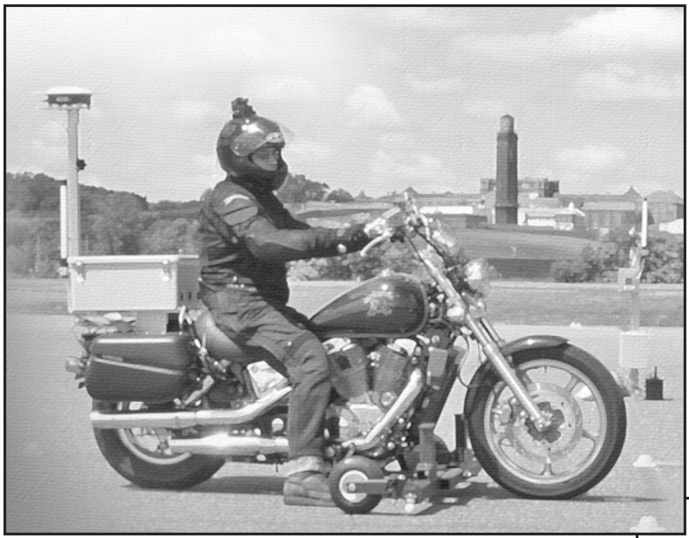
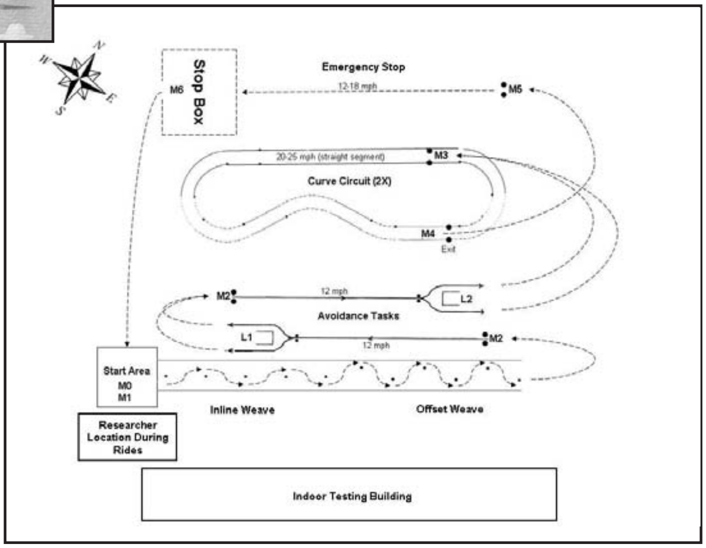
U.S. Department of Transportation
National Highway Traffic Safety Administration

Effects of Alcohol on Motorcycle Riding Skills

Final Report





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16. Abstract

Alcohol is known to disrupt the effect of neurotransmitters and impair various psychomotor skills. Indeed, alcohol intoxication is a significant risk factor for fatal traffic crashes, especially when riding a motorcycle. At present, there is sparse research on the impairing effects of alcohol on skills involved in motorcycle control. This study was designed to measure the effect of alcohol (up to a blood alcohol concentration of .08 grams per deciliter) on a broad set of basic riding skills. These riding skills were assessed on a test track with task scenarios based on the Motorcycle Safety Foundation's training program. This study used a balanced incomplete block design to remove confounding artifacts (learning effects) by randomizing four BACs across three test days. Performance was characterized in terms of riding strategy used to cope with the effects of alcohol as a neurological stressor and the amount of resulting impairment with reference to specified performance standards. The analysis controlled for rider gender and age, riding skill, and drinking history. The results showed there were observable changes in motorcycle control and rider behavior in response to alcohol that are indicative of impairment. In general, intoxicated riders demonstrated longer response times and adopted larger tolerances leading to more task performance errors. Riders appeared to protect bike stability at the expense of other task performance and riders tried harder -- where possible -- to fully or partially compensate for the negative effects of alcohol. Most of the alcohol effects were evident at the per se BAC .08 g/dL level, but some of the effects were observed at the lower BAC .05. Given that this study used experienced riders performing highly practiced tasks with low to moderate levels of alcohol, the effect of alcohol on motorcycle control and rider behavior were modest except when task demand was high (offset weave), time pressure was high (hazard avoidance for near obstacles), and tolerances were constrained (circuit track). The practical significance of the findings was discussed in terms of study constraints.

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Executive Summary

Alcohol is a greater risk factor for fatal crashes involving motorcycles than other types of vehicle operation (NHTSA, 2006). For example, 1 in 4 automobile driver fatalities in the United States were alcohol-related during 2005. In comparison, a higher proportion of motorcycle rider fatalities (1 in 3) were related to alcohol in the same year (see also Subramanian, 2005). Although researchers have hypothesized that motorcycle riding performance could be impaired at levels below established per se limits (Colburn et al., 1993), there has also been limited research to characterize the impairing effect of alcohol on motorcycle control. The purpose of this study was to observe the effects of different levels of blood alcohol concentrations (BAC) on motorcycle riders' performance on a closed test course. This study set explicit performance standards for a set of skill-based riding tasks to assess rider ability to maintain that performance at different levels of blood alcohol concentrations. The study also evaluated riders' subjective perceptions of their level of impairment and intoxication.

Methods

Twenty-four male participants age 21 to 50 (*M*=32 years) completed three test days for this experiment. All participants had a minimum of 5 years of riding experience (*M*=14.97 years), drank alcohol at least once a week, and had no history of medical or psychological (i.e., alcohol dependence) problems that would preclude them from participating in the study. The study design consisted of a balanced incomplete block design (BIBD) where participants were randomly assigned to one of four possible conditions. Participants in each condition experienced three out of four possible levels of alcohol presentation (placebo, .02 g/dL, .05 g/dL, .08 g/dL) and completed one level per test day. All testing took place from July 1to Aug. 31, 2006, and under dry conditions only. Testing was postponed and rescheduled for another day if rain occurred on a test day.

A motorcycle test course was developed in conjunction with two certified motorcycle coach instructors from the Minnesota Motorcycle Safety Center (MMSC) based on standard exercises within the Motorcycle Safety Foundation (MSF) training program, including the MSF Basic Rider Course (BRC) and the Experienced Rider Course (ERC). This course was designed to include specific task scenarios from these training programs that tested performance of riding skills deemed relevant to the safe control of motorcycles. The task scenarios from these programs (see Table 1 in Methods) were modified when necessary to facilitate data collection, but the premise of each task was preserved. The resulting set of task scenarios that comprised the test course included weaves (slalom) around pylons, hazard avoidance, curve negotiation, and emergency

stops (see Figure 2 in Methods). The test motorcycle was an instrumented 2000 Honda Shadow VT1100 equipped with outriggers and sensor equipment for data collection.

Data was collected for two baseline rides and two test rides at one of four alcohol conditions (BAC .00, .02, .05 and .08) each day. Data was also collected for a set of subjective measures that evaluated mental workload for the riding tasks and the riders' perceived levels of intoxication and impairment. The data analysis used baseline riding performance, riding experience (years), and drinking experience (drinks/week) as covariates. BAC condition was the main independent variable for each performance measure. For all dependent measures, two sets of post-hoc tests (Tukey HSD Test) were completed in response to a significant BAC effect in the ANCOVA model:

- General Alcohol Effect: The BAC .00 condition was compared to the alcohol conditions (BAC .02, .05, .08) to identify the lowest level of alcohol that significantly affected participants ($p < .05$).
- Equivalent Alcohol Effect: The BAC .08 condition was compared to all other alcohol conditions (.02, .05) to examine the generalization of alcohol effects ($p < .05$).

Results

The results showed that performance for several dependent measures of riding performance were impaired at the BAC .08 condition.

- In the offset weave (slalom) task, participants missed or hit more pylons and had smaller passing distances around the pylons in the BAC .08 condition compared to the other alcohol and placebo conditions.

- In the hazard avoidance task where a warning was provided when the motorcycle was 1.5 seconds away from the hazard, participants had slower reaction times in both the BAC .08 and .05 conditions compared to the placebo condition.

- In the hazard avoidance task where a warning was provided when the motorcycle was 2.5 seconds away from the hazard, participants in the BAC .08 and .05 conditions passed at a closer distance to the obstacle than in the placebo or BAC .02 conditions. For both hazard tasks, riders turned in the wrong direction more often in the BAC .08 condition.

- In the curve circuit task, there was a significant main effect of BAC for maximum speed and speed variability. Although post-hoc tests were not significant, participants in all alcohol conditions tended to have faster maximum speeds and increased variability in speed in the circuit compared to the placebo condition. Participants in the BAC .08 condition were also more likely to cross outside the curve circuit boundaries than participants in other conditions.

- In the emergency stop task, participants in the BAC .05 condition reached maximum deceleration faster than participants the other alcohol conditions. This difference was significant between the BAC .05 and .08 conditions. Finally, there was a significant change in motorcycle position during the emergency stopping task between the BAC .08 and .02 conditions, where the BAC .08 condition showed more deviation in their stopping path compared to the BAC .02 condition.

- Participants reported requiring more effort to ride and complete the tasks in the BAC .08 condition when compared to the placebo condition. Their levels of subjective intoxication also increased significantly with increasing BACs. Participants reported that their perceived levels of performance impairment was higher for the BAC .05 and .08 conditions compared to the placebo and BAC .02 conditions. Participants in the BAC .05 and .08 conditions also reported they would be less willing to ride a motorcycle for any reason.

Conclusions

This study demonstrates some changes in riding behavior in response to alcohol consumption that may be construed as impairment relative to standard performance and the self-assessment of riders. Most of the impairing effects on riding performance were evident at the per se alcohol limit of BAC .08. However, some of these same impairing effects were also evident in the lower BAC .05 condition. Admittedly, the effect sizes (Eta^2) calculated for the significant main effect of alcohol may be considered small (a range of 2% to 8% of variance was accounted for by the alcohol effect). Given that this study used experienced riders performing highly practiced tasks on a closed course at low to moderate BACs, the effect of alcohol on motorcycle control and rider behavior was modest except when task demand was high (offset weave), time pressure was high (hazard avoidance for near obstacles), and tolerances were constrained (circuit track). Larger impairments may be expected with less experienced riders, on less familiar roads, with more complex and novel tasks at higher alcohol doses.

Although the participants' self-reports suggest that riders may be aware of the intoxicating and impairing effects of alcohol, this study cannot conclude that corollary self-regulation would be sufficient to mitigate crash risk. Similarly, more research is needed to determine real-world implications of BAC during the riding experience.

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1 INTRODUCTION

Motorcycle crashes account for nearly 11 percent of all traffic fatalities in the United States (NCSA, 2007). This contribution to traffic fatalities is disproportional to the percentage of registered vehicles that are motorcycles (3%) and the percentage of vehicle miles traveled by motorcycles (0.4%) (NCSA, 2007). Indeed, the risk of a fatal crash per vehicle mile traveled is 26 times greater for travel by motorcycle than by passenger car (NHTSA, 2003). Moreover, with the increase in ridership (especially amongst riders older than 40) and ownership (especially for larger displacement motorcycles), the annual number of motorcycle fatalities have doubled in recent years (IIHS, 2002, 2006). This trend for increasing traffic fatalities involving motorcycles is in sharp contrast to the reverse trends observed for passenger vehicles and pedestrians (IIHS, 2002). As a result, the National Highway Traffic Safety Administration has noted that “the increase in motorcycle popularity has been followed by a rise in fatalities, and we must find ways to prevent these unnecessary deaths” (NHTSA, 2001).

Alcohol is a significant risk factor within the transportation system (Compton et al., 2002). For example, 39 percent of the 43,443 total traffic fatalities in 2005 were alcohol-related. Overall, 9,312 drivers and 1,751 motorcycle riders were killed in alcohol-related crashes during this period (NHTSA, 2006). Based on recent economic models, the comprehensive cost associated with alcohol-related crashes has been estimated to be $120 billion per year (Miller, Lestina, & Spicer, 1998). Given the high incidence and associated cost of alcohol-related crashes, NHTSA has identified the reduction of alcohol-related traffic fatalities as a priority for improving traffic safety (NHTSA, 2001).

In particular, as shown in Figure 1, alcohol is a greater risk factor for fatal crashes involving motorcycles than other types of vehicle operation (NHTSA, 2006). For example, 1 in 4 automobile driver fatalities in the United States were alcohol-related during 2005. In comparison, a higher proportion of motorcycle rider fatalities (1 in 3) were related to alcohol in the same year (see also Subramanian, 2005). With recent increases in the licensing of (older) riders and ownership of (larger) motorcycles, it is expected that the frequency of motorcycle fatalities will increase in the future unless effective motorcycle safety programs can be developed (NHTSA, 2001, 2003).

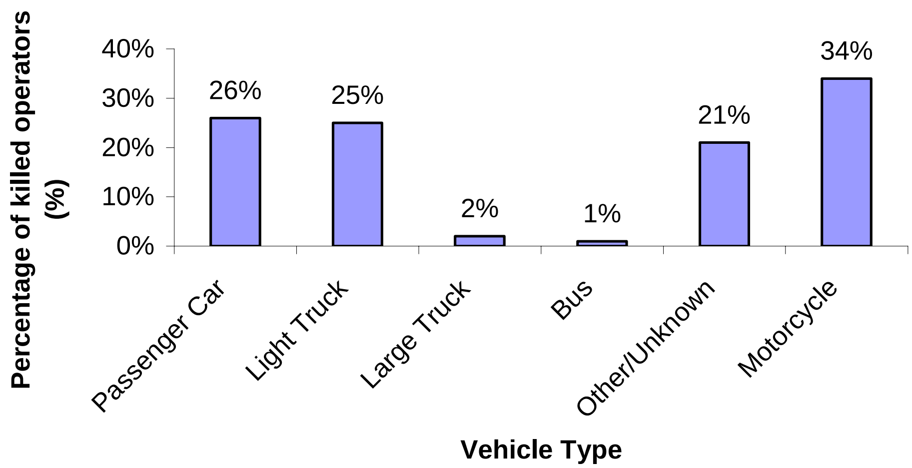

Figure 1. Percentage of U.S. vehicle operators killed in crashes in 2005 with alcohol involvement with BAC ≥ .01 (NHTSA, 2006).

In order to develop effective traffic safety programs that target motorcycle crashes, it is necessary to identify and understand the (fatal) crash risk factors for motorcycles. Alcohol is a significant risk factor within the transportation system (NHTSA, 2005). Notably, the risk imposed by alcohol is greatest amongst fatal crashes involving motorcycles. Thus, alcohol is a relevant topic for traffic safety programs that focus on motorcycles.

