

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Percentage Correct	Cox & Snell R Square	Nagelkerke R Square	Hosmer and Lemeshow
	Constant	.012				
FrontRearDistribution	FrontRearDistribution	.051	56.5	.065	.087	.030
	Constant	.050				

Nonsignificant Models (from Logistic Regression of Braking Measures by EB-2 Collisions):

Predictor Variables Entered into Model	Predictor Variables Not in Model	Sig.	Overall Percentage Correct
F_ReacTime	F_ReacTime	.054	51.6
	Overall Statistics	.054	
R_Peak_CF_dot_g	R_Peak_CF_dot_g	.325	60.4
	Overall Statistics	.325	
R_InputDuration	R_InputDuration	.078	60.4
	Overall Statistics	.078	
R_MS_Dev_CF_gsq	R_MS_Dev_CF_gsq	.069	60.4
	Overall Statistics	.069	
F_PeakSlipRatio_Adj	F_PeakSlipRatio_Adj	.055	51.6
	Overall Statistics	.055	
PP_Delta	PP_Delta	.116	51.6
	Overall Statistics	.116	
FrontRearDistribution80	FrontRearDistribution80	.282	64.0
	Overall Statistics	.282	

Logistic Regression of Braking Measures by UB-4 Collisions

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Percentage Correct	Cox & Snell R Square	Nagelkerke R Square	Hosmer and Lemeshow
F_ReacTime	F_ReacTime	.000	77.1	.357	.483	.276
	Constant	.000				
F_Peak_CF_g	F_Peak_CF_g	.003	77.1	.275	.372	.026
	Constant	.011				
F_Peak_CF_time	F_Peak_CF_time	.005	77.1	.199	.270	.099
	Constant	.003				
F_Mean_CF_g	F_Mean_CF_g	.003	75.0	.247	.334	.376
	Constant	.015				
F_MS_Dev_CF_gsq	F_MS_Dev_CF_gsq	.012	68.8	.261	.353	.559
	Constant	.074				
R_Peak_CF_g	R_Peak_CF_g	.039	82.9	.144	.206	.491
	Constant	.228				
R_Peak_CF_time	R_Peak_CF_time	.024	74.3	.167	.239	.779
	Constant	.008				
R_Mean_CF_g	R_Mean_CF_g	.040	82.9	.148	.213	.212
	Constant	.235				
MeanAx	MeanAx	.000	85.4	.393	.532	.027
	Constant	.001				
PeakAx	PeakAx	.000	79.2	.359	.485	.640
	Constant	.002				
F_PeakSlipRatio_Adj	F_PeakSlipRatio_Adj	.024	60.4	.210	.285	.245
	Constant	.064				
R_PeakSlipRatio_Adj	R_PeakSlipRatio_Adj	.049	75.0	.140	.190	.078
	Constant	.459				
FrontRearDistribution	FrontRearDistribution	.042	72.9	.090	.121	.277
	Constant	.022				

Nonsignificant Models (from Logistic Regression of Braking Measures by UB-4 Collisions):

Predictor Variables Entered into Model	Predictor Variables Not in Model	Sig.	Overall Percentage Correct
F_Peak_CF_dot_g	F_Peak_CF_dot_g	.449	60.4
	Overall Statistics	.449	
F_InputDuration	F_InputDuration	.232	60.4
	Overall Statistics	.232	
F_Mean_CF_80_g	F_Mean_CF_80_g	.352	69.0
	Overall Statistics	.352	
R_ReacTime	R_ReacTime	.123	71.4
	Overall Statistics	.123	
R_Peak_CF_dot_g	R_Peak_CF_dot_g	.316	71.4
	Overall Statistics	.316	
R_InputDuration	R_InputDuration	.647	71.4
	Overall Statistics	.647	
R_MS_Dev_CF_gsq	R_MS_Dev_CF_gsq	.086	71.4
	Overall Statistics	.086	
R_Mean_CF_80_g	R_Mean_CF_80_g	.402	73.5
	Overall Statistics	.402	
PP_Delta	PP_Delta	.496	60.4
	Overall Statistics	.496	
MeanThrottle	MeanThrottle	.809	56.9
	Overall Statistics	.809	
FrontRearDistribution80	FrontRearDistribution80	.893	73.5
	Overall Statistics	.893	

Logistic Regression of Braking (A, AT) by EB-2 Collisions

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct	Cox & Snell R Square	Nagelkerke R Square	Hosmer and Lemeshow
ATF, AF	ATF	.007	74.2	.373	.498	.822
	AF	.001				
	Constant	.000				
ATF, AF, ATF*AF	ATF	.007	74.2	.373	.498	.822
	AF	.001				
	ATF*AF	NS				
	Constant	.000				
ATR, AR	ATR	.053	82.3	.487	.649	.911
	AR	.006				
	Constant	.000				
ATR, AR ATR*AR	ATR	.053	82.3	.487	.649	.911
	AR	.006				
	ATR*AR	NS				
	Constant	.000				
ATF, AF, ATR, AR	ATF	.012	91.9	.621	.828	.381
	AF	.010				
	ATR	NS				
	AR	.001				
	Constant	.004				
ATF, AF, ATR, AR, AF*ATF, AF*AR, AF*ATR, AR*ATF, ATF*ATR, AR*ATR	AF	NS	91.9	.602	.804	.407
	ATF	NS				
	AR	NS				
	ATR	NS				
	AF*ATF	NS				
	AF*AR	.004				
	AF*ATR	NS				
	AR*ATF	.013				
	ATF*ATR	NS				
	AR*ATR	NS				
	Constant	.001				

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct	Cox & Snell R Square	Nagelkerke R Square	Hosmer and Lemeshow
AF1.2	AF1.2	.000	66.1	.273	.365	.393
	Constant	.002				
AF1.4	AF1.4	.000	69.4	.355	.474	.243
	Constant	.000				
AF1.6	AF1.6	.000	74.2	.376	.502	.907
	Constant	.000				
AF1.8	AF1.8	.000	77.4	.397	.530	.933
	Constant	.000				
AF2.0	AF2.0	.000	78.7	.376	.502	.730
	Constant	.000				
AR1.2	AR1.2	.000	79.0	.387	.516	.040
	Constant	.001				
AR1.4	AR1.4	.000	80.6	.430	.573	.765
	Constant	.000				
AR1.6	AR1.6	.000	80.6	.457	.610	.476
	Constant	.000				
AR1.8	AR1.8	.000	80.6	.478	.638	.102
	Constant	.000				
AR2.0	AR2.0	.000	83.6	.503	.671	.655
	Constant	.000				
AR1.2, AF1.2	AR1.2	.000	79.0	.387	.516	.040
	Constant	.001				
	AF1.2	NS				
AR1.2, AF1.2, AR1.2*AF1.2	AR1.2	.000	79.0	.387	.516	.040
	AF1.2	NS				
	AR1.2*AF1.2	NS				
	Constant	.001				
AR1.4, AF1.4	AR1.4	.001	80.6	.497	.662	.778
	AF1.4	.015				
	Constant	.000				

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct	Cox & Snell R Square	Nagelkerke R Square	Hosmer and Lemeshow
AR1.4, AF1.4, AR1.4*AF1.4	AR1.4	.001	80.6	.497	.662	.778
	AF1.4	.015				
	AR1.4*AF1.4	NS				
	Constant	.000				
AR1.6, AF1.6	AR1.6	.001	88.7	.548	.731	.362
	AF1.6	.009				
	Constant	.001				
AR1.6, AF1.6, AF1.6*AR1.6	AR1.6	NS	90.3	.546	.728	.367
	AF1.6	NS				
	AF1.6*AR1.6	.000				
	Constant	.000				
AR1.8, AF1.8	AR1.8	.002	91.9	.615	.820	.862
	AF1.8	.008				
	Constant	.004				
AR1.8, AF1.8, AR1.8*AF1.8	AR1.8	NS	91.9	.600	.801	.540
	AF1.8	NS				
	AR1.8*AF1.8	.001				
	Constant	.002				
AR2.0, AF2.0	AR2.0	.008	95.1	.644	.859	.684
	AF2.0	.014				
	Constant	.009				
AR2.0, AF2.0, AR2.0*AF2.0	AR2.0	NS	91.8	.629	.839	.981
	AF2.0	NS				
	AR2.0*AF2.0	.004				
	Constant	.007				
AR, AF	AR	.000	85.5	.533	.712	.549
	AF	.005				
	Constant	.000				

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct	Cox & Snell R Square	Nagelkerke R Square	Hosmer and Lemeshow