Despite the relevance of alcohol to motorcycle safety, there has been no epidemiological case-control study to derive the crash-risk curve for operating a motorcycle as a function of blood alcohol level. Instead, the same per se alcohol limit of BAC .08 that was based on analyses of the crash-risk curve for automobiles is currently applied to motorcycles despite the fact that operating a motorcycle is a fundamentally different task. Although researchers have hypothesized that motorcycle riding performance could be impaired at levels below established per se limits (Colburn et al., 1993), there has also been limited research to characterize the impairing effect of alcohol on motorcycle control. However, Moskowitz and Florentino (2000) conducted a review of studies that examined the effect of alcohol on individual tests of psychomotor performance. The results of this review suggest that psychomotor tasks that involve "controlled skills" requiring divided attention and effort to integrate multiple information sources are most sensitive to the impairment effects of alcohol. To the extent that complex real-world skills such as driving a vehicle or riding a motorcycle are dependent on controlled skills, alcohol can impair vehicle operations (Moskowitz et al., 2000).

Motorcycle safety programs that target alcohol as a fatal crash factor should consider the effect of impairment on motorcycle riding skill. Operating a motorcycle requires effort and attention to cope with multiple objects in the traffic environment while engaged in the complex control actions of operating the motorcycle (Ecker et al., 2001; MSF, 2004). Basic research indicates that tasks involving controlled skills that require effort to divide attention to multiple information sources are most sensitive to the impairment effects of alcohol (Halloway, 1995; Moskowitz & Fiorentino, 2000). In this regard, motorcycle control skills that are dependent on divided attention may be expected to be impaired by alcohol. Notably, 52 percent of fatal single-vehicle motorcycle crashes are alcohol-related (e.g., “run-off-road” at curve) in comparison with only 28 percent of multiple-vehicle, fatal motorcycle crashes (NCSA, 2004). These single-vehicle crashes are frequently precipitated by rider error related to inattention and distraction (Kasantikul & Ouellet, 2005).

Despite the relevance of alcohol impairment to motorcycle safety, there have been few studies to date that specifically examined the behavioral effects of alcohol on rider performance. For example, a single motorcycle simulator study has shown that the most common error for intoxicated operators at BACs ranging from .038-.059 g/dL was to “run-off-road,” particularly when negotiating curves (Colburn, Meyer, Wrigley & Bradley, 1993). Participants in this 1993 simulator study also rode at excessive and inappropriate speeds. Overall, the authors observed that even basic motorcycle handling skills were impaired at the BAC .10 g/dL (which was the per se limit set for that year) and they concluded that the results supported their hypothesis that the “legal alcohol level” should be lowered for motorcycle operators. Analyses of crash data support the results of this early simulator study. However, data from a single simulator study limits the generalizations that can be made regarding the types of impairment that occur among motorcycle operators after consuming alcohol.

Given the scarcity of motorcycle impairment research, the main objectives of this project were to evaluate possible forms of riding skill impairment during realistic driving conditions as a function of alcohol level and to characterize the strategies used by riders to cope with alcohol impairment.

1.1.1 Performance Impairment

Normal vehicle control is based on an assessment of current behavior with respect to the desired performance goal. The performance goal may be implicit such as riding in the center of a lane to avoid departing the road and crashing. The performance goal may also be explicit as a formal *performance standard* such as a posted speed limit. These performance goals are comprised of a *target situated vehicle state* with an associated *tolerance margin* for deviations from the goal. Depending on the context, the thresholds of the tolerance margin may also impose a *safety boundary.* For example, a wide margin for accepted lane position may include the lane edge as a boundary that if violated may increase the risk of a crash. The discrepancy between the actual and goal state can be “corrected” by adjusting control of the vehicle. The necessity for these corrections increases with the frequency and severity of the discrepancy, especially when a safety boundary is violated. Based on these definitions, the impairment of performance can be assessed in terms of the ability of riders to achieve *performance standards* that are stipulated for skill-based riding tasks and the observed changes in tolerance margins and violation of safety boundaries. Accordingly, this study set explicit performance standards for a set of skill-based riding tasks to assess rider ability to maintain that performance at different levels of blood alcohol concentrations.

This framework was developed by Rakauskas et al. (2006) to provide the theoretical basis to describe critical characteristics of driving behavior (metrics) that signify the effect of impairment on the normal process of driving. These metrics pertain to the target level of behavior in a given situation, the margin of variation (tolerance) accepted around that target, and the amount of effort invested to maintain behavior within those margins without violating set safety boundaries. Boer and his colleagues (Boer, Rakauskas, & Ward, 2004; Boer & Goodrich, 2005; Boer, 2006) developed several metrics that are consistent with this framework and characterization of behavioral coping mechanisms: "the key is to assess shifts in accepted tolerances as well as the degree to which the driver struggles to maintain performance within those limits" (Boer, personal communication).

1.1.2 Coping Strategy

In order to achieve the performance standards on each task, the riders had to develop a strategy to control the vehicle that compensated for the impairment effect of alcohol. According to Hockey (1986, 1993, 2003), a person may adopt several strategies to cope with potential impairment of behavior in relation to a performance goal: (1) try harder and invest resources to achieve the goal; (2) lower performance goal by increasing tolerance margin (thereby reducing effort demand); (3) modify the source of impairment (4) do nothing and endure the consequence of impaired performance. In this study, riders only had the opportunity to actively cope by applying either more effort or accepting lower performance. Measures were included in this study to quantify effort, performance goals, tolerance margins, and safety boundary violations. Logically, the activation of these coping mechanisms is dependent on the salience of the performance discrepancies. In order for a performance discrepancy to be salient, it must be perceived and assessed to be relevant to the rider in terms of exceeding accepted tolerance boundaries for performance goals. To interpret the form of coping used, the key is to assess shifts in accepted tolerance margins as well as the degree to which the driver struggles to maintain performance within those limits.

To examine performance impairment and coping strategy, this study used a within-subjects design that controlled for learning effects to examine rider impairment across multiple alcohol levels on different test days. Riding performance at different levels of alcohol consumption was measured for a set of tasks that were designed to measure basic riding skills. These tasks comprised a series of riding scenarios on a closed-course test track using an instrumented motorcycle to automatically record data.

2 Methods

2.1 Participant Screening

The study participants were recruited in St. Cloud, Minnesota, through local media advertising. The advertisements indicated that participants were required to be males between the ages of 21 to 50 and have at least five years of motorcycle riding experience. This demographic group was targeted in this study because over 90 percent of fatal alcohol-involved motorcycle crashes involve male riders, the majority of whom (approximately 78%) are between the ages of 20 and 49 (Shankar, 2001a). The threshold for riding experience was included as a proxy for an implicit minimum level of skill in riding a motorcycle.

The minimum age for participation was set at 21 to be compliant with the legal minimum drinking age. Participants were also required to have a history of drinking alcohol so that the impairment effects were not novel (or dangerous). The advertisement instructed interested participants to use a toll-free phone number to provide their contact information to an automatic messaging system.

All responding individuals were contacted by research staff to complete a screening questionnaire to select suitable participants for the study (Appendix A). This questionnaire solicited basic information about participant demographics, health, and availability for the requirements of the study. Given that drinking experience is known to be a mediating factor for the effect of alcohol (Holloway, 1995), participants were excluded if they reported drinking alcohol less than once every two weeks (but no more than 20 alcoholic beverages per week). In addition, the CAGE alcoholism screener (Mayfield et al., 1974) was used to exclude participants with potential alcohol problems (Appendix B). Finally, participants were administered the American College of Sport Medicine's Physical Activity Readiness Questionnaire (PAR-Q; 1995) to exclude those with health issues (heart, liver, or kidney conditions, etc.) that could be exacerbated by drinking alcohol (Appendix C).

2.2 Participant Sample

The screening procedure resulted in a sample of 33 male licensed motorcycle riders who were scheduled to participate in the study. A total of 24 participants from this sample completed all three scheduled days of testing and are the basis of the reported data analysis. Participants in the analysis sample were on average

32 years old (range 21 to 49 years) with 14.97 years of riding experience (range 5 to 33 years), and reportedly consumed an average of 6.4 drinks per week (range 1 to 15). Overall, 14 participants reported driving their motorcycles less than 5,000 miles per year, 9 reported driving between 5,001 to 10,000 miles per year, and only one reported driving between 10,001 to 15,000 miles per year.

2.3 Material and Apparatus

2.3.1 Test Course

For conclusions about motorcycle riding performance related to alcohol to be relevant to motorcycle safety policy, it is necessary that the measurement of riding control be relevant to safety and representative of basic riding skills. Accordingly, a "motorcycle test course" was developed in conjunction with two certified motorcycle coach instructors from the Minnesota Motorcycle Safety Center (MMSC) based on standard "exercises" within the Motorcycle Safety Foundation (MSF) training program, including the MSF Basic Rider Course (BRC) and the Experienced Rider Course (ERC). This course was designed to include specific "task scenarios" from these training programs that tested performance of riding skills deemed relevant to the safe control of motorcycles. The task scenarios from these programs (Table 1) were modified when necessary to facilitate data collection, but the premise of each task was preserved. The resulting set of task scenarios that comprised the test course is illustrated in Figure 2: weaves (slalom) around pylons, hazard avoidance, curve negotiation, and emergency stops.

The test course was painted onto the pavement of the test site. In addition, the location of critical markers in the test course were recorded into a digital map. This map then served as the foundation for real-time tracking of the motorcycle location within the test course using a Differential Global Positioning System (DGPS). Many of the dependent measures of motorcycle control were then derived from deriving relative position within the digital map. This methodology has been employed in previous experimental studies to track vehicle location in real-time with respect to map features in order to compute metrics of vehicle lateral and longitudinal performance (Sergi, Newstrom, Gorjestani, Shankwitz, & Donath, 2003; Alexander et al., 2004).

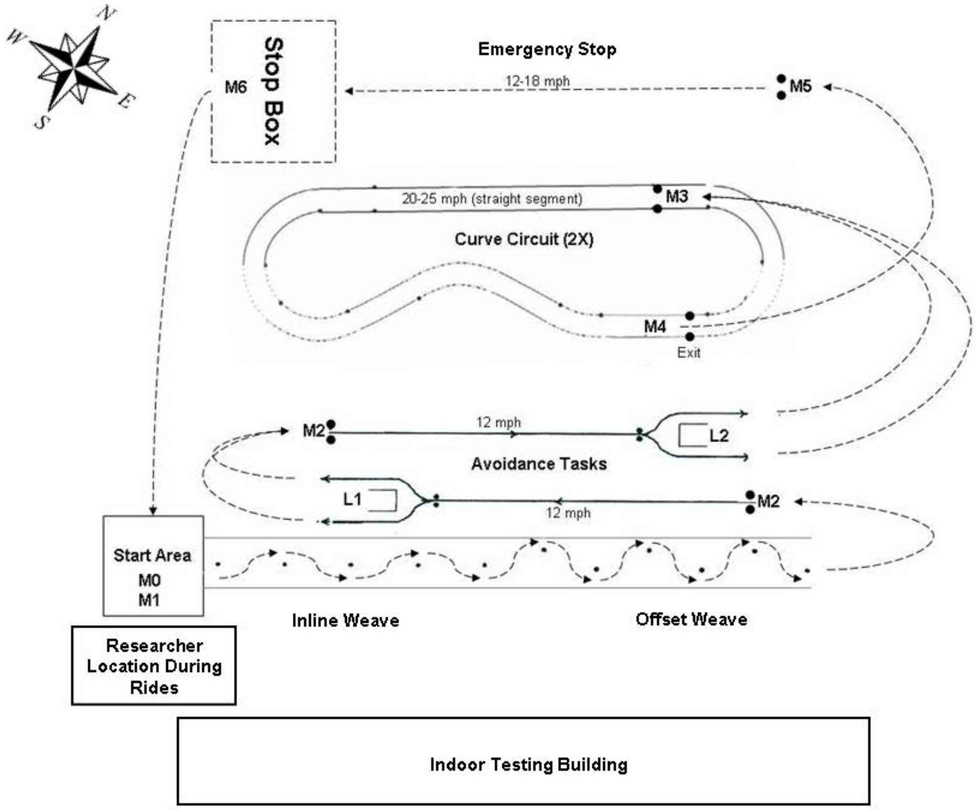

Figure 2. Illustration of motorcycle test course and location of test facilities. Solid lines on course indicate areas of the test track that were painted.

The description of each task scenario is presented in Table 1. All task scenarios required rider attention to control the motorcycle in order to achieve *performance standards* that were stipulated for each task. The ability of the riders to achieve these standards was used as a basis to interpret "impairment." Impairment of motorcycle control was characterized by the deviation of observed riding performance from the standard performance that was specified for each task scenario.

Table 1. Description of course, associated MSF exercise and task goals.