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct	Cox & Snell R Square	Nagelkerke R Square	Hosmer and Lemeshow
AR, AF, AR*AF	AR	NS	85.5	.547	.730	.788
	AF	NS				
	AR*AF	.000				
	Constant	.000				
ATAx, Aax	ATAx	.002	88.7	.559	.746	.009
	AAx	.001				
	Constant	.000				
ATAx, Aax, ATAx*Aax	ATAx	.020	95.2	.671	.895	1.000
	AAx	.020				
	ATAx*Aax	.018				
	Constant	.881				

Logistic Regression of Braking (A, AT) by UB-4 Collisions

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct	Cox & Snell R Square	Nagelkerke R Square	Hosmer and Lemeshow
ATF, AF	AF	.000	84.3	.532	.714	.885
	Constant	.001				
ATF, AF, ATF*AF	ATF	NS	84.3	.532	.714	.885
	AF	.000				
	ATF*AF	NS				
	Constant	.001				
ATR, AR	ATR	NS	76.5	.351	.471	.814
	AR	.000				
	Constant	.009				
ATR, AR, ATR*AR	ATR	NS	76.5	.351	.471	.814
	AR	.000				
	ATR*AR	NS				
	Constant	.009				
ATAx, Aax	AAx	.001	86.3	.592	.795	.645
	Constant	.002				
ATAx, Aax, ATAx*Aax	ATAx	NS	86.3	.592	.795	.645
	AAx	.001				
	ATAx*Aax	NS				
	Constant	.002				
ATF, AF, ATR, AR	AF	.000	84.3	.532	.714	.885
	Constant	.001				
AF,ATF,AR,ATR, AF*ATF,AF*AR, AF*ATR,AR*AR, ATF*ATR,AR*ATR	AF	.000	84.3	.532	.714	.885
	ATF	NS				
	AR	NS				
	ATR	NS				
	AF*ATF	NS				
	AF*AR	NS				
	AF*ATR	NS				
	AR*ATF	NS				
	ATF*ATR	NS				
	AR*ATR	NS				

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct	Cox & Snell R Square	Nagelkerke R Square	Hosmer and Lemeshow
	Constant	.001				
AF1.2	AF1.2	.055	64.7	.156	.210	.037
	Constant	.573				
AF1.4	AF1.4	.019	66.7	.218	.293	.480
	Constant	.280				
AF1.6	AF1.6	.009	74.0	.271	.364	.001
	Constant	.106				
AF1.8	AF1.8	.005	78.0	.343	.459	.232
	Constant	.026				
AF2.0	AF2.0	.001	86.0	.436	.584	.003
	Constant	.004				
AR1.2	AR1.2	.062	66.7	.098	.132	.209
	Constant	.867				
AR1.4	AR1.4	.021	66.7	.174	.233	.779
	Constant	.410				
AR1.6	AR1.6	.009	70.0	.221	.297	.465
	Constant	.191				
AR1.8	AR1.8	.004	72.0	.272	.364	.235
	Constant	.081				
AR2.0	AR2.0	.001	76.0	.309	.414	.724
	Constant	.033				
AR1.2, AF1.2	AR1.2	NS	64.7	.156	.210	.037
	AF1.2	.055				
	Constant	.573				
AR1.2, AF1.2 AR1.2*AF1.2	AR1.2	NS	64.7	.156	.210	.037
	AF1.2	.055				
	AR1.2*AF1.2	NS				
	Constant	.573				
AR1.4, AF1.4	AR1.4	.021	66.7	.174	.233	.779
	AF1.4	NS				
	Constant	.410				
AR1.4, AF1.4, AR1.4*AF1.4	AR1.4	.021	66.7	.174	.233	.779
	AF1.4	NS				

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct	Cox & Snell R Square	Nagelkerke R Square	Hosmer and Lemeshow
	AR1.4*AF1.4	NS				
	Constant	.410				
AR1.6, AF1.6	AR1.6	NS	74.0	.271	.364	.001
	AF1.6	.009				
	Constant	.106				
AR1.6, AF1.6, AR1.6*AF1.6	AR1.6	NS	74.0	.271	.364	.001
	AF1.6	.009				
	AR1.6*AF1.6	NS				
	Constant	.106				
AR1.8, AF1.8	AR1.8	NS	78.0	.343	.459	.232
	AF1.8	.005				
	Constant	.026				
AR1.8, AF1.8, AR1.8*AF1.8	AR1.8	NS	78.0	.343	.459	.232
	AF1.8	.005				
	AR1.8*AF1.8	NS				
	Constant	.026				
AR2.0, AF2.0	AR2.0	NS	86.0	.436	.584	.846
	AF2.0	.001				
	Constant	.004				
AR2.0, AF2.0, AR2.0*AF2.0	AR2.0	NS	86.0	.436	.584	.846
	AF2.0	.001				
	AR2.0*AF2.0	NS				
	Constant	.004				
AR, AF	AR	NS	84.3	.532	.714	.885
	AF	.000				
	Constant	.001				
AR, AF, AR,*AF	AR	NS	84.3	.532	.714	.885
	AF	.000				
	AR,*AF	NS				
	Constant	.001				

This section describes the relationship between braking measures and the outcome in which the rider lost control. First the emergency (EB-2) and then the urgent scenario (UB-4) are presented.

Logistic Regression of Braking Measures by EB-2 Lost Control

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Percentage Correct	Cox & Snell R Square	Nagelkerke R Square	Hosmer and Lemeshow
R_Peak_CF_g	R_Peak_CF_g	.058	83.0	.086	.143	.531
	Constant	.011				
R_Peak_CF_dot_g	R_Peak_CF_dot_g	.029	83.0	.098	.164	.885
	Constant	.000				
R_InputDuration	R_InputDuration	.001	86.8	.320	.536	.638
	Constant	.007				
R_Mean_CF_g	R_Mean_CF_g	.018	88.7	.146	.244	.089
	Constant	.003				
R_Mean_CF_80_g	R_Mean_CF_80_g	.023	84.0	.115	.189	.648
	Constant	.002				
F_PeakSlipRatio_Adj	F_PeakSlipRatio_Adj	.045	87.1	.060	.103	.213
	Constant	.000				
R_PeakSlipRatio_Adj	R_PeakSlipRatio_Adj	.011	83.9	.109	.186	.526
	Constant	.000				
MeanThrottle	MeanThrottle	.038	83.9	.118	.202	.239
	Constant	.715				
F_PeakSlipRatio_Adj R_PeakSlipRatio_Adj	F_PeakSlipRatio_Adj	.016	82.3	.195	.333	.156
	R_PeakSlipRatio_Adj	.006				
	Constant	.000				
F_PeakSlipRatio_Adj, R_PeakSlipRatio_Adj, F_PeakSlipRatio_Adj *R_PeakSlipRatio_Adj	F_PeakSlipRatio_Adj	.028	91.9	.446	.759	.994
	R_PeakSlipRatio_Adj	.002				
	F_PeakSlipRatio_Adj *R_PeakSlipRatio_Adj	.022				
	Constant	.005				

Nonsignificant Models (from Logistic Regression of Braking Measures by EB-2 Lost Control):

Predictor Variables Entered into Model	Predictor Variables Not in Model	Sig.	Overall Percentage Correct
F_ReacTime	F_ReacTime	.489	83.9
	Overall Statistics	.489	
F_Peak_CF_g	F_Peak_CF_g	.727	83.9
	Overall Statistics	.727	
F_Peak_CF_time	F_Peak_CF_time	.294	83.9
	Overall Statistics	.294	
F_Peak_CF_dot_g	F_Peak_CF_dot_g	.683	83.9
	Overall Statistics	.683	
F_InputDuration	F_InputDuration	.077	83.9
	Overall Statistics	.077	
F_Mean_CF_g	F_Mean_CF_g	.360	83.9
	Overall Statistics	.360	
F_MS_Dev_CF_gsq	F_MS_Dev_CF_gsq	.542	83.9
	Overall Statistics	.542	
F_Mean_CF_80_g	F_Mean_CF_80_g	.504	83.6
	Overall Statistics	.504	
R_ReacTime	R_ReacTime	.763	83.0
	Overall Statistics	.763	
R_Peak_CF_time	R_Peak_CF_time	.785	83.0
	Overall Statistics	.785	
R_MS_Dev_CF_gsq	R_MS_Dev_CF_gsq	.208	83.0
	Overall Statistics	.208	
MeanAx	MeanAx	.728	83.9
	Overall Statistics	.728	
PeakAx	PeakAx	.790	83.9
	Overall Statistics	.790	
PP_Delta	PP_Delta	.866	83.9
	Overall Statistics	.866	
FrontRearDistribution	FrontRearDistribution	.168	83.9
	Overall Statistics	.168	
FrontRearDistribution80	FrontRearDistribution80	.146	82.0