Task Scenario	Skills Tested	MSF Exercise	Description	Performance Standards
Task				
Inline Weave	Balance, control of motorcycle, judgment of safety margin to	BRC #5	80-ft segment with cones 20 ft apart in straight line; painted yellow lines 4 ft from center;	1a. Ride around cones (outside) as closely as possible, but 1b. do not touch cones 2. Stay inside painted yellow lines

	obstacle		leads into offset weave	3. Do not put feet down on course 4. Try to ride using a consistent speed and without braking
Offset Weave	Balance, control of motorcycle, judgment of safety margin	BRC #6	80-ft segment with cones 20 ft apart and offset 8 ft; painted yellow lines 12 ft from center	1a. Ride around cones (outside) as closely as possible, but 1b. do not touch cones 2. Stay inside painted yellow lines 3. Do not put feet down on course 4. Try to ride using a consistent speed and without braking
Avoidance Task (x2) (Swerving)	Appropriate input to initiate swerve, reaction time to hazards, judgment of safety margin to obstacle	BRC #16 and Skills Test (BRC exercises and test are performed without light boxes)	A cone barrier was placed in front of a light box that had a left and right arm with a light; as the participant approached the barrier, either the left or right light would turn on 1.5 s (first pass) or 2.5 s (second pass) from the barrier to indicate direction of travel rider should take	1. Approach cone barrier at 12 mph (5.36 m/s) 2. Respond immediately to light when it comes on by swerving in direction indicated (left or right) 3. Go through escape lane 4. Do not brake while swerving
Curve Circuit	Cornering judgment – including proper entry speed, cornering technique and path of travel	ERC #9	Curved course with 12-foot lane that includes one straight segment; one 210-degree curve, one 60-degree curve, one 30-degree curve and one 180-degree curve. On each lap of the	1. Accelerate to 20-25 mph (8.94-11.18 m/s) in straight segment 2. Slow to appropriate speed to enter first curve (210-degree) 3. Choose a consistent speed in circuit that allows participant to negotiate all curves safely 4. Do not ride outside yellow

			test course, participants completed the circuit twice. While completing the circuit, participants were also required to complete a secondary task to increase overall cognitive demand. Participants heard a random 2-digit number over their headset and decided if the sum of the two digits was odd or even. If the sum was odd, they pressed the horn button (disabled) on the left handlebar. If the sum was even, they pressed the starter button (disabled) on the right handlebar.	lines
Emergency Stop	Reaction time, Stopping technique (vehicle control)	BRC #9, 17 and Skill Test (BRC exercises and test are performed without auditory signal)	Start is marked with 2 green cones; guide cones (2 orange) mark approach; participant achieves constant speed heading towards guide cones; in a designated box (not marked) prior to the end a car horn sounds in the participant's helmet at a random location	1. Accelerate to 12-18 mph (5.36-8.05 m/s) and maintain a consistent speed (Do not anticipate horn by slowing down) 2. Brake as soon as hear car horn. 3a. Brake rapidly, 3b. to come to a complete stop in the shortest possible distance, 3c. while maintaining proper vehicle control.

			inside the box; participant responds to horn sound by stopping motorcycle quickly and safely	

2.3.2 Motorcycle

The test motorcycle was an instrumented 2000 Honda Shadow VT1100 equipped with outriggers and sensor equipment for data collection as shown in Figure 3. This type of motorcycle was chosen for the study because it is a common model and its engine size of 1100 cc is representative of the majority of motorcycles operated in the United States (Shankar, 2005). The outriggers pivoted from the lower frame and used caster wheels with rubber tires. The outrigger was designed to prevent the bike falling on the rider, but does not provide balance or support for the motorcycle. Riders were instructed to ignore the location of the outriggers while riding and to perform tasks only in relation to where the bike is. Note that pilot testing indicated that the outrigger did not interfere with the natural balance of the bike or the control of the rider. The training session also took into account the potential effect of the outriggers on performance. Participants were asked to ignore the outriggers and to ride as they normally would under these conditions, according to the task specifications. Additionally, any potential effect of the outrigger on performance is a within-subject effect and, therefore, does not weaken or confound the alcohol effect. In addition, the motorcycle was equipped with a radio-controlled switch to turn off the motor. This switch could be activated remotely by the observing experimenter using a secure radio channel.

Figure 3. Pictures of the instrumented test motorcycle, a 2000 Honda Shadow VT1100.

2.3.3 Motorcycle Data Acquisition System (MoDAQ)

To measure and record participant and motorcycle movement, a Motorcycle Data Acquisition (MoDAQ) system was developed and installed on the motorcycle. This system consisted of a suite of sensors attached to the participant and control surfaces of the motorcycle to measure steering, brake, and throttle activation (Appendix D). In addition, separate six-axis inertial measurement units (IMUs) were fixed to the participant helmet and the center of the motorcycle frame to measure three axes of acceleration and three axes of rotational rate. Individual data channels were recorded at various rates depending on the instrument (10-125 Hz). Data from all instruments was recorded to an onboard microprocessor with a 200-gigabyte removable hard drive. All sensors and data recording channels were validated and verified prior to commencing the study.

The MoDAQ was also configured for real-time monitoring of the motorcycle location within the digitized test course map using DGPS.[1] This configuration provided location data in each time sample from which to derive performance measures based on lateral (e.g., passing distance to obstacle) and longitudinal (e.g., speed) position. In addition, the location-based data was used to automatically trigger specific sound files that presented test instructions to the participants using helmet-mounted speakers.

All critical components of the MoDAQ were monitored by a watchdog system that wirelessly communicated system status to a remote Panasonic Toughbook laptop operated by the experimenter on the side of the test course. This computer contained software to control the recording of data and diagnosing of system status.

2.3.4 Breathalyzer

The Draeger Alcotest 7410Plus is a portable breathalyzer system using a heat- and temperature-controlled electrochemical fuel cell that is certified for U.S. Department of Transportation alcohol testing. This unit measures breath alcohol concentration (BrAC) and converts it to blood alcohol concentration (BAC) using a 1:2,100 BrAC-to-BAC partition coefficient. The breathalyzer was calibrated by the manufacturer just prior to commencing the study to ensure accurate performance. The accuracy of the unit was also verified by the research staff periodically during the study using the air blank test provided by the manufacturer.

[1] The GPS antenna was mounted on a post on the back of the bike (see Figure 3). This caused lateral position estimates based on GPS data to be displaced depending on the lean angle of the bike. To correct for this displacement error, the lean angle was computed through integration of the IMU roll angle rate, and used to correct the measured GPS location to the actual location of where the rear tire touches the ground.

2.4 Study Design

2.4.1 Independent Variables

This study examined the effect of four BAC conditions ranging from sober up to the per se legal limit of .08 (.00, .02, .05, and .08). Each participant was tested in three of these BAC conditions on three separate days. On each test day, participants completed two successive laps of the test course (see Figure 2). Thus, this study included independent variables for the effects of BAC, DAY, and LAP.

With each subject experiencing a different BAC condition on successive days, it is possible that DAY could represent learning effects that could confound the BAC effect. For example, it is possible that the participants could become more competent on the test course over time. In this case, the DAY effect would confound the BAC effect if the BAC conditions were assigned in a sequential order across days. To remove this potential confound, the study used a balanced incomplete block design to randomize BAC condition across DAY (and participants). With this design, each participant experienced only three of the four designated BAC conditions *in an orthogonal counter-balanced order* as demonstrated in Table 2.[2]

Table 2. Balanced incomplete block design. Participants were assigned randomly to one of four alcohol presentation orders to be completed on three separate days.

	Order			
Day	**1**	**2**	**3**	**4**
1	.00	.02	.05	.08
2	.02	.05	.08	.00
3	.05	.08	.00	.02

2.4.2 Dependent Variables

2.4.2.1 Subjective Effort

The NASA Raw Task Load Index (NASA RTLX; Hart & Staveland, 1988) was used to measure subjective perceptions of workload while riding the test course (Appendix F). Sources of workload were expected to be physical effort to control the motorcycle and division of attention to the various stimuli in the test environment. The NASA RTLX is comprised of six subjective workload subscales: mental demand, physical demand, temporal demand (time pressure), performance, effort, and frustration. Higher scores on these subscales indicate increased perceptions of workload.

[2] By reducing the number of test days per participant to three, this incomplete design also reduced the probability of attrition while retaining 90 percent of the statistical efficiency of a complete design (in which all participants get all four BAC levels counter-balanced across four separate days).

2.4.2.2 *Subjective Impairment*

To measure subjective impairment, a "Riding Capability Questionnaire" (adapted from Rakauskas, Ward, Bernat, Cadwallader, & de Waard, 2005) was used to measure perceived levels of intoxication, performance impairment, and willingness to ride (Appendix G). This questionnaire consisted of two questions that assessed perceived intoxication and perceived impairment of riding performance. Three additional questions asked participants to indicate how willing they would be to ride for different trip purposes based on how they felt at the moment.

2.4.2.3 *Motorcycle Riding Performance Measures*

For each task scenario in the test course, Table 3 defines the dependent measures used to assess motorcycle control and the expected characterization of impairment. These measures were selected to assess specific rider skills in relation to the stipulated performance standards for each task (Table 1). Consequently, the characterizations of impairment for these control skills are framed in relation to deviation from the performance standards assigned to each task scenario. The expected alcohol effects assume that the priority for the riders is to protect stability to avoid loosing balance of the motorcycle.

Table 3. Dependent variables for each task scenario and the expected characterization of impairment based on task scenario performance standards (see Table 1).

Task Scenario	Dependent Variable (# Performance Standard)	Definition	Expected Alcohol Effects (Impairment Characteristic)
Weave (Inline / Offset)	1a. Minimum Passing Distance between Motorcycle and Pylons	Measure of the minimum distance of motorcycle to the pylons (correct passes only). The unit of measurement is meters (m).	It is expected that riders will try and avoid large destabilizing steering actions in order to protect stability. As a result, they will pass closer to the cones to minimize steering action.
	1b. Missed or Hit Pylons	Count of pylons missed (wrong side) or hit by motorcycle. The unit of measurement is count data.	The strategy to pass near the cones to minimize steering actions (protect stability) will result in more missed or hit pylons since this strategy is more sensitive to error.
	2. Number of times exceed painted lane lines	Measure of how frequently participants ride outside the painted lines of the weave. The unit of measurement is count data.	The emphasis on passing close to the pylons to minimize steering would result in fewer violations of lane boundaries. The exception would be a strategy to successfully pass

			the pylons by making wide turns that may deviate to a lane boundary violation.
	3. Number of times feet leave pedals	Measure of how frequently participant put their feet down on this part of the course.	Riders at higher BACs will put their feet down more often in this weave due to the difficulty of navigating the offset weave. If riders protect stability, they will try to avoid this at the expense of missing a few cones.
	4. Measure of speed consistency	Measure of the standard deviation of speed in this part of the course.	Riders at higher BACs will show more variability in their speed as they try to control the motorcycle through the course. This is especially expected if their initially chosen speed is too high. (Note: they are limited in reducing their speed because it would destabilize the bike too much).
Hazard Avoidance (Near / Far)	1. Mean Speed at Light Ignition	Measure of the mean speed of participants when the light box is triggered. The unit of measurement is meters per second (m/s). Include 95th Confidence Intervals (CI) to determine if means speed within specified target range of 12 mph.	Riders at higher BACs may not achieve the target speed if they have more trouble controlling their speed while riding. (Note: if the task is too demanding to maintain speed by looking at the speedometer, then it is expected that speed maintenance deteriorates).
	2. Reaction Time & Direction Choice	Measure of the elapsed time from the onset of the direction light signal to the start of the lateral swerve of the motorcycle path. The unit of measurement is seconds (s). Choice of direction is correct or incorrect.	Riders should have slower reaction times to the light at higher BACs as information processing is slowed. Participants at higher BACs may anticipate incorrectly and swerve in the wrong direction.
	3. Passing Distance to Obstacle	Measure of the passing distance between the motorcycle and the	Riders at higher BACs may pass closer to the obstacle during the avoidance

		obstacle that defined the hazard. The unit of measurement is meters (m).	maneuver due to reduce response time to the light and reluctance to steer strongly (in order to protect stability).
Curve Circuit	1. Maximum Speed (Straight Section)	Measure of maximum speed calculated over both entire circuits (completed twice on each lap of the test course). The maximum speeds occurred during the straight section of the circuit. The unit of measurement is meters per second (m/s). Larger values indicate a faster speed – suggesting a more aggressive speed choice (less perceived risk).	Faster speeds on straight sections with alcohol were expected based on previous research that has demonstrated increased speeding with alcohol while driving (Moskowitz et al., 2000) and riding a motorcycle (Compton et al., 1993).
	2. Minimum Speed (Curve Sections)	Measure of minimum speed calculated over both entire circuits (completed twice on each lap of the test course). The minimum speeds occurred during the curve sections of the circuit. The unit of measurement is meters per second (m/s).	Faster speeds on curves with alcohol were expected based on previous research that has demonstrated increased speeding with alcohol while driving (Moskowitz et al., 2000) and riding a motorcycle (Compton et al., 1993).
	3. Standard Deviation of Speed in the Circuit	Measure of variability of speed throughout the circuit. Measured in meters per second (m/s).	Riders at higher BACs should show larger variation in speed since they are forced to adjust speed more often from the higher initial speeds to maintain control in the circuit.
	4. Number of Times Exceed Painted Lane Lines	Measure of the number of times participants went outside the lane boundaries of the	Riders at higher BACs may exit the lane boundaries due to increased speed and incorrect adoption of correct speeds in the curves.

		curve circuit. The unit of measurement is count data.	
Emergency Stop	1. Speed at Horn Trigger	Measure of speed at the point the horn sound was triggered to signify the emergency stop. The unit of measurement is meters per second (m/s). Include 95th Confidence Intervals (CI) to determine if means speed within specified target range of 12-18 mph.	Riders at higher BACs may not achieve the target speed if they have more trouble controlling their speed while riding.
	2. Reaction Time to Horn	Measure of the elapsed time from the onset of the horn signal to the activation of the brakes. The unit of measurement is seconds (s).	Participants at higher BACs may have longer reaction times due to the slowing of information processing.
	3a. Elapsed Time to Maximum Deceleration	Measure of the elapsed time from the onset of the horn signal to maximum deceleration rate during the emergency stop. The unit of measurement is seconds (s).	Riders at higher BACs may reach maximum deceleration sooner in an attempt to compensate for reductions in reaction time.
	3b. Stopping Distance	Measure of the distance traveled from the onset of the horn that triggered to emergency stop until the motorcycle speed reached a small value above noise of 0.5 m/s. The unit of measurement is meters (m).	Riders at higher BACs may require a longer distance to stop due to the slower reaction time.
	3c. Deviation of Motorcycle Along Stopping Path	Measure of participants' control of the motorcycle once	Riders at higher BACs may have more difficulty controlling the motorcycle

		stop is initiated. The unit of measurement is meters (m).	and keeping the stopping path along a straight line due to the higher deceleration.

2.5 Procedure

2.5.1 Participant Consent

Participants selected from the recruitment and screening phase were contacted by mail or e-mail with an introduction letter and participation schedule. Participants were instructed not to eat for at least four hours prior to their participation in the study and to abstain from alcohol or any medications for 24 hours prior to the test days. Participants were scheduled to participate on three separate test days (with one to seven intervening days between scheduled test days). All participants completed their three test days within a three-week period.

Each participant was assigned one of four different alcohol levels on each test day based on their random assignment to a counterbalanced BAC condition order (see Table 2). Upon arrival at the test track, participants completed the informed consent process (approved by the both Institutional Review Boards of the University of Minnesota and Saint Cloud State University). This consent process required participants to receive a ride home and abstain from driving for 12 hours at the end of the test day. Participants who consented to participate reviewed and initialed their answers to the phone screening questionnaires to indicate that the information collected was correct. Participants then provided a pre-test breath sample to verify the absence of alcohol before commencing. While riding the motorcycle, all participants were required to wear full safety gear (provided) and an ambulance crew was on site during the test rides.