Predictor Variables Entered into Model	Predictor Variables Not in Model	Sig.	Overall Percentage Correct
	Overall Statistics	.146	

Logistic Regression of Braking Measures by UB-4 Lost Control

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Percentage Correct	Cox & Snell R Square	Nagelkerke R Square	Hosmer and Lemeshow
F_Peak_CF_g	F_Peak_CF_g	.010	89.6	.155	.250	.142
	Constant	.000				
F_InputDuration	F_InputDuration	.006	83.3	.218	.352	.948
	Constant	.092				
F_Mean_CF_g	F_Mean_CF_g	.011	89.6	.162	.262	.044
	Constant	.001				
F_MS_Dev_CF_gsq	F_MS_Dev_CF_gsq	.003	91.7	.225	.364	.049
	Constant	.000				
F_Mean_CF_80_g	F_Mean_CF_80_g	.025	83.3	.153	.245	.402
	Constant	.002				
R_InputDuration	R_InputDuration	.017	80.0	.233	.354	.324
	Constant	.111				
MeanAx	MeanAx	.050	83.3	.094	.152	.398
	Constant	.006				
PeakAx	PeakAx	.027	85.4	.127	.205	.161
	Constant	.004				
F_PeakSlipRatio_Adj	F_PeakSlipRatio_Adj	.025	89.6	.251	.406	.570
	Constant	.000				
R_PeakSlipRatio_Adj	R_PeakSlipRatio_Adj	.045	81.2	.079	.128	.411
	Constant	.000				
PP_Delta	PP_Delta	.014	81.3	.134	.216	.766
	Constant	.000				
F_PeakSlipRatio_Adj R_PeakSlipRatio_Adj	F_PeakSlipRatio_Adj	.025	89.6	.251	.406	.570
	R_PeakSlipRatio_Adj	NS				
	Constant	.000				
F_PeakSlipRatio_Adj, R_PeakSlipRatio_Adj, F_PeakSlipRatio_Adj *R_PeakSlipRatio_Adj	F_PeakSlipRatio_Adj	.025	89.6	.251	.406	.570
	R_PeakSlipRatio_Adj	NS				
	F_PeakSlipRatio_Adj *R_PeakSlipRatio_Adj	NS				
	Constant	.000				

Nonsignificant Models (from Logistic Regression of Braking Measures by UB-4 Lost Control):

Predictor Variables Entered into Model	Predictor Variables Not in Model	Sig.	Overall Percentage Correct
F_ReacTime	F_ReacTime	.945	81.3
	Overall Statistics	.945	
VarF_Peak_CF_timeiables	F_Peak_CF_time	.757	81.3
	Overall Statistics	.757	
F_Peak_CF_dot_g	F_Peak_CF_dot_g	.117	81.3
	Overall Statistics	.117	
R_ReacTime	R_ReacTime	.770	77.1
	Overall Statistics	.770	
R_Peak_CF_g	R_Peak_CF_g	.194	77.1
	Overall Statistics	.194	
R_Peak_CF_time	R_Peak_CF_time	.689	77.1
	Overall Statistics	.689	
R_Peak_CF_dot_g	R_Peak_CF_dot_g	.665	77.1
	Overall Statistics	.665	
R_Mean_CF_g	R_Mean_CF_g	.079	77.1
	Overall Statistics	.079	
R_Mean_CF_80_g	R_Mean_CF_80_g	.154	76.5
	Overall Statistics	.154	
MeanThrottle	MeanThrottle	.664	82.4
	Overall Statistics	.664	
FrontRearDistribution	FrontRearDistribution	.628	81.3
	Overall Statistics	.628	
FrontRearDistribution80	FrontRearDistribution80	.411	76.5
	Overall Statistics	.411	

The following tables describe the relationship between individual rider factors and both the braking measures and the outcomes. For each, the emergency (EB-2) and then the urgent event (UB-4) are considered.

Non-significant Models (for Logistic Regression of Rider Factors with EB-2 Collisions):

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
Years Riding	Years Riding	.152	51.6
	Overall Statistics	.152	
Miles for 2008	Miles for 2008	.827	51.6
	Overall Statistics	.827	
Average Miles	Average Miles	.256	51.6
	Overall Statistics	.256	
Aggressiveness Rating	Aggressiveness Rating	.613	52.5
	Overall Statistics	.613	
Skill Rating	Skill Rating	.882	51.6
	Overall Statistics	.882	
Riding Frequency Rating	Riding Frequency Rating	.416	51.6
	Overall Statistics	.416	
Group Miles 2008	Group Miles 2008	.988	51.6
	Overall Statistics	.988	
Commute Miles 2008	Commute Miles 2008	.544	51.6
	Overall Statistics	.544	
Age	Age	.125	51.6
	Overall Statistics	.125	
Ride Category Num	Ride Category Num	.450	51.6
	Overall Statistics	.450	
BRC	BRC	.316	50.8
	Overall Statistics	.316	
ARC	ARC	.261	51.7
	Overall Statistics	.261	

Logistic Regression of Rider Factor Components (PCA) with EB-2 Collisions

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
PCA_RC_Distance	PCA_RC_Distance	.742	51.6
PCA_RC_Years	PCA_RC_Years	.150	51.6
PCA_RC_Frequency	PCA_RC_Frequency	.377	51.6

Non-significant Models (for Logistic Regression of Rider Factors with UB-4 Collisions):

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
Years Riding	Years Riding	.336	56.9
	Overall Statistics	.336	
Miles for 2008	MilesFor2009	.379	56.9
	Overall Statistics	.379	
Average Miles	Average Miles	.487	56.9
	Overall Statistics	.487	
Aggressiveness Rating	Aggressiveness Rating	.427	58.0
	Overall Statistics	.427	
Skill Rating	Skill Rating	.322	56.9
	Overall Statistics	.322	
Riding Frequency Rating	Riding Frequency Rating	.736	56.9
	Overall Statistics	.736	
Group Miles 2008	Group Miles 2008	.237	56.9
	Overall Statistics	.237	
Commute Miles 2008	Commute Miles 2008	.815	56.9
	Overall Statistics	.815	
Age	Age	.616	56.9
	Overall Statistics	.616	
Ride Category Num	Ride Category Num	.657	56.9
	Overall Statistics	.657	
BRC	BRC	.738	58.0
	Overall Statistics	.738	

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
ARC	ARC	.197	58.0
	Overall Statistics	.197	

Logistic Regression of Rider Factor Components (PCA) with UB-4 Collisions

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
PCA_RC_Distance	PCA_RC_Distance	.273	56.9
PCA_RC_Years	PCA_RC_Years	.676	56.9
PCA_RC_Frequency	PCA_RC_Frequency	.942	56.9

Rider Factors & Collision Groups. Rider Factors were explored by participant, each falling into a group consisting of those that did not have any collisions, those that had only 1 collision, those that had 2, and those that had 3 collisions over the course of the study.

Logistic Regressions for Individual Rider Factors with Collision Group (0 vs. >=1)

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct	Cox & Snell R Square	Nagelkerke R Square	Hosmer and Lemeshow
Years Riding	Years Riding	.015	66.0	.130	.180	.193
	Constant	.003				
Miles for 2008	Miles for 2008	.891	66.0			
	Overall Statistics	.891				
Average Miles	Average Miles	.462	66.0			
	Overall Statistics	.462				
Aggressiveness Rating	Aggressiveness Rating	.384	66.0			
	Overall Statistics	.384				
Skill Rating	Skill Rating	.899	66.0			
	Overall Statistics	.899				
Riding Frequency Rating	Riding Frequency Rating	.657	66.0			
	Overall Statistics	.657				
Group Miles 2008	Group Miles 2008	.792	66.0			
	Overall Statistics	.792				
Commute Miles 2008	Commute Miles 2008	.973	66.0			
	Overall Statistics	.973				
Age	Age	.027	64.0	.107	.148	.421
	Constant	.009				
Ride Category Num	Ride Category Num	.488	66.0			
	Overall Statistics	.488				
BRC	BRC	.242	66.0			
	Overall Statistics	.242				
ARC	ARC	.073	66.0			
	Overall Statistics	.073				

Logistic Regression of Rider Factor Components (PCA) with EB-2 Collision Groups (0 vs. >=1)

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct	Cox & Snell R Square	Nagelkerke R Square	Hosmer and Lemeshow
PCA_RC_Distance	PCA_RC_Distance	.634	67.3			
PCA_RC_Years	PCA_RC_Years	.033	69.4	.101	.141	0
	Constant	.018				
PCA_RC_Frequency	PCA_RC_Frequency	.419	67.3			

Logistic Regressions Rider Factors by Collision Group (<=1 vs. >=2)

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
Years Riding	Years Riding	.592	62.0
	Overall Statistics	.592	
Miles for 2008	Miles for 2008	.523	62.0
	Overall Statistics	.523	
Average Miles	Average Miles	.552	62.0
	Overall Statistics	.552	
Aggressiveness Rating	Aggressiveness Rating	.528	62.0
	Overall Statistics	.528	
Skill Rating	Skill Rating	.123	62.0
	Overall Statistics	.123	
Riding Frequency Rating	Riding Frequency Rating	.869	62.0
	Overall Statistics	.869	
Group Miles 2008	Group Miles 2008	.492	62.0
	Overall Statistics	.492	
Commute Miles 2008	Commute Miles 2008	.953	62.0
	Overall Statistics	.953	
Age	Age	.376	62.0
	Overall Statistics	.376	
Ride Category Num	Ride Category Num	.944	62.0

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
	Overall Statistics	.944	
BRC	BRC	.610	62.0
	Overall Statistics	.610	
ARC	ARC	.109	62.0
	Overall Statistics	.109	

Logistic Regression of Rider Factor Components (PCA) with EB-2 Collision Groups (<=1 vs. >=2)

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
PCA_RC_Distance	PCA_RC_Distance	.412	61.2
PCA_RC_Years	PCA_RC_Years	.842	61.2
PCA_RC_Frequency	PCA_RC_Frequency	.699	61.2

Logistic Regressions for Rider Factors by Collision Group (<=2 vs. >=3)

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
Years Riding	Years Riding	.383	92.0
	Overall Statistics	.383	
Miles for 2008	Miles for 2008	.516	92.0
	Overall Statistics	.516	
Average Miles	Average Miles	.213	92.0
	Overall Statistics	.213	
Aggressiveness Rating	Aggressiveness Rating	.983	92.0
	Overall Statistics	.983	
Skill Rating	Skill Rating	.796	92.0
	Overall Statistics	.796	
Riding Frequency Rating	Riding Frequency Rating	.377	92.0
	Overall Statistics	.377	
Group Miles 2008	Group Miles 2008	.635	92.0
	Overall Statistics	.635	
Commute Miles 2008	Commute Miles 2008	.257	92.0
	Overall Statistics	.257	
Age	Age	.598	92.0
	Overall Statistics	.598	
Ride Category Num	Ride Category Num	.933	92.0
	Overall Statistics	.933	
BRC	BRC	.633	92.0
	Overall Statistics	.633	
ARC	ARC	.297	92.0
	Overall Statistics	.297	

Logistic Regression of Rider Factor Components (PCA) with EB-2 Collision Groups (<=2 vs. >=3)

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
PCA_RC_Distance	PCA_RC_Distance	.556	91.8
PCA_RC_Years	PCA_RC_Years	.438	91.8
PCA_RC_Frequency	PCA_RC_Frequency	.316	91.8

Logistic Regressions for Rider Factors by Collision Group (0 vs. 3)

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
Years Riding	Years Riding	.085	81.0
	Overall Statistics	.085	
Miles for 2008	Miles for 2008	.427	81.0
	Overall Statistics	.427	
Average Miles	Average Miles	.181	81.0
	Overall Statistics	.181	
Aggressiveness Rating	Aggressiveness Rating	.711	81.0
	Overall Statistics	.711	
Skill Rating	Skill Rating	.785	81.0
	Overall Statistics	.785	
Riding Frequency Rating	Riding Frequency Rating	.559	81.0
	Overall Statistics	.559	
Group Miles 2008	Group Miles 2008	.529	81.0
	Overall Statistics	.529	
Commute Miles 2008	Commute Miles 2008	.349	81.0
	Overall Statistics	.349	
Age	Age	.190	81.0
	Overall Statistics	.190	
Ride Category Num	Ride Category Num	.748	81.0
	Overall Statistics	.748	
BRC	BRC	.422	81.0
	Overall Statistics	.422	
ARC	ARC	.619	81.0
	Overall Statistics	.619	

Logistic Regression of Rider Factor Components (PCA) with EB-2 Collision Groups (0 vs. 3)

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
PCA_RC_Distance	PCA_RC_Distance	.382	80.0
PCA_RC_Years	PCA_RC_Years	.116	80.0
PCA_RC_Frequency	PCA_RC_Frequency	.588	80.0

Non-significant Models (for Logistic Regression of Rider Factors with all Lost Control):

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
Years Riding	Years Riding	.916	83.2
	Overall Statistics	.916	
Miles For 2008	Miles for 2008	.277	83.2
	Overall Statistics	.277	
Average Miles	Average Miles	.282	83.2
	Overall Statistics	.282	
Aggressiveness Rating	Aggressiveness Rating	.422	82.9
	Overall Statistics	.422	
Skill Rating	Skill Rating	.197	83.2
	Overall Statistics	.197	
Riding Frequency Rating	Riding Frequency Rating	.196	83.2
	Overall Statistics	.196	
Group Miles 2008	Group Miles 2008	.470	83.2
	Overall Statistics	.470	
Commute Miles 2008	Commute Miles 2008	.544	83.2
	Overall Statistics	.544	
Age	Age	.415	83.2
	Overall Statistics	.415	
Ride Category Num	Ride Category Num	.166	83.2
	Overall Statistics	.166	
BRC	BRC	.424	82.9

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
	Overall Statistics	.424	
ARC	ARC	.296	82.7
	Overall Statistics	.296	

Non-significant Models (for Logistic Regression of Rider Factors with EB-2 Lost Control):

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
Years Riding	Years Riding	.711	83.9
	Overall Statistics	.711	
Miles For 2008	Miles for 2008	.118	85.5
	Constant	.000	
Average Miles	Average Miles	.119	83.9
	Overall Statistics	.119	
Aggressiveness Rating	Aggressiveness Rating	.510	83.6
	Overall Statistics	.510	
Skill Rating	Skill Rating	.311	83.9
	Overall Statistics	.311	
Riding Frequency Rating	Riding Frequency Rating	.327	83.9
	Overall Statistics	.327	
Group Miles 2008	Group Miles 2008	.116	83.9
	Overall Statistics	.116	
Commute Miles 2008	Commute Miles 2008	.914	83.9
	Overall Statistics	.914	
Age	Age	.564	83.9
	Overall Statistics	.564	
Ride Category Num	Ride Category Num	.043	83.9
	Constant	.014	
BRC	BRC	.346	83.6
	Overall Statistics	.346	
ARC	ARC	.881	83.3
	Overall Statistics	.881	

Logistic Regression Rider Factor Components (PCA) with EB-2 Lost Control

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct	Cox & Snell R Square	Nagelkerke R Square
PCA_RC_Distance	PCA_RC_Distance	.122	85.5	.044	.075
	Constant	.000			
PCA_RC_Years	PCA_RC_Years	.536	83.9		
PCA_RC_Frequency	PCA_RC_Frequency	.524	83.9		

Non-significant Models (for Logistic Regression of Rider Factors by UB-4 Lost Control):

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
Years Riding	Years Riding	.809	82.4
	Overall Statistics	.809	
Miles for 2008	Miles for 2008	.649	82.4
	Overall Statistics	.649	
Average Miles	Average Miles	.931	82.4
	Overall Statistics	.931	
Aggressiveness Rating	Aggressiveness Rating	.632	82.0
	Overall Statistics	.632	
Skill Rating	Skill Rating	.423	82.4
	Overall Statistics	.423	
Riding Frequency Rating	Riding Frequency Rating	.387	82.4
	Overall Statistics	.387	
Group Miles 2008	Group Miles 2008	.599	82.4
	Overall Statistics	.599	
Commute Miles 2008	Commute Miles 2008	.443	82.4
	Overall Statistics	.443	
Age	Age	.564	82.4
	Overall Statistics	.564	
Ride Category Num	Ride Category Num	.762	82.4
	Overall Statistics	.762	

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
BRC	BRC	.854	82.4
	Overall Statistics	.854	
ARC	ARC	.098	82.4
	Overall Statistics	.098	

Logistic Regression of Rider Factor Components (PCA) with UB-4 Lost Control

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
PCA_RC_Distance	PCA_RC_Distance	.686	82.4
PCA_RC_Years	PCA_RC_Years	.700	82.4
PCA_RC_Frequency	PCA_RC_Frequency	.969	82.4

Rider Factors and Braking Measures (AfAr Groups).