2.5.2 Training Session

Once participants completed the informed consent process, they received structured training for the motorcycle and test course. The goal of training was for riders to become familiar with the motorcycle and test course in order to extinguish learning effects as evidenced by a performance plateau. The performance plateau was defined as error-free performance on the course during the training phase. Error-free (asymptotic) performance consisted of completing all riding tasks on the course according to the instructions, including maintaining the prescribed speeds and completing sections smoothly and without running over course cones or leaving the test course. The researchers determined error-free performance by observing the behavior of the rider on the course and by questioning the rider upon completion of the course about course instructions. Thus, the determination of asymptotic performance was subjective, but based on expert judgment. Notably, a certified MSF Rider Coach (and member of the

Minnesota Motorcycle Safety Center) trained researchers to observe correct behavior on the course and judge asymptotic performance.

In the practice session of the first test day, the motorcycle and helmet headset were explained to participants before they began practicing. Participants then completed a walkthrough of the course with the researcher who explained the instructions for each riding task (see Table 4). Next, participants completed three practice rides that required them to stop at the beginning of each new task on the course and listen to the recorded instructions that were automatically communicated over a speaker headset in the helmet (see Table 4). Participants were provided verbal feedback at the end of each practice ride regarding their performance to ensure adherence to task instructions. The researcher used a checklist to discuss key points of the course with the rider after each practice ride to encourage asymptotic performance (Appendix E). Once the instructed practice rides were complete and participants were comfortable with each task, they rode an additional three practice rides without instructions and without stopping at the beginning of each task. However, the researcher still provided verbal feedback regarding correct performance after each of these three rides. Thereafter, participants were required to complete additional practice rides until error free performance was demonstrated. A minimum of six practice rides were scheduled for each participant and the majority of participants demonstrated error free performance in this period.

Table 4. Walkthrough and audio instructions for course training and practice.

Task	Course Walkthrough Instructions	Audio Instructions (over headset; see Figure 2 for location of message presentation)
Ready to Ride	• Included M0. • Researcher explained that rider should wait after pressing the horn button until instruction M1 occurs.	M0: Get ready to ride the test course. When you and the bike are ready, hit the horn button once.
Inline/Offset Weave	• Included M1. • Researcher explained that rider should stay as close to the cones as possible without hitting them; to keep motorcycle inside yellow lines (outrigger position does not matter). • Researcher answered any questions rider had	M1: When you are ready, weave around the cones, starting on the right side of the first cone. Slow at the end and make a left turn, staying inside the perimeter.
Avoidance Tasks (near / far)	• Included M2. • Researcher explained that rider should concentrate on maintaining 12 mph until	M2: Line up bike path between cones and approach barrier at around 12 mph. Maintain steady speed. Respond immediately to the light signal

	seeing the light and to ride on the painted white line towards the obstacle. • Researcher emphasized responding immediately and turning in correct direction. • Researcher emphasized rider not to brake during the maneuver. • Researcher pointed out boundaries of right/left escape lanes and that rider should go through appropriate lane. • Researcher answered any questions rider had.	by swerving in the direction indicated. Do not brake while swerving.
Curve Circuit	• Included M3 and M4. • Researcher explained speed for straight segment and told rider to slow appropriately to take first curve. • Researcher explained that rider should choose a consistent/steady speed throughout remainder of course that allows proper cornering techniques. • Researcher emphasized staying inside yellow lines (outrigger position does not matter). • Researcher answered any questions rider had.	M3: Ride the circuit in a counter clockwise direction until instructed to exit. Stay within the lane boundaries. Increase speed in long straightaway between 20 and 25 miles per hour. Slow to a suitable entry speed before each curve. Maintain a slow, steady speed in curve and use proper cornering techniques. M4: Exit the circuit and turn left.
Emergency Stop	• Included M6 and M7. • Researcher emphasized that rider should reach at least 12 mph and not exceed 18 mph on approach to target zone. • Researcher emphasized importance of responding immediately to car horn. • Researcher emphasized importance of stopping quickly <u>and</u> safely in shortest distance possible. • Researcher instructed rider to ensure they came to a full stop and to wait until final instruction (M7) was played before returning to start box.	M6: Line up the bike between the far pair of cones. Accelerate quickly to a speed between 12-18 miles per hour. Maintain a steady speed. When you hear a car horn sound, safely stop in the shortest distance possible. Shift into first gear during the stop if you need to. Do not anticipate the horn by slowing or applying the brakes before you hear the sound. Once stopped, do not move until instructed to do so. M7: Turn left and ride outside the course to return to the start position.

On subsequent test days, participants were also provided with three "refresher" practice rides. These refresher rides were used to ensure that the participants remained comfortable with the motorcycle and remembered the course instructions (demonstrated by error-free performance).

After completing the practice rides with error-free performance, participants completed two additional rides of the test course while sober. These *baseline trials* were used in the analysis of the data as a covariate to adjust BAC data.

2.5.3 Alcohol Administration

The determination of alcohol dose for a BACcondition was based on the Blood Alcohol Level calculator created by Curtin (2000). This dose calculator is based on the formula by Watson (1989) that estimates total body water based on participant height, weight, age, and gender to determine how much alcohol is required to reach a desired BAC.[3] Using this calculation, the participant was expected to peak at the target BAC approximately 30 minutes after they started drinking their beverages. Beverages were mixed using an approximate 6:1 juice-to-alcohol ratio and divided into two glasses and participants were blinded to the amount of alcohol they were receiving each day. The placebo beverage (BAC .00) was misted with alcohol and the volumes of all beverages were calculated to appear similar in all BAC conditions. The main goal of the placebo was to mask the BAC .00 condition and to make participants think they were receiving some level of alcohol in every trial. Participants were observed during the 10 minute period in which they were instructed to consume the beverage at a regular pace. Participants consumed their beverages and interacted in a group recreational setting to facilitate the social aspects that influence the effects of recreational drugs such as alcohol (Smiley, Noy, & Tostowaryk, 1987; Ward & Dye, 1998). Participants were breathalyzed 10 and 20 minutes after they finished consuming the beverage.

A participant was considered to have peaked at a BAC if at least 30 minutes had passed since they began drinking and their BAC was within the BAC range for the assigned condition (see Table 5). If a participant was below the target BAC range after 30 minutes from when drinking began, breath samples were tested at 5-minute intervals until they reached the target BAC range. Based on the dosing procedure, all participants were within the BAC condition ranges within 50 minutes after completing drinking. Most participants were estimated to be on the ascending phase of the alcohol absorption curve while operating the motorcycle on the test course. A final breath test was conducted at the end of the entire testing session to identify whether participants remained within the assigned

[3] The exact calculations used in the calculator by Curtin can be found at http://dionysus.psych.wisc.edu/Methods%5Calcohol%5CDoseCalculation.htm.

BAC condition throughout testing (see Table 5). On average, participants remained within the specified BAC ranges for the duration of the testing sessions.

Table 5. Target BACs, Acceptable BAC Ranges, and Actual Means and Standard Deviations achieved for each level.

Target BAC	Acceptable BAC Ranges	Pre-Ride Mean (SD)	Post-Test Mean (SD)
.02	.01-.03	.025 (.007)	.013 (.008)
.05	.04-.06	.052 (.006)	.046 (.009)
.08	.07-.09	.080 (.007)	.079 (.009)

2.5.4 Test Trials

After completing the practice rides and the baseline trials, participants then completed two laps of the test course in the assigned BAC condition. Over the study period, this regime produced a total of 6 *test trials* for each participant.

2.5.5 Post-Test Questionnaires and Tasks

Once participants had completed their test trials, they were taken inside the testing building (see Figure 2) for the administration of the subjective questionnaires (see Section 2.4.2.1, 2.4.2.2). Table 6 shows the subjective measure questions and the expected alcohol effects.

Table 6. Expected effect of alcohol on answers to the subjective questionnaires.

Subjective Measure	Question	Expected Alcohol Effects
NASA RTLX	**Mental Demand:** How much thinking, deciding, calculating, remembering, looking, searching did you need to do?	Participants at higher BACs may report that more mental demand was required to attend to the tasks and remember task requirements due to impairment.
	Physical Demand: How much physical activity was required?	Participants at higher BACs may feel physically less able to ride the motorcycle and may report that more physical effort was required to complete the course due to the physical sensations that accompany impairment (e.g., nausea, dizziness).
	Time Pressure: How much time pressure did you feel due to the pace of the tasks?	Participants at higher BACs may report feeling less able to make rapid responses in the tasks requiring a quick decision in response to stimulus because alcohol impairs complex reaction time.
	Performance: How successful do you think you were in accomplishing the goals of the tasks set by the experimenter?	Participants at higher BACs may report that their performance was not as good, particularly if they report feeling impaired.

	Effort: How hard did you have to work mentally and physically to accomplish your level of performance?	Participants at higher BACs may report more effort was required to complete tasks and compensate for any impairment effects they report feeling.
	Frustration Level: How insecure, discouraged, irritated, stressed and annoyed during the task?	Participants at higher BACs may report more frustration with the tasks because of impairment effects.
Riding Capability	How intoxicated do you feel at this moment?	Participants at higher BACs should report higher levels of perceived intoxication compared to the BAC .00 and .02 conditions.
	How impaired do you feel your performance would be riding a motorcycle right now?	Participants at higher BACs may report poorer perceived performance, particularly if they report feeling more impaired at higher levels.
	How willing would you be to operate a motorcycle right now for an unimportant though gratifying reason (e.g., ride to a party)?	Given the self-awareness of intoxication and impairment, participants at higher BACs may report that they would not be willing to ride for an unimportant reason if they report feeling intoxicated and having impaired performance.
	How willing would you be to operate a motorcycle right now for an important, but avoidable reason (e.g., give a friend a ride home who feels mildly ill, when they could get a taxi)?	Given the self-awareness of intoxication and impairment, participants at higher BACs may report that they would not be willing to ride for an important reason if they report feeling intoxicated and having impaired performance.
	How willing would you be to operate a motorcycle right now for an urgent purpose (e.g., ride to a hospital to help a sick relative who has no one else to contact)?	Given the self-awareness of intoxication and impairment, participants at higher BACs may report that they would not be willing to ride for an unimportant reason if they report feeling intoxicated and having impaired performance.

3 RESULTS

The motorcycle riding performance measures were analyzed using an analysis of covariance (ANCOVA, using MACANOVA v5.05) to fit a model to test the main effect of BAC condition. Terms for the PARTICIPANT, DAY and LAP variables were also included in the model. Baseline riding performance in the sober trials, and number of years of riding experience were used as covariates in the model to statistically control for rider skill level. The number of reported drinks per week was also included as a covariate to statistically control for experience with alcohol impairment. Age was not included as a covariate as it was highly correlated with riding experience ($r=0.88$, $p<0.0001$).

The randomization scheme for BAC condition assignment across day and participant (see Table 2) eliminated confounds between the learning effects across test days and the order of BAC exposure. However, the separate day and lap terms were included in this model to explicitly test for non-confounded learning effects. The participant variable accounts for the between-subject variability within the BACs. The main interest for this study was the effect of alcohol represented by the fitted BAC term. The effects of covariates (baseline performance, drinks/week, years riding experience) in the analysis model are shown in Appendix I only for significant variables.

A similar fixed-effect ANCOVA model (Youden-Square) was fitted for the subjective response data with the exclusion of baseline performance and the lap term that was not applicable for these measures.

For all dependent measures, two sets of post-hoc tests (Tukey HSD Test) were completed in response to a significant BAC effect in the ANCOVA model:

- General Alcohol Effect: The BAC .00 condition was compared to the alcohol conditions (BAC .02, .05, .08) to identify the lowest level of alcohol that significantly affected participants ($p < .05$).
- Equivalent Alcohol Effect: The BAC .08 condition was compared to all other alcohol conditions (.02, .05) to examine the generalization of alcohol effects ($p < .05$).

For each analysis, model residuals were plotted and examined for homogeneity of variance and normality. Appropriate data transformations were applied as necessary. For each significant ANCOVA model, the (non-transformed) means for the BAC condition were graphed after adjusting for the effects of the included covariates. The graphs also include the percent change in a measure for each alcohol level compared to BAC .00 condition.

3.1 Motorcycle Riding Performance

3.1.1 Data Preparation

All sensor data channels were processed within specified regions of the digital map that defined the test course (Appendix H). Data preparation comprised the inspection for aberrant signals prior to computing the dependent measures. First, spurious spikes in the data channel signals were removed automatically using a spurious data sample detector. This detector replaced the spurious samples with interpolated values from correct samples in adjacent time sample windows. This data interpolation was completed at 50Hz.

In addition, other forms of signal noise were removed from the data signals using a non-causal 2^{nd} order Butterworth filter with a low pass cutoff frequency of 1Hz. This filter frequency is above the frequencies observed in the rider action and bike movement data such that no meaningful information in the data sets was removed. A non-causal filter was used to assure that the filter would introduce no artificial lag since that could affect reaction time estimations.

3.1.2 Missing Data Substitution

Each data collection trial for every dependent measure was examined for missing values and extreme outliers. In the case of detected outliers, the raw data signals were examined to determine if the outlier case represented spurious data or an unusual riding event. Such outliers were then treated as missing values for that case. Overall, the amount of missing data was low with less than 1.4 percent of the trials resulting in missing data.

A procedure was devised to replace missing values with a valid *substitute value*, because the BIBD requires dependent measure values to be present in each experimental cell. A sequential missing value replacement procedure was applied separately to the baseline and test trials as shown in Table 7. With this procedure, the baseline trials comprised the two post-training laps completed by each participant without alcohol on each of the three test days (totaling six baseline trials). The test trials comprised the two laps completed by each participant in the three assigned BAC conditions (totaling six test trials).

Table 7. Missing data substitution procedure for baseline and test trials.

	Trial	
Data Availability	**Baseline Trials**	**Test Trials**
Both laps on test day are valid	No substitution	No substitution
One lap on test day missing	Substitute valid lap value	Substitute valid lap value
Both laps on test day missing	Substitute with median value across all valid trials for same participant.	Substitute with median value across all participant trials at same BAC.

3.1.3 Inline Weave Task

The inline weave task assessed riding performance in terms of motorcycle control and balance along a simple path. This task also assessed judgment of safety margins with respect to the obstacles.

1a. Minimum Passing Distance Between Motorcycle and Pylons

There was no significant effect of BAC condition on the minimum passing distance between the motorcycle and the pylons for the inline weave task.

1b. Missed or Hit Pylons

No pylons were missed or hit in the inline weave task.

2. Number of Times Lane Boundaries Crossed

None of the subjects rode outside the lane boundaries for the inline weave task.

3. Number of Times Feet Leave Pegs

There was no significant effect of BAC condition on the number of times participants' took their feet off the pegs during the inline weave task.

4. Standard Deviation of Speed

There was no significant effect of BAC condition on the standard deviation of speed for the inline weave task.

3.1.4 Offset Weave Task

The offset weave task assessed riding performance in terms of motorcycle control and balance along a path. This task also assessed judgment of safety margins with respect to the obstacles.

1a. Minimum Passing Distance Between Motorcycle and Pylons

There was a significant main effect of BAC condition for the (baseline-adjusted) **minimum distance** of the motorcycle path from the *correctly passed* pylons in the offset weave task [$F(3,112) = 5.39$, $p=0.002$]. As shown in Figure 4, post-hoc tests (Tukey HSD) indicated that the participants in the BAC .08 condition rode the motorcycle significantly closer when correctly passing the pylons compared to the BAC .00 condition. On average, participants in the BAC .08 condition rode .08 m (8 cm) closer to the pylons than participants in the BAC .00 condition. On average, participants in the BAC .08 condition also rode significantly closer to the pylons when compared to the BAC .02 condition.

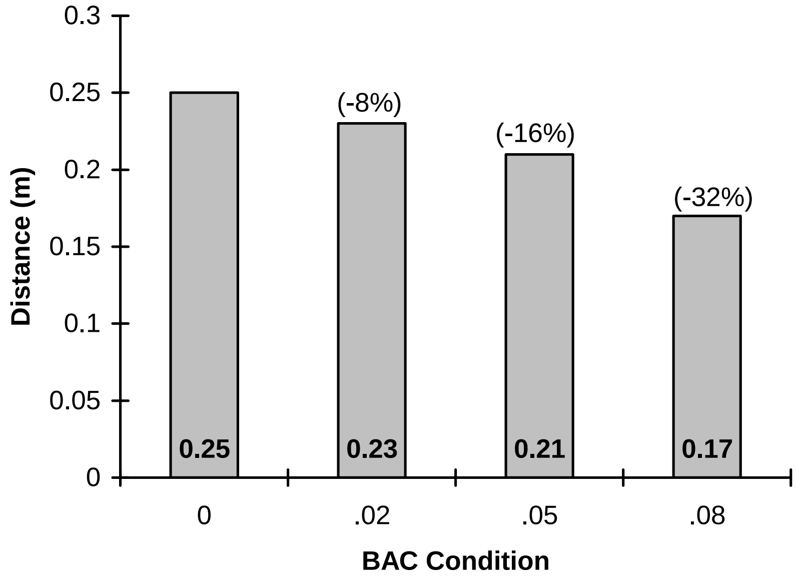

Figure 4. Effect of BAC condition on minimum pylon passing distance in the offset weave task. Note: Group means are displayed in bold at the base of the bars. The values in (brackets) indicate the percent change between BAC .00 and the indicated BAC.

1b. Missed or Hit Pylons

Figure 5 presents the total number of pylons missed (or hit) by all participants in each condition (based on two laps of the test course). Although the count data is too small to support inferential statistics, the largest number of missed or hit pylons occurred in the BAC .08 condition.

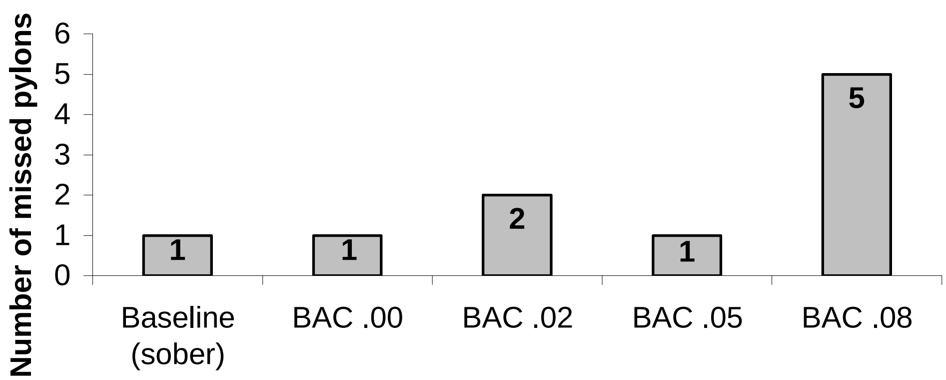

Figure 5. Total Number of Missed or Hit Pylons in each Trial (based on two laps in each condition).[4]

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[4] Only one participant missed a pylon on more than one BAC. Two participants missed pylons during both sober and BAC trials.

2. Number of Times Lane Boundaries Crossed

Only one subject rode outside the lane boundaries for the offset weave task.

3. Number of Times Feet Leave Pegs

There was no significant effect of BAC condition on the number of times participants' took their feet off the pegs in the offset weave task.

4. Standard Deviation of Speed

There was no significant effect of BAC condition on the standard deviation of speed for the offset weave task.

3.1.5 Hazard Avoidance Task (1.5 s TTC)

The first hazard avoidance task assessed riding performance in terms of the speed of the participant's decision to initiate and accurately control a swerve to avoid a "near" obstacle. This task also assessed judgment of safety margins with respect to the obstacles.

1. Mean Speed

There was no significant main effect of BAC condition on mean speed at light box ignition for the first hazard avoidance task. As shown in Figure 6, the 95th percentile confidence intervals (CI) indicate that the average speed within each BAC condition was consistent with the instructed target of riding at 12 mph (5.36 m/s).

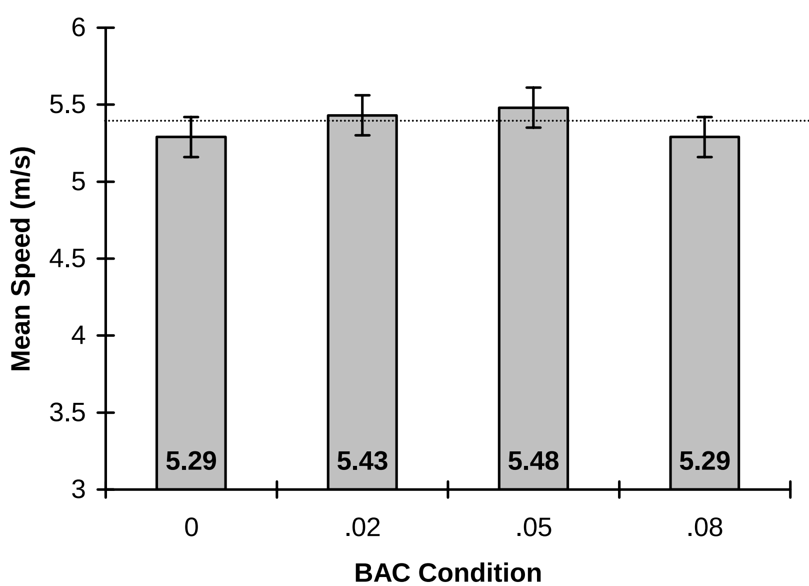

Figure 6. Effect of BAC condition on mean speed on approach to the light box, including 95 percent Confidence Intervals. Note: Range for 95th Percentile confidence interval are represented at the top of the bar graphs and the overlaid dashed line represents the performance standard speed (instructed speed).

2. Reaction Time

There was a marginally significant main effect of BAC condition for **reaction time** in the near-distance hazard avoidance task [$F(3,112) = 2.62, p=0.055$]. As shown in Figure 7, post-hoc tests (Tukey HSD) indicated that the participants in the BAC .05 and BAC .08 conditions reacted significantly slower compared to the BAC .00 condition. On average, reaction times in the BAC .08 and .05 conditions were 50 ms slower than in the BAC .00 and .02 conditions. Additionally, the overall number of direction errors (whereby riders failed to turn in the correct direction indicated by the light box) in <u>both</u> hazard avoidance tasks was highest for the BAC .08 condition (Table 8).

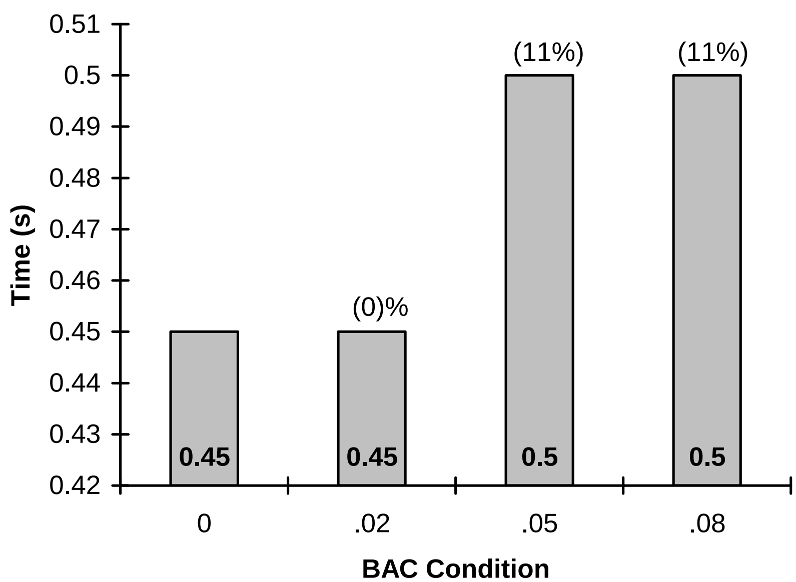

Figure 7. Effect of BAC condition on reaction time in the near-distance (1.5 s) hazard avoidance task.

Table 8. Number of direction errors for both hazard avoidance tasks (1.5 s and 2.5 s TTC).

BAC Condition	Number of Direction Errors
.00	1
.02	2
.05	1
.08	6

3. Passing Distance to Obstacle

There was no significant effect of BAC condition on the distance of the motorcycle from the obstacle for the near-distance hazard avoidance task.

4. Braking Events

No participants initiated braking during this hazard avoidance task.

3.1.6 Hazard Avoidance Task (2.5 s TTC)

The second hazard avoidance task assessed riding performance in terms of the speed of the participant's decision to initiate and accurately control a swerve to avoid a "far" obstacle. This task also assessed judgment of safety margins with respect to the obstacles.

1. Mean Speed

There was no significant main effect of BAC condition on mean speed at light box ignition for the far hazard avoidance task. As shown in Figure 8, the 95th percentile confidence intervals indicate that the average speed within each BAC condition was consistent with the instructed target of riding at 12 mph (5.36 m/s).

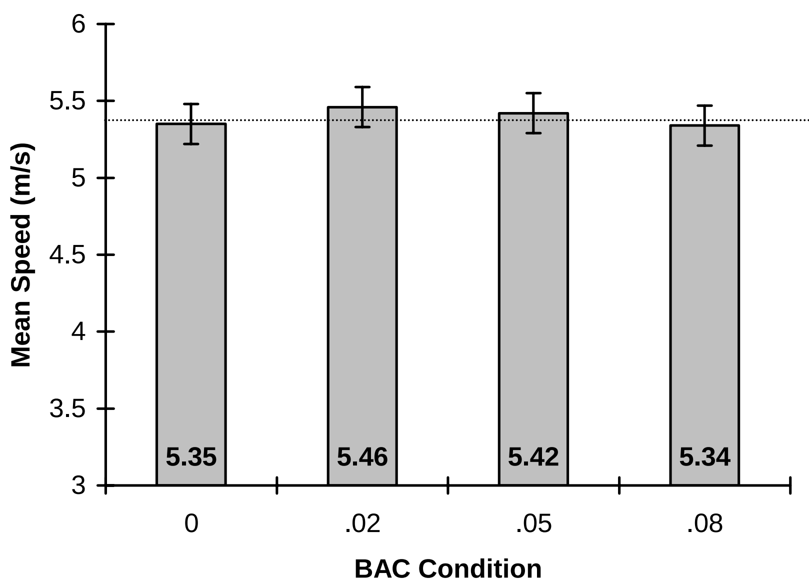

Figure 8. Effect of BAC condition on mean speed on approach to the light box.

2. Reaction Time

There was no significant effect of BAC condition on reaction time for the far swerve decision task.

3. Passing Distance to Obstacle

There was a significant main effect of BAC condition for the **passing distance to obstacle** in the far-distance hazard avoidance task [$F(3,112) = 2.99$, $p=0.03$]. As shown in Figure 9, the trend was for participants in the BAC .05 and .08 conditions to pass significantly closer to the obstacle compared to the BAC .00 condition. The distance to the object for the BAC .08 condition was significantly closer than in the BAC .02 condition (Tukey HSD). Additionally, Table 8 shows the number of incorrect turn maneuvers that occurred in both hazard avoidance tasks.

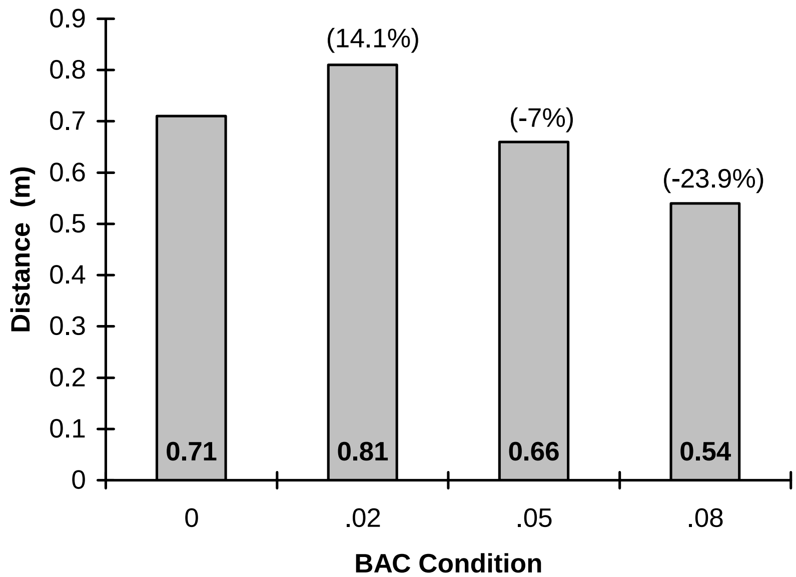

Figure 9. Effect of BAC condition on distance from obstacle in the far-distance (2.5 s TTC) hazard avoidance task.

4. Braking Events

No participants initiated braking during this hazard avoidance task.

3.1.7 Curve Circuit Task

The curve circuit task assesses riding performance related to proper entry into curves, speed control, cornering technique and path of travel as these relate to safely negotiating curves.