Logistic Regressions of Rider Factors with AfAr Group (90 vs. 10)

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
Years Riding	Years Riding	.099	50.0
	Overall Statistics	.099	
Miles for 2008	Miles for 2008	.837	50.0
	Overall Statistics	.837	
Average Miles	Average Miles	.423	50.0
	Overall Statistics	.423	
Aggressiveness Rating	Aggressiveness Rating	.772	51.1
	Overall Statistics	.772	
Skill Rating	Skill Rating	.596	50.0
	Overall Statistics	.596	
Riding Frequency Rating	Riding Frequency Rating	.149	50.0
	Overall Statistics	.149	
Group Miles 2008	Group Miles 2008	.421	50.0
	Overall Statistics	.421	
Commute Miles 2008	Commute Miles 2008	.361	50.0
	Overall Statistics	.361	
Age	Age	.125	50.0
	Overall Statistics	.125	
Ride Category Num	Ride Category Num	.149	50.0
	Overall Statistics	.149	
BRC	BRC	.471	51.1
	Overall Statistics	.471	
ARC	ARC	1.000	50.0
	Overall Statistics	1.000	

Logistic Regression for Rider Factor Components (PCA) with AfAr Group (90 vs. 10)

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
PCA_RC_Distance	PCA_RC_Distance	.737	50.0
PCA_RC_Years	PCA_RC_Years	.108	50.0
PCA_RC_Frequency	PCA_RC_Frequency	.109	50.0

Logistic Regressions of Rider Factors by AfAr Group (95 vs. 5)

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
Years Riding	Years Riding	.103	55.0
	Overall Statistics	.103	
Miles for 2008	Miles for 2008	.144	55.0
	Overall Statistics	.144	
Average Miles	Average Miles	.115	55.0
	Overall Statistics	.115	
Aggressiveness Rating	Aggressiveness Rating	.976	53.8
	Overall Statistics	.976	
Skill Rating	Skill Rating	.945	55.0
	Overall Statistics	.945	
Riding Frequency Rating	Riding Frequency Rating	.321	55.0
	Overall Statistics	.321	
Group Miles 2008	Group Miles 2008	.204	55.0
	Overall Statistics	.204	
Commute Miles 2008	Commute Miles 2008	.470	55.0
	Overall Statistics	.470	
Age	Age	.088	55.0
	Overall Statistics	.088	
Ride Category Num	Ride Category Num	.525	55.0
	Overall Statistics	.525	
BRC	BRC	.412	55.0

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
	Overall Statistics	.412	
ARC	ARC	.506	53.8
	Overall Statistics	.506	

Logistic Regression for Rider Factor Components (PCA) with AfAr Group (95 vs. 5)

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
PCA_RC_Distance	PCA_RC_Distance	.109	55.0
PCA_RC_Years	PCA_RC_Years	.111	55.0
PCA_RC_Frequency	PCA_RC_Frequency	.360	55.0

Logistic Regressions of Rider Factor by AfAr Group (100 vs. 0)

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct	Cox & Snell R Square	Nagelkerke R Square	Hosmer and Lemeshow
Years Riding	Years Riding	.059	65.4	.146	.195	.895
	Constant	.076				
Miles for 2008	Miles for 2008	.406	53.8			
	Overall Statistics	.406				
Average Miles	Average Miles	.378	53.8			
	Overall Statistics	.378				
Aggressiveness Rating	Aggressiveness Rating	.350	52.0			
	Overall Statistics	.350				
Skill Rating	Skill Rating	.603	53.8			
	Overall Statistics	.603				
Riding Frequency Rating	Riding Frequency Rating	.311	53.8			
	Overall Statistics	.311				
Group Miles 2008	Group Miles 2008	.372	53.8			
	Overall Statistics	.372				
Commute Miles 2008	Commute Miles 2008	.665	53.8			
	Overall Statistics	.665				
Age	Age	.098	53.8			
	Constant	.098				
Ride Category Num	Ride Category Num	.431	53.8			
	Overall Statistics	.431				
BRC	BRC	.462	53.8			
	Overall Statistics	.462				
ARC	ARC	.271	53.8			
	Overall Statistics	.271				

Logistic Regression for Rider Factor Component (PCA) with AfAr Group (100 vs. 0)

Predictor Variables Entered into Model	Predictor Variables in Model	Sig.	Overall Percentage Correct
PCA_RC_Distance	PCA_RC_Distance	.267	53.8
PCA_RC_Years	PCA_RC_Years	.066	53.8
PCA_RC_Frequency	PCA_RC_Frequency	.726	53.8

This section contains Linear Regressions comparing Rider Factors with the Braking Measures Af and Ar.

Linear Regression of Rider Factors with EB-2 Braking Measures (Af2.0)

		Predictors for Af2.0	
Predictors Entered into Model	Predictors in Model	Pearson R	Pearson R Sig.
Total Miles (2008)	Total Miles (2008)	.106	.208
Miles / Year (2006 - 2008)	Miles / Year (2006 - 2008)	.127	.165
Aggressiveness Rating	Aggressiveness Rating	-.074	.288
Skill Rating	Skill Rating	.039	.383
Riding Frequency Rating	Riding Frequency Rating	.222	.043
Group Miles (2008)	Group Miles (2008)	.068	.303
Commute Miles (2008)	Commute Miles (2008)	-.001	.498
BRC	BRC	.048	.357
ARC	ARC	-.042	.375
Age	Age	.106	.208
Total Years Riding	Total Years Riding	.111	.197
Ride Category (Num)	Ride Category (Num)	.089	.247

Linear Regression of Rider Factor Components (PCA) with EB-2 Braking Measures (Af2.0)

		Predictors for Af2.0	
Predictors Entered into Model	Predictors in Model	Pearson R	Pearson R Sig.
PCA_RC_Distance	PCA_RC_Distance	.091	.243
PCA_RC_Years	PCA_RC_Years	.125	.168
PCA_RC_Frequency	PCA_RC_Frequency	.098	.227

Linear Regression of Rider Factor with EB-2 Braking Measures (Ar2.0)

		Predictors for Ar2.0		Model		
Predictors Entered into Model	Predictors in Model	Pearson R	Pearson R Sig.	Sig.	R	Adjusted R Square
Total Miles (2008)	Total Miles (2008)	.035	.406			
Miles / Year (2006 - 2008)	Miles / Year (2006 - 2008)	.086	.276			
Aggressiveness Rating	Aggressiveness Rating	.310	.015	.030	.310	.077
	(Constant)			.821		
Skill Rating	Skill Rating	-.154	.143			
Riding Frequency Rating	Riding Frequency Rating	.220	.062			
Group Miles (2008)	Group Miles (2008)	.034	.409			
Commute Miles (2008)	Commute Miles (2008)	-.056	.350			
BRC	BRC	-.066	.325			
ARC	ARC	-.139	.171			
Age	Age	.163	.130			
Total Years Riding	Total Years Riding	.207	.075			
Ride Category (Num)	Ride Category (Num)	.048	.369			

Linear Regression of Rider Factor Components (PCA) with EB-2 Braking Measures (Ar2.0)

		Predictors for Ar2.0	
Predictors Entered into Model	Predictors in Model	Pearson R	Pearson R Sig.
PCA_RC_Distance	PCA_RC_Distance	.018	.444
PCA_RC_Years	PCA_RC_Years	.230	.037
PCA_RC_Frequency	PCA_RC_Frequency	.141	.139

Linear Regression of Rider Factors with UB-4 Braking Measures (Ar)

		Predictors for Af	
		Pearson R	Pearson R Sig.
Total Miles (2008)	Total Miles (2008)	-.036	.401
Miles / Year (2006 - 2008)	Miles / Year (2006 - 2008)	.038	.396
Aggressiveness Rating	Aggressiveness Rating	.234	.051
Skill Rating	Skill Rating	-.126	.190
Riding Frequency Rating	Riding Frequency Rating	.139	.165
Group Miles (2008)	Group Miles (2008)	-.018	.451
Commute Miles (2008)	Commute Miles (2008)	-.025	.430
BRC	BRC	-.123	.198
ARC	ARC	-.199	.083
Age	Age	.100	.244
Total Years Riding	Total Years Riding	.222	.059
Ride Category (Num)	Ride Category (Num)	.022	.439

Linear Regression of Rider Factors with UB-4 Braking Measures (Af2.0)