1. Maximum Speed (circuit straight section)

There was a significant main effect of BAC condition for the **maximum speed** in the circuit task [$F(3,109) = 8.49$, $p < 0.0001$].[5] Maximum speed was usually reached on the straight sections of the circuit. As shown in Figure 10, participants in all alcohol conditions (BAC .02, .05 and .08) tended to have faster maximum speeds in the circuit compared to the BAC .00 condition. Overall, the maximum speeds in the BAC .02, BAC .05, and BAC .08 conditions were 0.52 m/s (1.87 km/h), 0.78 m/s (2.81 km/h), and 0.68 m/s (2.45 km/h) faster, respectively, than

[5] There was a significant main effect of BAC condition for **mean speed** over the entire circuit task [$F(3,112) = 5.97$, $p=0.001$]. Post-hoc tests (Tukey HSD) indicated that participants in the BAC .08 condition rode faster on average in the circuit compared to the BAC .00 condition. On average, the mean speed in the BAC .08 conditions was 0.324 km/h faster than in the BAC .00 condition. On average, the mean speed in the BAC .05 condition was significantly faster than in the BAC .02 condition and the BAC .08 condition was also significantly faster than the BAC .05 condition.

in the BAC .00 condition. The maximum speed in the BAC .05 condition was statistically significantly faster than in the BAC .02 condition.

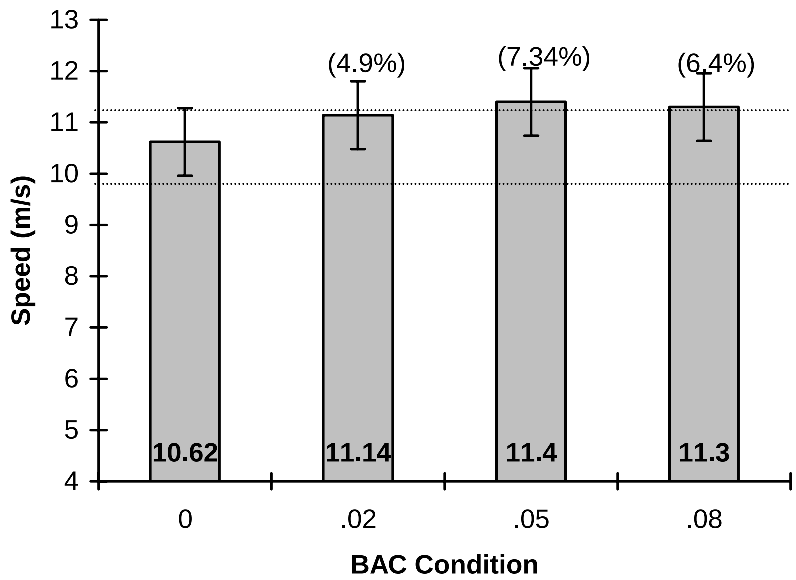

Figure 10. Effect of BAC condition on maximum speed (in the straight sections) of the circuit task.

2. Minimum Speed (curve sections)

There was no significant effect of BAC condition on minimum speed. Minimum speed was usually reached on the curve sections of the circuit.

3. Standard Deviation of Speed in the Circuit

There was a significant main effect of BAC condition for the **standard deviation of speed** in the circuit [$F(3,112) = 4.32$, $p=0.006$]. As shown in Figure 11, there was a trend towards increased variability in speed throughout the circuit for all the BAC conditions (.02, .05, .08).

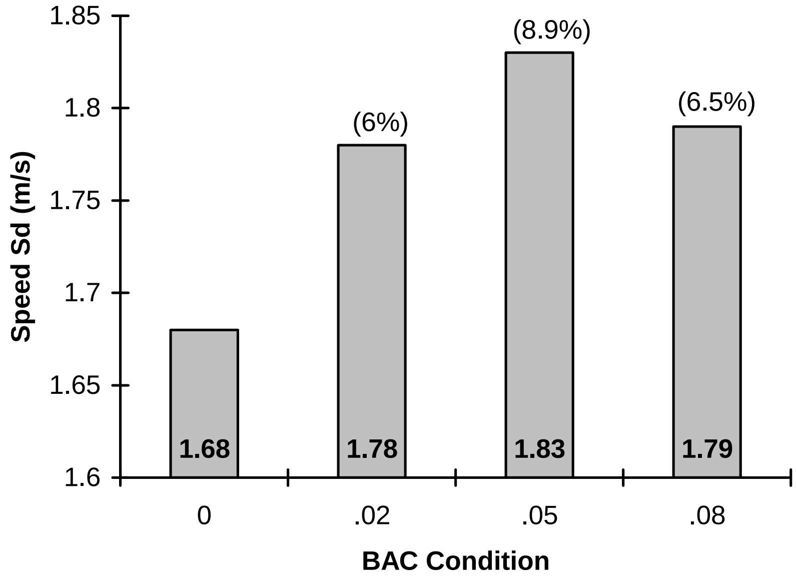

Figure 11. Effect of BAC condition on standard deviation of speed in the curve circuit task.

4. Number of Times Lane Boundaries Were Crossed

There was a significant main effect of BAC condition for the **total number of times participants went outside the yellow lane boundaries** in the curve circuit [$F(3,112) = 4.25$, $p=0.007$].[6] As shown in Figure 12, post-hoc tests (Tukey HSD) indicated that participants in the BAC .08 condition went outside the curve circuit lane boundaries more frequently than did participants in the BAC .00, .02 and .05 conditions. On average, participants in the BAC .08 condition had a higher average number of lane crossings than participants in the BAC .00 condition.

[6] There was also a significant main effect of BAC condition for the **standard deviation of the lateral position** of the motorcycle along the marked path in the circuit task [$F(3,112) = 5.45$, $p=0.002$]. Post-hoc tests indicated that the BAC .08 condition tended to show the largest variability in lane position within the circuit. The standard deviation of lateral position in the BAC .08 condition was significantly larger than in the BAC .02 condition (Tukey HSD).

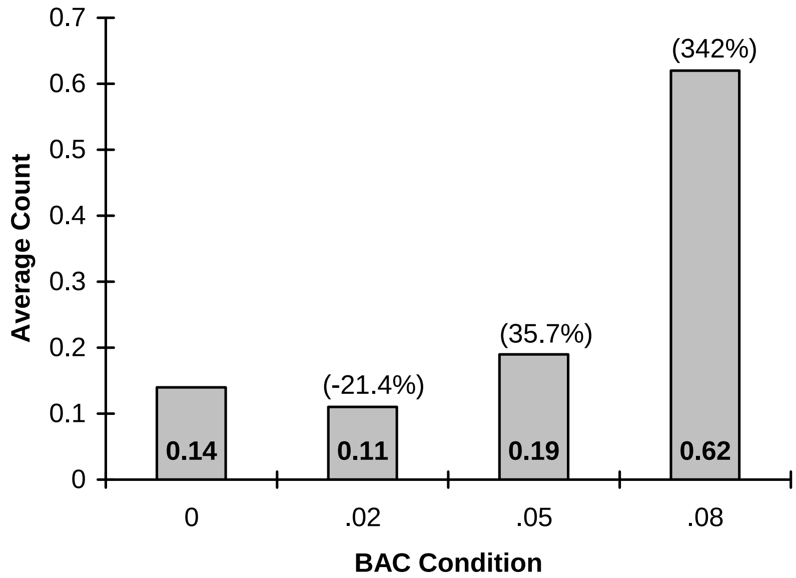

Figure 12. Effect of BAC condition on number of times lane boundaries were exceeded in the curve circuit. Note: Average count is less than 1 because some riders had zero lane departures.

3.1.8 Emergency Stop Task

The emergency stop task assesses a participant's ability to react quickly to an emergency situation by stopping the motorcycle safely and quickly in the shortest distance possible.

1. Speed at Horn Trigger

There was no significant effect of BAC condition on the speed of the motorcycle when the horn sound was triggered. As shown in Figure 13, the 95th percentile confidence intervals indicate that the average speed within each BAC condition was consistent with the instructed target of riding at 12-18 mph (5.36-8.05 m/s), with an mean across all groups around 15.5 mph.

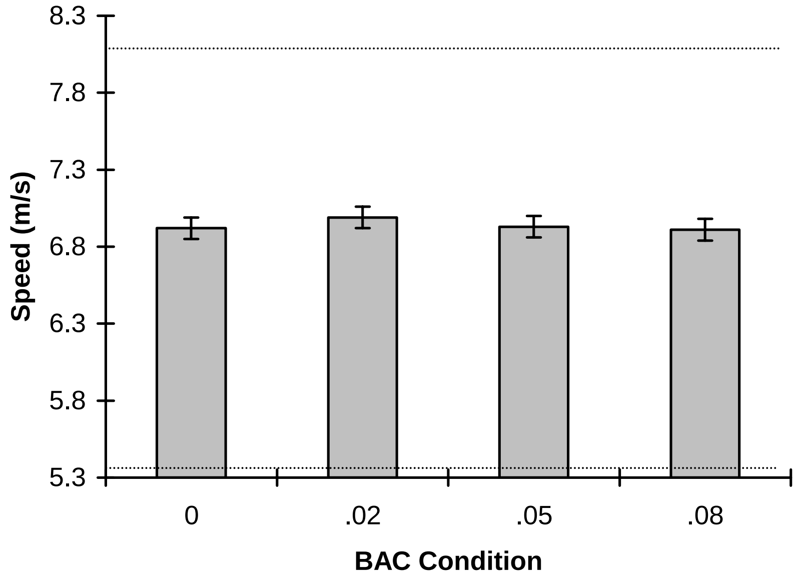

Figure 13. Effect of BAC condition on speed at horn trigger in curve circuit, including 95 percent confidence intervals. Horizontal lines indicated the required speed range

2. Reaction Time to Horn

There was no significant effect of BAC Condition on the reaction time for the emergency stop task.

3a. Elapsed Time to Maximum Deceleration

There was a marginally significant main effect of BAC condition for the **elapsed time** to reach maximum deceleration in the emergency stop task [$F(3,112) = 2.17$, p=0.09]. As shown in Figure 14, post-hoc tests (Tukey HSD) indicated that the participants in the BAC .08 condition reached maximum deceleration significantly slower when compared to the BAC .05 condition. On average, the elapsed time to maximum deceleration in the BAC .08 condition was 0.14 s slower than in the BAC .05 condition. However, BAC was not consistently related to the time needed to reach maximum deceleration.

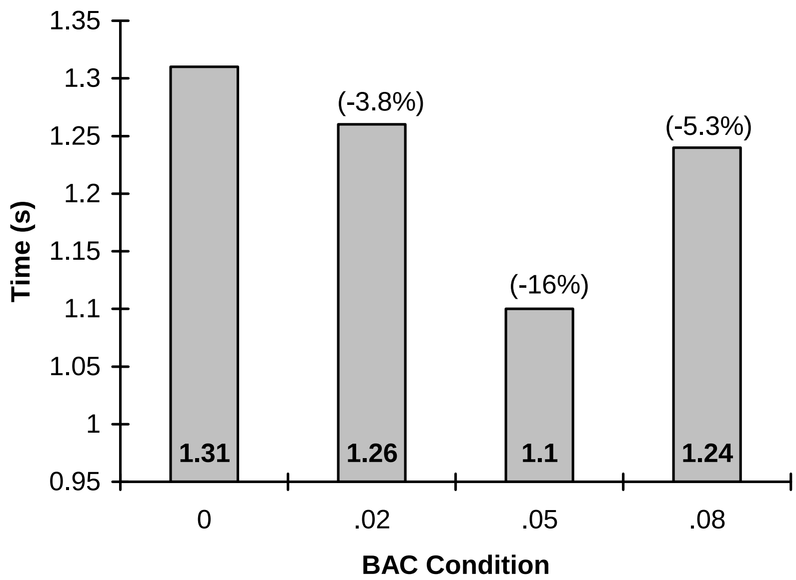

Figure 14. Effect of BAC condition on time to reach maximum deceleration in the emergency stop task.

There was also a small but significant main effect of BAC condition on the **maximum deceleration** in the emergency stop task [$F(3,112)=3.66$, $p=0.015$]. As shown in Figure 15, alcohol significantly increased the maximum rate of deceleration with the trend indicating that participants in the alcohol conditions decelerated increasingly faster in the higher alcohol conditions. On average, the maximum deceleration rate in the BAC .08 condition was 0.56 m/s^2, or 8 percent, faster than in the BAC .00 condition.

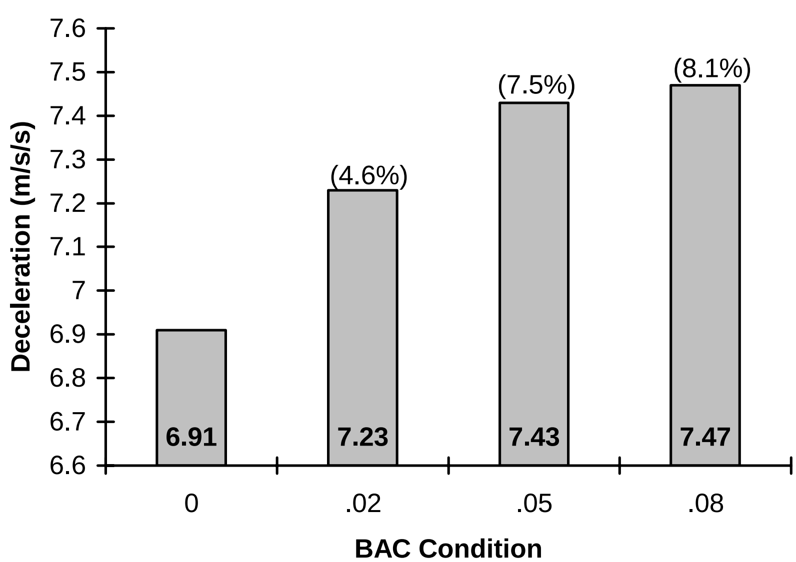

Figure 15. Effect of BAC condition on maximum deceleration in the emergency stop task.

3b. Stopping Distance

There was no significant effect of BAC condition on total stopping distance for the emergency stop task.

3c. Deviation of Motorcycle Along Stopping Path

There was a significant main effect of BAC condition for the **change in motorcycle position during the stop** in the emergency stop task [$F(3,112)=3.05$, $p=0.03$]. As shown in Figure 16, the relationship was not a simple one, and the significant effect was due to the difference between the .02 BAC and .08 BAC and not to the difference between any alcohol level and the zero alcohol level.