		Predictors for Af2.0		Model		
		Pearson R	Pearson R Sig.	Sig.	R	Adjusted R Square
Total Miles (2008)	Total Miles (2008)	.162	.130			
Miles / Year (2006 - 2008)	Miles / Year (2006 - 2008)	.130	.184			
Aggressiveness Rating	Aggressiveness Rating	.300	.018	.037	.300	.070
	(Constant)			.788		
Skill Rating	Skill Rating	-.212	.070			
Riding Frequency Rating	Riding Frequency Rating	.119	.206			
Group Miles (2008)	Group Miles (2008)	.173	.115			
Commute Miles (2008)	Commute Miles (2008)	-.011	.469			
BRC	BRC	-.038	.399			
ARC	ARC	-.035	.405			
Age	Age	.168	.121			
Total Years Riding	Total Years Riding	.160	.133			
Ride Category (Num)	Ride Category (Num)	-.155	.142			

Linear Regression of Rider Factor Component (PCA) with UB-4 Braking Measures (Af2.0)

		Predictors for Ar2.0	
Predictors Entered into Model	Predictors in Model	Pearson R	Pearson R Sig.
PCA_RC_Distance	PCA_RC_Distance	.188	.095
PCA_RC_Years	PCA_RC_Years	.094	.259
PCA_RC_Frequency	PCA_RC_Frequency	-.003	.495

Linear Regression of Rider Characteristics by UB-4 Braking Measures (Ar2.0)

		Predictors for Ar2.0		Model		
		Pearson R	Pearson R Sig.	Sig.	R	Adjusted R Square
Total Miles (2008)	Total Miles (2008)	.035	.406			
Miles / Year (2006 - 2008)	Miles / Year (2006 - 2008)	.086	.276			
Aggressiveness Rating	Aggressiveness Rating	.310	.015	.030	.310	.077
	(Constant)			.821		
Skill Rating	Skill Rating	-.154	.143			
Riding Frequency Rating	Riding Frequency Rating	.220	.062			
Group Miles (2008)	Group Miles (2008)	.034	.409			
Commute Miles (2008)	Commute Miles (2008)	-.056	.350			
BRC	BRC	-.066	.325			
ARC	ARC	-.139	.171			
Age	Age	.163	.130			
Total Years Riding	Total Years Riding	.207	.075			
Ride Category (Num)	Ride Category (Num)	.048	.369			

Linear Regression of Rider Factor Components (PCA) with UB-4 Braking Measures (Ar2.0)

		Predictors for Ar2.0	
Predictors Entered into Model	Predictors in Model	Pearson R	Pearson R Sig.
PCA_RC_Distance	PCA_RC_Distance	.070	.316
PCA_RC_Years	PCA_RC_Years	.120	.203
PCA_RC_Frequency	PCA_RC_Frequency	.068	.321

Logistic Regression
Scenario = EB-2
All Rider Factors vs. Collision

Model Summary[b]

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	75.353[a]	.101	.135

a. Estimation terminated at iteration number 37 because parameter estimates changed by less than .001.

b. Scenario = EB-2

Hosmer and Lemeshow Test[a]

Step	Chi-square	df	Sig.
1	.000	0	.

a. Scenario = EB-2

Classification Table[a,b]

Observed			Predicted		
			Collision		
			0	1	Percentage Correct
Step 1	Collision	0	31	0	100.0
		1	24	4	14.3
		Overall Percentage			59.3

a. Scenario = EB-2

b. The cut value is .500

Variables in the Equation[b]

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1	ARC by Ride Category Num	37.799	7.103E7	.000	1	1.000	2.606E16
	Constant	-.256	.272	.886	1	.347	.774

Variables not in the Equation

Step 1 Variables	Score	df	Sig.
Years Riding	2.966	1	.085
Ride Category Num	1.632	1	.201
Miles for 2008	.000	1	1.000
Average Miles	.888	1	.346
Aggressiveness Rating	.023	1	.878
Skill Rating	.911	1	.340
Riding Frequency Rating	.245	1	.620
Group Miles 2008	.023	1	.878
Commute Miles 2008	.771	1	.380
BRC	.545	1	.460
ARC	.002	1	.965
Age	3.314	1	.069
Total Motion Discomfort	.003	1	.959
Health	.479	1	.489
Ride Category Num by Years Riding	1.338	1	.247
Miles for 2008 by Years Riding	.373	1	.541
Average Miles by Years Riding	1.100	1	.294
Aggressiveness Rating by Years Riding	1.710	1	.191
Skill Rating by Years Riding	3.334	1	.068
Riding Frequency Rating by Years Riding	2.388	1	.122
Years Riding by Group Miles 2008	.391	1	.532
Years Riding by Commute Miles 2008	.523	1	.470
BRC by Years Riding	1.661	1	.197
ARC by Years Riding	.429	1	.512
Age by Years Riding	1.444	1	.230
Miles for 2008 by Ride Category Num	2.538	1	.111
Average Miles by Ride Category Num	3.702	1	.054
Aggressiveness Rating by Ride Category Num	2.070	1	.150
Ride Category Num by Skill Rating	1.482	1	.223

Variables not in the Equation

Step 1 Variables	Score	df	Sig.
Ride Category Num by Riding Frequency Rating	1.869	1	.172
Ride Category Num by Group Miles 2008	1.887	1	.169
Ride Category Num by Commute Miles 2008	.931	1	.335
BRC by Ride Category Num	.696	1	.404
Age by Ride Category Num	.981	1	.322
Average Miles by Miles for 2008	.222	1	.638
Aggressiveness Rating by Miles for 2008	.035	1	.851
Miles for 2008 by Skill Rating	.020	1	.887
Miles for 2008 by Riding Frequency Rating	.048	1	.826
Miles for 2008 by Group Miles 2008	.569	1	.451
Miles for 2008 by Commute Miles 2008	2.958	1	.085
BRC by Miles for 2008	.046	1	.830
ARC by Miles for 2008	.027	1	.870
Age by Miles for 2008	.608	1	.436
Aggressiveness Rating by Average Miles	.797	1	.372
Average Miles by Skill Rating	.785	1	.376
Average Miles by Riding Frequency Rating	.537	1	.464
Average Miles by Group Miles 2008	.406	1	.524
Average Miles by Commute Miles 2008	2.912	1	.088
Average Miles by BRC	.082	1	.775
ARC by Average Miles	.114	1	.736
Age by Average Miles	1.813	1	.178
Aggressiveness Rating by Skill Rating	.306	1	.580
Aggressiveness Rating by Riding Frequency Rating	.542	1	.461
Aggressiveness Rating by Group Miles 2008	.161	1	.688

Variables not in the Equation

Step 1 Variables	Score	df	Sig.
Aggressiveness Rating by Commute Miles 2008	1.535	1	.215
Aggressiveness Rating by BRC	.493	1	.483
ARC by Aggressiveness Rating	.230	1	.632
Age by Aggressiveness Rating	1.861	1	.173
Riding Frequency Rating by Skill Rating	.881	1	.348
Skill Rating by Group Miles 2008	.108	1	.743
Skill Rating by Commute Miles 2008	.912	1	.340
BRC by Skill Rating	.532	1	.466
ARC by Skill Rating	.037	1	.848
Age by Skill Rating	3.671	1	.055
Riding Frequency Rating by Group Miles 2008	.144	1	.704
Riding Frequency Rating by Commute Miles 2008	.959	1	.328
BRC by Riding Frequency Rating	.565	1	.452
ARC by Riding Frequency Rating	.046	1	.830
Age by Riding Frequency Rating	2.263	1	.132
Commute Miles 2008 by Group Miles 2008	2.796	1	.094
BRC by Group Miles 2008	.117	1	.732
ARC by Group Miles 2008	.007	1	.935
Age by Group Miles 2008	.367	1	.544
BRC by Commute Miles 2008	.589	1	.443
ARC by Commute Miles 2008	.172	1	.678
Age by Commute Miles 2008	.729	1	.393
ARC by BRC	.137	1	.711
Age by BRC	.335	1	.563
ARC by Age	.005	1	.941
Ride Category Num by Total Motion Discomfort	.061	1	.805

Variables not in the Equation

Step 1 Variables	Score	df	Sig.
Miles for 2008 by Total Motion Discomfort	.980	1	.322
Average Miles by Total Motion Discomfort	.847	1	.357
Aggressiveness Rating by Total Motion Discomfort	.063	1	.802
Skill Rating by Total Motion Discomfort	.078	1	.780
Riding Frequency Rating by Total Motion Discomfort	.043	1	.836
Total Motion Discomfort by Group Miles 2008	2.663	1	.103
Total Motion Discomfort by Commute Miles 2008	.239	1	.625
BRC by Total Motion Discomfort	.037	1	.847
ARC by Total Motion Discomfort	.739	1	.390
Age by Total Motion Discomfort	.050	1	.823
Ride Category Num by Health	1.728	1	.189
Miles for 2008 by Health	.233	1	.629
Average Miles by Health	1.611	1	.204
Aggressiveness Rating by Health	.004	1	.947
Skill Rating by Health	.885	1	.347
Riding Frequency Rating by Health	.872	1	.350
Health by Group Miles 2008	.064	1	.800
Health by Commute Miles 2008	.705	1	.401
BRC by Health	.105	1	.746
ARC by Health	.119	1	.730
Age by Health	1.250	1	.264