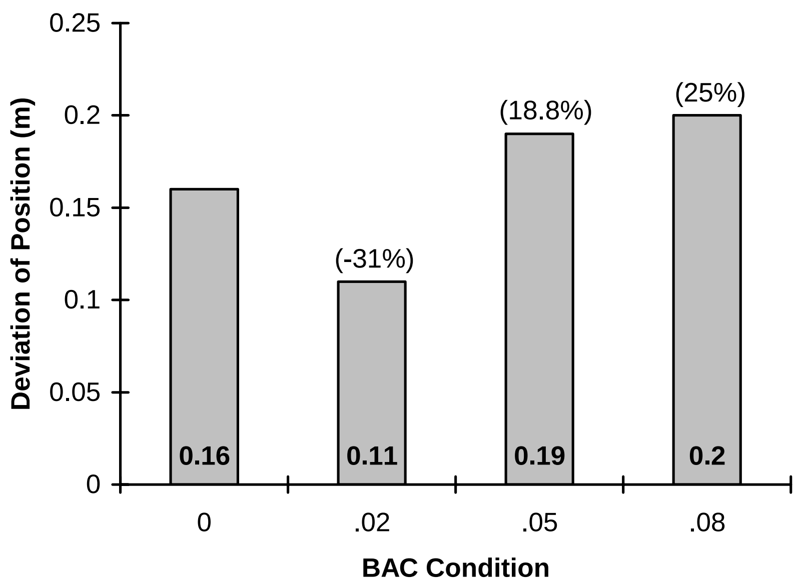

Figure 16. Effect of BAC condition on stopping path deviation.

3.1.9 Summary of Motorcycle Riding Performance

Table 9 lists a summary of the significant effects of alcohol on the riding performance measures. From this summary, it is apparent that most of the significant alcohol effects were evident in the BAC .08 condition. However, many of these same alcohol effects were significant in the lower BAC .05 condition, and there was some evidence of significant alcohol effects in the BAC .02 condition.

Table 9. Summary of all significant motorcycle performance results, showing differences between BAC .02, .05 or .08 when compared to BAC .00. Effect sizes (eta-squared) are shown for the main effect of BAC for all variables. A check mark indicates a significant result.

		BAC Effects Sizes	BAC		
			.02	.05	.08
Tasks	**Measures**				
Inline Weave	Missed or Hit Pylons	N/A			
	Minimum Passing Distance Between Motorcycle and Pylons	.016			
	SD Passing Distance between Motorcycle and Pylons				
	Number of Times Lane Boundaries Crossed	N/A			
	Number of Times Feet Came off Pegs	N/A			
	SD of Speed	.024			
Offset Weave	Missed or Hit Pylons	✓ N/A			✓
	Minimum Passing Distance Between Motorcycle and Pylons	✓ .083			✓
	SD Passing Distance Between Motorcycle and Pylons	.028			
	Number of Times Lane Boundaries Crossed	.053			
	Number of Times Feet Came off Pegs	.034			
	SD of Speed	.006			
Hazard Avoidance 1.5s	Mean Speed at Light Ignition	.021			
	Reaction Time	✓ .042		✓	✓
	Distance to Obstacle	.027			
	Braking Events	N/A			
Hazard Avoidance 2.5s	Mean Speed at Light Ignition	.009			
	Reaction Time	.019			
	Distance to Obstacle	✓ .051		✓	✓
	Braking Events	N/A			
	Incorrect Direction Choice (both tasks)	N/A			✓
Curve Circuit	Maximum Speed (Straight)	✓			

		.031			
	Minimum Speed (Curves)	.003			
	SD of Speed (Total Circuit)	✓ .02			
	Number of Times Lane Boundaries Crossed	✓ .08			✓
Emergency Stop	Speed at Horn Trigger	.001			
	Reaction Time to Horn	.01			
	Elapsed Time to Maximum Deceleration	✓ .022			
	Stopping Distance	.015			
	Deviation in Stopping Path	✓ .05			

3.2 Subjective Responses

3.2.1 NASA Task Load Index

The scores for each RTLX subscale were examined. Overall, the only significant effect was for the effort subscale. There were no significant effects in the mental workload, physical workload, time pressure, performance or frustration subscales.

3.2.1.1 Effort

There was a significant main effect of BAC condition for **the effort subscale** [$\underline{F}(3,43)=3.21$, $p=0.003$]. As shown in Figure 17, post-hoc tests (Tukey HSD) indicated that the participants in the BAC .08 condition reported significantly more effort while riding compared to the BAC .00 condition. On average, participants in the BAC .08 condition rated effort 29.7 percent higher than those in the BAC .00 condition. Ratings of effort were also significantly higher in the BAC .08 condition when compared to the BAC .02 condition.

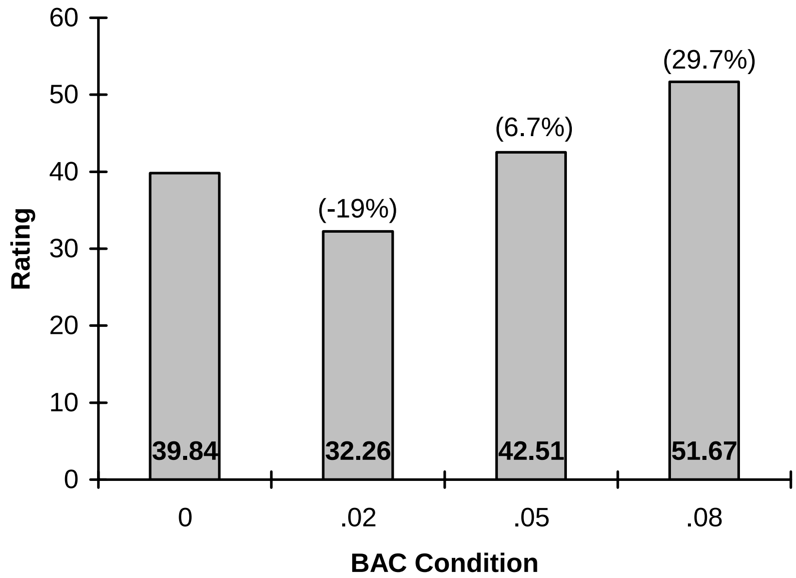

Figure 17. Ratings of effort by BAC condition (numbers in parentheses indicate the percent increase in the rating between the non-zero BAC and the zero BAC)

3.2.2 Perceived Riding Capability

3.2.2.1 How intoxicated do you feel at this moment?

There was a significant main effect of BAC condition for reported feelings of intoxication [$F(3,43)=28.06$, $p<0.001$]. As shown in Figure 18, post-hoc tests (Tukey HSD) indicated that, on average, the participants in all the alcohol conditions (BAC .02, .05, .08) reported significantly more subjective intoxication compared to the BAC .00 condition. The level of subjective intoxication reported in the BAC .08 condition was also significantly greater than in the BAC .02 and .05 conditions. Finally, the BAC .05 condition reported significantly higher ratings of intoxication compared to the BAC .02 condition. It is also notable that the level of subjective intoxication reported by participants in the BAC .00 conditions was significantly above zero [95th CI = 13.35 ± 9.24]. This implies that the method for administrating the placebo beverage (see Section 2.5.3) was successful in terms generating an expectation that alcohol was possible in each drink.

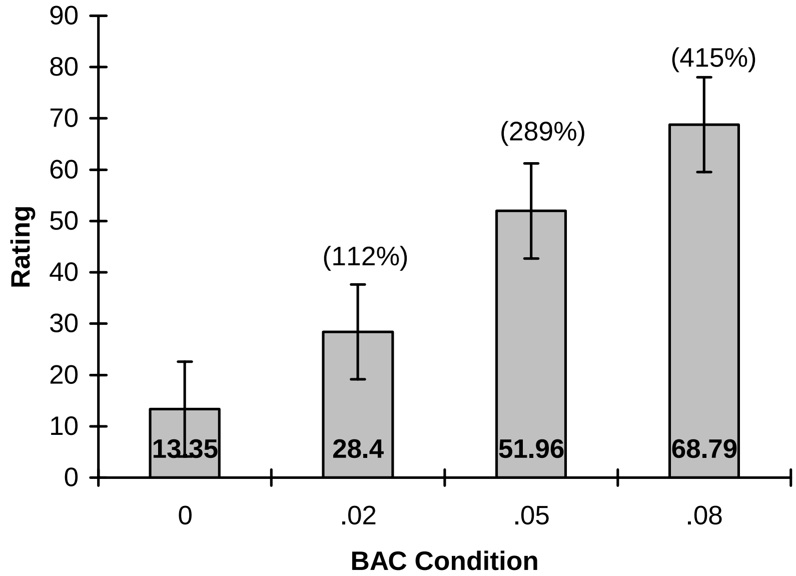

Figure 18. Ratings of intoxication by BAC condition (numbers in parentheses indicate the percent difference between the rating at non-zero BAC and the rating at the zero BAC).

3.2.2.2 How impaired do you feel your performance would be riding a motorcycle right now?

There was as significant main effect of BAC condition for ratings of performance impairment [$F(3,43)=24.18$ $p<0.0001$]. As shown in Figure 19, post-hoc tests (Tukey HSD) indicated that, on average, participants in the BAC .05 and .08 conditions reported significantly more subjective impairment compared to the BAC .00 condition. Furthermore, the level of subjective impairment reported in the BAC .08 and .05 conditions were significantly greater than in the BAC .02 condition. The BAC .08 and .05 conditions were statistically similar. Again, it is also notable that the level of subjective impairment reported by participants in the BAC .00 conditions was significantly above zero [95^{th} CI = 18.9 ± 9.31], thereby demonstrating the effectiveness of the placebo beverage protocol (see Section 2.5.3) in generating an expectation that alcohol was possible in each drink.

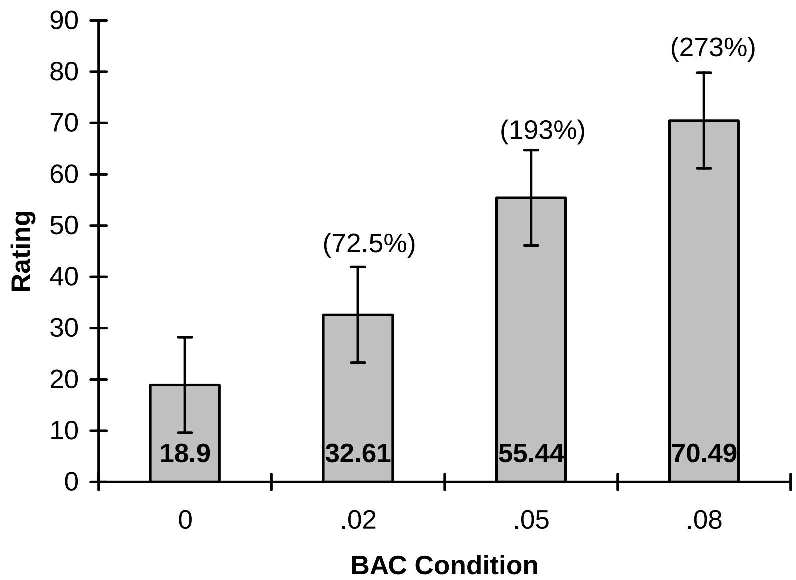

Figure 19. Ratings of how impaired participants perceived their riding performance to be in the different BAC conditions (numbers in parentheses indicate the percent difference between the rating at non-zero BAC and the rating at the zero BAC) .

3.2.3 Willingness to Ride

There were three questions pertaining to willingness to ride in the context of different trip purposes based on how the participant felt.

3.2.3.1 How willing would you be to operate a motorcycle right now for an unimportant though gratifying reason (e.g., ride to a party)?

There was a significant main effect of BAC condition [$F(3,43)=6.12$, $p=0.002$] for willingness to ride for a gratifying reason. As shown in Figure 20, post-hoc tests (Tukey HSD) indicated that, on average, the participants in the BAC .05 and .08 conditions were significantly less willing to ride for gratifying reasons compared to the BAC .00 condition. On average, participants in the BAC .08 condition rated their willingness to ride 52.7 percent lower than those in the BAC .00 condition, while participants in the BAC .05 condition rated their willingness to ride 56.6 percent lower than the BAC .00 condition. The BAC .05 and .08 conditions also had significantly lower ratings of willingness to ride for a gratifying reason when compared to the BAC .02 condition.

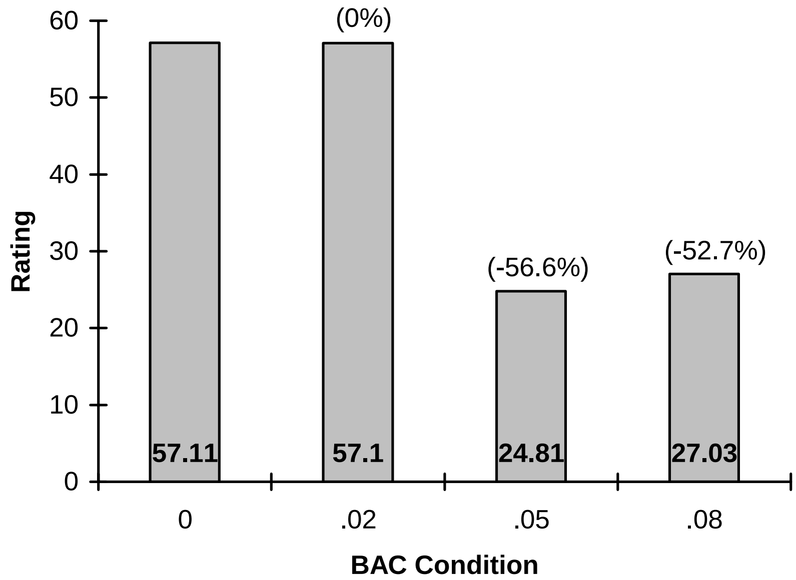

Figure 20. Ratings of willingness to ride for a gratifying but unimportant reason by BAC condition (numbers in parentheses indicate the percent difference between the rating at non-zero BAC and the rating at the zero BAC) .

3.2.3.2 How willing would you be to operate a motorcycle right now for an important, but avoidable reason (e.g., give a friend a ride home who feels mildly ill, when they could get a taxi)?

There was a significant main effect of BAC condition [$F(3,43)=5.87$, $p=0.002$] for willingness to ride for an important reason. As shown in Figure 21, post-hoc tests (Tukey HSD) indicated that participants in the BAC .05 and .08 conditions were significantly less willing to ride for important reasons compared to the BAC .00 condition. On average, participants in the BAC .08 condition rated their willingness to ride for an important reason 50.9 percent lower than those in the BAC .00 condition, while participants in the BAC .05 condition rated their willingness to ride 53.7 percent lower than the BAC .00 condition. Furthermore, the reported willingness to ride for an important reason in the BAC .08 condition was significantly lower than in the BAC .02 condition.