Logistic Regression
Scenario = UB-4
All Rider Factors vs. Collision

Model Summary[c]

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	61.975[a]	.084	.113
2	55.859[b]	.191	.258

a. Estimation terminated at iteration number 4 because parameter estimates changed by less than .001.

b. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.

c. Scenario = UB-4

Hosmer and Lemeshow Test[a]

Step	Chi-square	df	Sig.
1	.126	1	.723
2	.599	5	.988

a. Scenario = UB-4

Classification Table[a,b]

Observed			Predicted: Collision 0	Predicted: Collision 1	Percentage Correct
Step 1	Collision	0	27	2	93.1
		1	15	5	25.0
		Overall Percentage			65.3
Step 2	Collision	0	27	2	93.1
		1	16	4	20.0
		Overall Percentage			63.3

Variables in the Equation[c]

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	ARC by Group Miles 2008	.001	.001	3.001	1	.083	1.001
	Constant	-.625	.324	3.733	1	.053	.535
Step 2[b]	Years Riding by Commute Miles 2008	.000	.000	2.995	1	.084	1.000
	ARC by Group Miles 2008	.002	.001	4.561	1	.033	1.002
	Constant	-.284	.349	.660	1	.417	.753

a. Variable(s) entered on step 1: ARC * Group Miles 2008 .

b. Variable(s) entered on step 2: Years Riding * Commute Miles 2008 .

c. Scenario = UB-4

Variables not in the Equation[a,b]

Variables	Score	df	Sig.
Years Riding	1.671	1	.196
Ride Category Num	.290	1	.590
Miles for 2008	1.053	1	.305
Average Miles	1.420	1	.233
Aggressiveness Rating	.734	1	.391
Skill Rating	.065	1	.799
Riding Frequency Rating	.737	1	.391
Group Miles 2008	1.134	1	.287
Commute Miles 2008	1.485	1	.223
BRC	.300	1	.584
ARC	.256	1	.613
Age	.861	1	.353
Total Motion Discomfort	2.147	1	.143
Health	.467	1	.494
Ride Category Num by Years Riding	.009	1	.926
Miles for 2008 by Years Riding	2.079	1	.149
Average Miles by Years Riding	1.702	1	.192
Aggressiveness Rating by Years Riding	3.393	1	.065

Variables not in the Equation[a,b]			
Variables	Score	df	Sig.
Skill Rating by Years Riding	2.326	1	.127
Riding Frequency Rating by Years Riding	2.343	1	.126
Years Riding by Group Miles 2008	1.274	1	.259
Years Riding by Commute Miles 2008	4.576	1	.032
BRC by Years Riding	.283	1	.595
ARC by Years Riding	.080	1	.778
Age by Years Riding	.491	1	.484
Miles for 2008 by Ride Category Num	.003	1	.956
Average Miles by Ride Category Num	.251	1	.616
Aggressiveness Rating by Ride Category Num	.841	1	.359
Ride Category Num by Skill Rating	.025	1	.874
Ride Category Num by Riding Frequency Rating	.112	1	.738
Ride Category Num by Group Miles 2008	.646	1	.421
Ride Category Num by Commute Miles 2008	.100	1	.751
BRC by Ride Category Num	.188	1	.665
ARC by Ride Category Num	.086	1	.769
Age by Ride Category Num	.027	1	.869
Average Miles by Miles for 2008	1.011	1	.315
Aggressiveness Rating by Miles for 2008	1.189	1	.276
Miles for 2008 by Skill Rating	.905	1	.341
Miles for 2008 by Riding Frequency Rating	.937	1	.333
Miles for 2008 by Group Miles 2008	.906	1	.341
Miles for 2008 by Commute Miles 2008	1.111	1	.292
BRC by Miles for 2008	.305	1	.581
ARC by Miles for 2008	.536	1	.464
Age by Miles for 2008	1.421	1	.233
Aggressiveness Rating by Average Miles	2.222	1	.136
Average Miles by Skill Rating	1.372	1	.241

Variables not in the Equation[a,b]			
Variables	Score	df	Sig.
Average Miles by Riding Frequency Rating	1.470	1	.225
Average Miles by Group Miles 2008	.946	1	.331
Average Miles by Commute Miles 2008	2.311	1	.128
Average Miles by BRC	.031	1	.861
ARC by Average Miles	1.046	1	.306
Age by Average Miles	1.305	1	.253
Aggressiveness Rating by Skill Rating	.637	1	.425
Aggressiveness Rating by Riding Frequency Rating	1.347	1	.246
Aggressiveness Rating by Group Miles 2008	1.138	1	.286
Aggressiveness Rating by Commute Miles 2008	1.408	1	.235
Aggressiveness Rating by BRC	.004	1	.948
ARC by Aggressiveness Rating	2.428	1	.119
Age by Aggressiveness Rating	2.281	1	.131
Riding Frequency Rating by Skill Rating	.683	1	.409
Skill Rating by Group Miles 2008	1.048	1	.306
Skill Rating by Commute Miles 2008	1.224	1	.269
BRC by Skill Rating	.082	1	.774
ARC by Skill Rating	.159	1	.690
Age by Skill Rating	1.314	1	.252
Riding Frequency Rating by Group Miles 2008	1.026	1	.311
Riding Frequency Rating by Commute Miles 2008	1.242	1	.265
BRC by Riding Frequency Rating	.279	1	.598
ARC by Riding Frequency Rating	.554	1	.457
Age by Riding Frequency Rating	1.828	1	.176
Commute Miles 2008 by Group Miles 2008	1.167	1	.280
BRC by Group Miles 2008	.968	1	.325

Variables not in the Equation[a,b]			
Variables	Score	df	Sig.
Age by Group Miles 2008	1.186	1	.276
BRC by Commute Miles 2008	.148	1	.700
ARC by Commute Miles 2008	.625	1	.429
Age by Commute Miles 2008	2.846	1	.092
ARC by BRC	.009	1	.925
Age by BRC	.012	1	.914
ARC by Age	.003	1	.956
Ride Category Num by Total Motion Discomfort	.921	1	.337
Miles for 2008 by Total Motion Discomfort	.133	1	.716
Average Miles by Total Motion Discomfort	.541	1	.462
Aggressiveness Rating by Total Motion Discomfort	2.610	1	.106
Skill Rating by Total Motion Discomfort	1.586	1	.208
Riding Frequency Rating by Total Motion Discomfort	1.648	1	.199
Total Motion Discomfort by Group Miles 2008	.276	1	.599
Total Motion Discomfort by Commute Miles 2008	.508	1	.476
BRC by Total Motion Discomfort	.475	1	.491
ARC by Total Motion Discomfort	.073	1	.788
Age by Total Motion Discomfort	2.420	1	.120
Ride Category Num by Health	.004	1	.949
Miles for 2008 by Health	1.463	1	.226
Average Miles by Health	2.032	1	.154
Aggressiveness Rating by Health	.850	1	.356
Skill Rating by Health	.801	1	.371
Riding Frequency Rating by Health	1.259	1	.262
Health by Group Miles 2008	1.173	1	.279
Health by Commute Miles 2008	2.364	1	.124

Variables not in the Equation[a,b]			
Variables	Score	df	Sig.
BRC by Health	.000	1	.994
ARC by Health	.604	1	.437
Age by Health	.390	1	.532
Years Riding	.750	1	.386
Ride Category Num	.138	1	.710
Miles for 2008	.664	1	.415
Average Miles	.202	1	.653
Aggressiveness Rating	.315	1	.575
Skill Rating	.051	1	.821
Riding Frequency Rating	.012	1	.911
Group Miles 2008	1.283	1	.257
Commute Miles 2008	1.364	1	.243
BRC	.002	1	.963
ARC	.012	1	.915
Age	.376	1	.540
Total Motion Discomfort	2.428	1	.119
Health	.206	1	.650
Ride Category Num by Years Riding	.013	1	.908
Miles for 2008 by Years Riding	.816	1	.366
Average Miles by Years Riding	.172	1	.678
Aggressiveness Rating by Years Riding	1.504	1	.220
Skill Rating by Years Riding	1.394	1	.238
Riding Frequency Rating by Years Riding	.582	1	.445
Years Riding by Group Miles 2008	1.180	1	.277
BRC by Years Riding	.331	1	.565
ARC by Years Riding	.162	1	.688
Age by Years Riding	.137	1	.711
Miles for 2008 by Ride Category Num	.112	1	.738
Average Miles by Ride Category Num	1.406	1	.236
Aggressiveness Rating by Ride Category Num	.940	1	.332
Ride Category Num by Skill Rating	.000	1	.989

Variables not in the Equation[a,b]			
Variables	Score	df	Sig.
Ride Category Num by Riding Frequency Rating	.144	1	.704
Ride Category Num by Group Miles 2008	.539	1	.463
Ride Category Num by Commute Miles 2008	2.994	1	.084
BRC by Ride Category Num	.031	1	.860
ARC by Ride Category Num	.007	1	.933
Age by Ride Category Num	.000	1	.983
Average Miles by Miles for 2008	.967	1	.325
Aggressiveness Rating by Miles for 2008	.720	1	.396
Miles for 2008 by Skill Rating	.553	1	.457
Miles for 2008 by Riding Frequency Rating	.518	1	.471
Miles for 2008 by Group Miles 2008	1.212	1	.271
Miles for 2008 by Commute Miles 2008	1.600	1	.206
BRC by Miles for 2008	.401	1	.526
ARC by Miles for 2008	.001	1	.979
Age by Miles for 2008	.549	1	.459
Aggressiveness Rating by Average Miles	.623	1	.430
Average Miles by Skill Rating	.237	1	.626
Average Miles by Riding Frequency Rating	.179	1	.672
Average Miles by Group Miles 2008	1.143	1	.285
Average Miles by Commute Miles 2008	1.261	1	.261
Average Miles by BRC	.000	1	.992
ARC by Average Miles	.002	1	.964
Age by Average Miles	.042	1	.838
Aggressiveness Rating by Skill Rating	.297	1	.586
Aggressiveness Rating by Riding Frequency Rating	.312	1	.576
Aggressiveness Rating by Group Miles 2008	1.202	1	.273

Variables not in the Equation[a,b]			
Variables	Score	df	Sig.
Aggressiveness Rating by Commute Miles 2008	1.607	1	.205
Aggressiveness Rating by BRC	.052	1	.820
ARC by Aggressiveness Rating	1.265	1	.261
Age by Aggressiveness Rating	.995	1	.318
Riding Frequency Rating by Skill Rating	.098	1	.754
Skill Rating by Group Miles 2008	1.145	1	.285
Skill Rating by Commute Miles 2008	2.169	1	.141
BRC by Skill Rating	.012	1	.914
ARC by Skill Rating	.000	1	.992
Age by Skill Rating	.828	1	.363
Riding Frequency Rating by Group Miles 2008	1.109	1	.292
Riding Frequency Rating by Commute Miles 2008	1.598	1	.206
BRC by Riding Frequency Rating	.072	1	.789
ARC by Riding Frequency Rating	.024	1	.876
Age by Riding Frequency Rating	.286	1	.593
Commute Miles 2008 by Group Miles 2008	.090	1	.764
BRC by Group Miles 2008	1.200	1	.273
Age by Group Miles 2008	1.178	1	.278
BRC by Commute Miles 2008	1.771	1	.183
ARC by Commute Miles 2008	1.134	1	.287
Age by Commute Miles 2008	.667	1	.414
ARC by BRC	.001	1	.976
Age by BRC	.203	1	.653
ARC by Age	.376	1	.540
Ride Category Num by Total Motion Discomfort	1.356	1	.244
Miles for 2008 by Total Motion Discomfort	.039	1	.843

Variables not in the Equation[a,b]

Variables	Score	df	Sig.
Average Miles by Total Motion Discomfort	.074	1	.786
Aggressiveness Rating by Total Motion Discomfort	2.006	1	.157
Skill Rating by Total Motion Discomfort	2.046	1	.153
Riding Frequency Rating by Total Motion Discomfort	1.490	1	.222
Total Motion Discomfort by Group Miles 2008	.156	1	.693
Total Motion Discomfort by Commute Miles 2008	.106	1	.745
BRC by Total Motion Discomfort	.861	1	.353
ARC by Total Motion Discomfort	.269	1	.604
Age by Total Motion Discomfort	2.749	1	.097
Ride Category Num by Health	.013	1	.909
Miles for 2008 by Health	.934	1	.334
Average Miles by Health	.451	1	.502
Aggressiveness Rating by Health	.181	1	.670
Skill Rating by Health	.495	1	.482
Riding Frequency Rating by Health	.097	1	.755
Health by Group Miles 2008	1.361	1	.243
Health by Commute Miles 2008	.525	1	.469
BRC by Health	.127	1	.721
ARC by Health	.002	1	.963
Age by Health	.153	1	.696

APPENDIX F

COMPUTED VARIABLES

Variable	Notes	Mnemonic
Front brake reaction time (sec)		F_ReacTime
Front Peak Control Force Overall (g commanded)	1	F_Peak_CF_g
Front Peak Control Force Rate Time (sec)		F_Peak_CF_time
Front Peak Control Force Rate Time (sec)		F_Peak_CF_dot_g
Front Duration of Brake Input (sec)		F_InputDuration
Front Mean Control Force (g commanded)	1	F_Mean_CF_g
Front Mean Square Deviation of Control Force (g commanded^2)	1	F_MS_Dev_CF_gsq
Front Mean Control Force to 80% of Speed (g commanded)	1,2	F_Mean_CF_80_g
Rear Reaction Time (sec)		R_ReacTime
Rear Peak Control Force Overall (g commanded)	1	R_Peak_CF_g
Rear Peak Control Force Rate Time (sec)		R_Peak_CF_time
Rear Peak Control Force Rate Time (sec)		R_Peak_CF_dot_g
Rear Duration of Brake Input (sec)		R_InputDuration
Rear Mean Control Force (g commanded)	1	R_Mean_CF_g
Rear Mean Square Deviation of Control Force (g commanded^2)	1	R_MS_Dev_CF_gsq
Rear Mean Control Force to 80% of Speed (g commanded)	1,2	R_Mean_CF_80_g
Mean Longitudinal Acceleration (g)	1	MeanAx
Peak Longitudinal Acceleration (g)	1	PeakAx
Peak Pitch Angle (deg)		PeakPitchAngle (deg)
Front Peak Longitudinal Slip Ratio (0 to 1)		F_Peak SlipRatio
Rear Peak Longitudinal Slip Ratio (0 to 1)		R_Peak SlipRatio
Peak to Peak Lateral Lane Deviation (m)		PP_LatLaneDev
Mean Square Lateral Lane Deviation (m^2)		MS_LatLaneDev
Peak to Peak Roll Angle (deg)		PP_Phi
Peak to Peak Steer Angle (deg)		PP_Delta
Mean throttle (%)		MeanThrottle
Initial Speed (km/h)		InitialSpeed
Collision		Collision
Collision Speed (km/h)		CollisionSpeed
Run aborted		RunAborted
Speed when run aborted (km/h)		

Front to rear brake distribution for means (%F commanded g)	3	FrontRearDistribution
Front to rear brake distribution to 80% of initial speed (%F commanded g)	2,3	FrontRearDistribution80
Deceleration needed so as not to hit oncoming vehicle for selected runs (g)	4	axneeded
Front brake, area under commanded g curve multiplied by time (1st moment)	5	ATF
Front brake, area under commanded g curve	5	AF
Rear brake, area under commanded g curve multiplied by time (1st moment)	5	ATR
Rear brake, area under commanded g curve	5	AR
Area under Ax curve multiplied by time (1st moment)	5	ATAx
Area under Ax curve	5	AAx
Area under front brake commanded g curve at 1.2 sec (g-sec) for selected runs	5	AF_12
Area under front brake commanded g curve at 1.4 sec (g-sec) for selected runs	5	AF_14
Area under front brake commanded g curve at 1.6 sec (g-sec) for selected runs	5	AF_16
Area under front brake commanded g curve at 1.8 sec (g-sec) for selected runs	5	AF_18
Area under front brake commanded g curve at 2.0 sec (g-sec) for selected runs	5	AF_20
Area under rear brake commanded g curve at 1.2 sec (g-sec) for selected runs	5	AR_12
Area under rear brake commanded g curve at 1.4 sec (g-sec) for selected runs	5	AR_14
Area under rear brake commanded g curve at 1.6 sec (g-sec) for selected runs	5	AR_16
Area under rear brake commanded g curve at 1.8 sec (g-sec) for selected runs	5	AR_18
Area under rear brake commanded g curve at 2.0 sec (g-sec) for selected runs	5	AR_20

DOT HS 811 448
March 2011

U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

NHTSA
www.nhtsa.gov