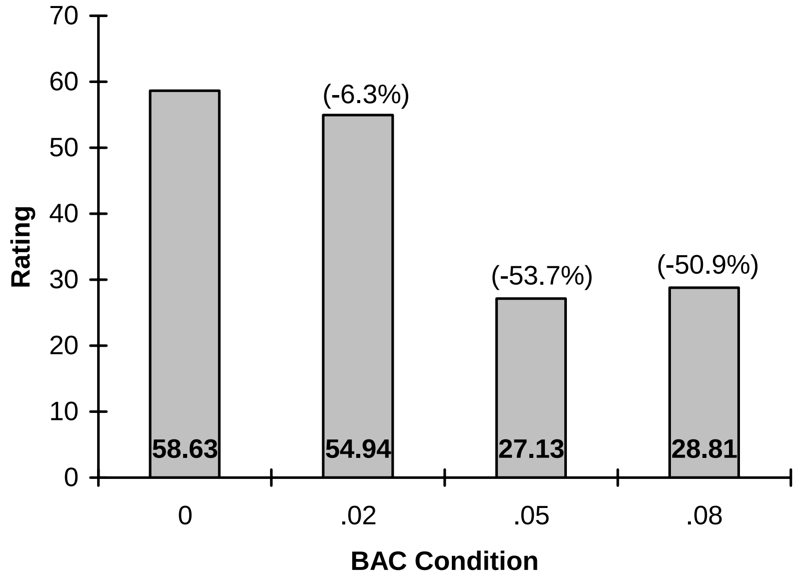

Figure 21. Ratings of willingness to ride for an important but avoidable reason by BAC condition (numbers in parentheses indicate the percent difference between the rating at non-zero BAC and the rating at the zero BAC).

3.2.3.3 How willing would you be to operate a motorcycle right now for an urgent purpose (e.g., ride to a hospital to help a sick relative who has no one else to contact)?

There was a significant main effect of BAC condition [$F(3,43)=4.00$, $p=0.01$] for willingness to ride for an urgent reason. As shown in Figure 22, post-hoc tests (Tukey HSD) indicated that participants in the BAC .08 condition were significantly less willing to ride for an urgent reason compared to the BAC .00 condition. On average, participants in the BAC .08 condition rated their willingness to ride for an important reason 32.4 percent lower than those in the BAC .00 condition. Furthermore, the reported willingness to ride for an urgent reason in the BAC .08 condition was significantly lower than in the BAC .02 condition.

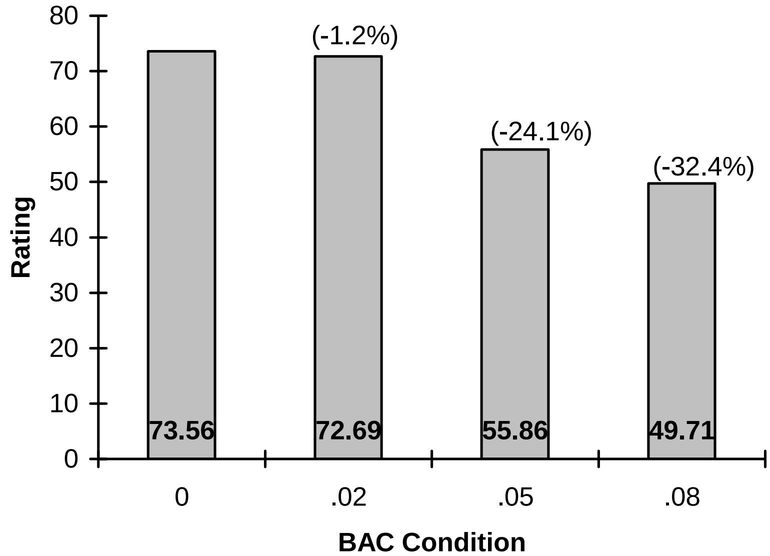

Figure 22. Ratings of willingness to ride for an urgent reason by BAC condition (numbers in parentheses indicate the percent difference between the rating at non-zero BAC and the rating at the zero BAC).

3.2.4 Summary of Subjective Responses

Table 12 lists a summary of the significant effects of alcohol on the subjective response measures.

Table 10. Summary of all significant subjective performance results, showing differences between BAC .02, .05 or .08 when compared to BAC .00. Effect sizes (eta-squared) are shown for the main effect of BAC for all variables. A check mark indicates a significant result.

		Main Effect of BAC	BAC		
			.02	.05	.08
Tasks	**Measures**				
NASA RTLX	Mental Demand	0.054			
	Physical Demand	0.025			
	Time Pressure	0.006			
	Performance	0.097			
	Effort	✓ 0.076			✓
	Frustration	0.038			
Riding Capability	How Intoxicated	✓ 0.46	✓	✓	✓
	How Impaired	✓ 0.36		✓	✓
	Ride for a gratifying reason	✓ 0.16		✓	✓
	Ride for an important, but avoidable reason	✓ 0.14		✓	✓
	Ride for an urgent reason	✓			✓

		0.072			

4 DISCUSSION

This study was designed to characterize the impairment effect of alcohol (up to the current per se limit of BAC .08) on motorcycle control and to characterize the form of coping riders adopt to control their motorcycle when impaired. Riding performance in this study was assessed with a set of controlled test scenarios developed in conjunction with the Minnesota Motorcycle Safety Center (MMSC). These scenarios were modified from the Motorcycle Safety Foundation (MSF) training program (including the MSF Basic Rider Course and the Experienced Rider Course) to measure performance on basic riding skills that are relevant to motorcycle safety.

4.1 Riding Performance

The specific results of this study for the objective measures of motorcycle control are summarized in Table 11 and compare results from the three impairment conditions (BAC .02, .05 and .08) to the sober condition (BAC .00). It is apparent that some of the alcohol effects observed in this study are consistent with the types of crash configurations frequently seen among drinking riders. For example, in this study, participants in the higher BAC conditions had higher maximum speeds and showed greater lane variability while navigating the curve circuit. Increased riding speed and run-off-road errors were also seen in the simulator study conducted by Colburn et al. (1993). These types of performance decrements may correspond to the high rate of run-off-road crashes that occurred in curves among the drinking riders observed by Kasantikul and Ouellet (2005). In particular, run-off-road and loss-of-control crashes among drinking motorcycle riders occurred significantly more frequently when BAC levels reached .05 (Oullet & Kasantikul, 2006).

Table 11. Summary of Alcohol Effects for Riding Performance.

Task Scenario	Dependent Variable (# Performance Standard)	Expected Alcohol Effects (Impairment Characteristic)	BAC	Results (Impairment compared to BAC .00 condition)
Weave (Inline / Offset)	1a. Minimum Passing Distance Between Motorcycle and Pylons	It is expected that riders will try and avoid large destabilizing steering actions in order to protect stability. As a result, they will pass closer to the	.02	

		cones to minimize steering action.	.05	
			.08	*Offset Weave:* Results show riders did pass closer the cones in the higher BAC condition.
	1b. Missed or Hit Pylons	The strategy to pass near the cones to minimize steering actions (protect stability) will result in more missed or hit pylons since this strategy is more sensitive to error.	.02	
			.05	
			.08	*Offset Weave:* Results show that riders did miss or ride more pylons in the higher BAC condition.
	2. Number of times exceed painted lane lines	The emphasis on passing close to the pylons to minimize steering would result in fewer violations of lane boundaries. The exception would be a strategy to successfully pass the pylons by making wide turns that may deviate to a lane boundary violation.	.02	
			.05	
			.08	
	3. Number of times feet leave pedals	Riders at higher BAC levels will put their feet down more often in this weave due to the difficulty of navigating the offset weave. If riders protect stability, they will try to avoid this at the expense of missing a few cones.	.02	
			.05	
			.08	

	4. Measure of speed consistency	Riders at higher BAC levels will show more variability in their speed as they try to control the motorcycle through the course. This is especially expected if their initially chosen speed is too high. (Note: they are limited in reducing their speed because it would destabilize the bike too much).	.02	
			.05	
			.08	
Hazard Avoidance (Near / Far)	1. Mean Speed at Light Ignition	Riders at higher BAC levels may not achieve the target speed if they have more trouble controlling their speed while riding. (Note: if the task is too demanding to maintain speed by looking at the speedometer, then it is expected that speed maintenance deteriorates).	.02	
			.05	
			.08	
	2. Reaction Time & Direction Choice	Riders should have slower reaction times to the light at higher BAC levels as information processing is slowed. Participants at higher BACs may anticipate incorrectly and swerve in the wrong direction.	.02	
			.05	*Near distance:* Results show riders did have slower reaction times to the lights in this BAC condition.
			.08	*Near distance:* Results show riders did have slower reaction times to the lights in this BAC condition. *Both distances:* Results show riders did make the most incorrect decision choices in response to the lights in this BAC condition.
	3. Passing Distance to Obstacle	Riders at higher BACs may pass closer to the obstacle during the avoidance maneuver due	.02	
			.05	

		to reduce response time to the light and reluctance to steer strongly (in order to protect stability).	.08	*Far distance:* Results show riders did pass closer to the obstacle in the highest BAC condition.
Curve Circuit	1. Maximum Speed (Straight Section)	Faster speeds on straight sections with alcohol were expected based on previous research that has demonstrated increased speeding with alcohol while driving (Moskowitz et al., 2000) and riding a motorcycle (Compton et al., 1993).	.02	Results show riders had faster maximum speeds in even the lowest BAC condition.
			.05	Results show riders had faster maximum speeds in this BAC condition.
			.08	Results show riders had faster maximum speeds in the highest BAC condition.
	2. Minimum Speed (Curve Sections)	Faster speeds on curves with alcohol were expected based on previous research that has demonstrated increased speeding with alcohol while driving (Moskowitz et al., 2000) and riding a motorcycle (Compton et al., 1993).	.02	
			.05	
			.08	
	3. Standard Deviation of Speed in the Circuit	Riders at higher BACrs should show larger variation in speed since they are forced to adjust speed more often from the higher initial speeds to maintain control in the circuit.	.02	Results show riders had larger variations in their speed throughout circuit in even the lowest BAC condition.
			.05	Results show riders had larger variations in their speed throughout circuit in this BAC condition.
			.08	Results show riders had larger variations in their speed throughout circuit in the highest BAC condition.
	4. Number of Times Exceed Painted Lane Lines	Riders at higher BACs may exit the lane boundaries due to increased speed and incorrect adoption of correct speeds in the	.02	
			.05	

		curves.	.08	Results show that riders did have more lane boundary violations in the highest BAC condition.
Emergency Stop	1. Speed at Horn Trigger	Riders at higher BACs may not achieve the target speed if they have more trouble controlling their speed while riding.	.02	
			.05	
			.08	
	2. Reaction Time to Horn	Riders at higher BACs may have longer reaction times due to the slowing of information processing.	.02	
			.05	
			.08	
	3a. Elapsed Time to Maximum Deceleration	Riders at higher BACs may reach maximum deceleration sooner in an attempt to compensate for reductions in reaction time.	.02	
			.05	Results show riders did reach maximum deceleration faster compared to all other conditions in this BAC condition. This condition also had higher maximum deceleration rates.
			.08	Results show riders did reach maximum deceleration sooner compared to .00 and .02, but took longer to reach maximum deceleration compared to .05. This condition also had higher maximum deceleration rates.
	3b. Stopping Distance	Riders at higher BACs may require a longer distance to stop due to the slower reaction time.	.02	
			.05	
			.08	
	3c. Deviation of Motorcycle Along Stopping Path	Riders at higher BACs may have more difficulty controlling the motorcycle and keeping the stopping path along a straight line due to the higher	.02	Results show that riders in this condition stopped along a straighter line than in the .00 condition.

		deceleration.	.05	Results show that riders in this condition had more difficulty keeping the bike on a straight stopping path in this condition.
			.08	Results show that riders in this condition had more difficulty keeping the bike on a straight stopping path in the highest BAC condition.

Note: All results are in comparison to BAC .00 condition, unless otherwise indicated.

This summary demonstrates that the observed alcohol effects occurred at the BAC .08 which is currently the per se limit for operating a motorcycle. However, some effects were also significant at the lower BAC .05. This suggests that lane deviation, speed maintenance and adherence to speed limits may be problematic for motorcycle riders even when impaired by lower levels of alcohol. It is interesting to note that similar measures related to the control of a car have been examined in relation to alcohol impairment in previous research. Moskowitz et al. (2000) showed significant increases in speed deviation, lane deviations, and number of times drivers went over the speed limit at BAC .06, .08 and .10 in a driving simulator study.

These results can be interpreted in terms of defining impairment and the coping strategies used by riders to cope with the effects of alcohol.

4.1.1 Defining Impairment

The "impairment" of riding skills was defined as any deviation in the observed motorcycle control with reference to the specific performance standards that were included in the instructions for the task scenario (see Table 3 and Table 4).

4.1.1.1 Weave Task

A pair of scenarios (weave) required riders to control the motorcycle through a simple (Inline) and more complex (Offset) slalom section defined by a sequence of obstacles. This scenario included measures to assess the ability of the rider to maintain balance and speed as well as judge safety margins with respect to the obstacles. The results from these scenarios indicated that the demand on the rider imposed by the simple section was not sufficient to demonstrate impairment effects. In contrast, impairment was evident in the more demanding weave section where control was poorer. More pylons were missed and drivers rode closer to the pylons in the BAC .08 condition than in the BAC .00 condition (placebo). Riding close to the pylons in a weaving task is consistent with the specified performance standard "ride close to the obstacles." However, alcohol also resulted in a higher number of missed obstacles or collisions with obstacles, which may be evidence of impairment given that this contradicts the performance standard "avoid hitting obstacles."

4.1.1.2 Hazard Avoidance Task

Another pair of scenarios (hazard avoidance) required riders to pay attention to a directional signal that was turned on just before reaching an obstacle, and control the motorcycle through an indicated escape lane to simulate a hazard avoidance maneuver. This was done with late (1.5 s TTC) and early (2.5 s TTC) warning of the signal indication to specify the escape direction. This scenario included measures to assess response (decision) time and the ability to control the motorcycle along the escape path while judging safety margins with respect to the hazard. The results indicated that with late warning, riders in the BAC .05 and .0.08 conditions were significantly slower to respond than when sober. They also more often escaped in the wrong direction. This slowing of response time and increase in direction errors contradicts the performance standard to "respond as quickly as possible", and reflects impaired cognitive functioning. In particular, rider attention, decision making, or selection of response behavior may have been impaired by alcohol. When the warning was given 1 second earlier (2.5 s TTC) response time was not impaired by alcohol. In fact, in this condition riders with BAC .05 and .08 entered the exit lane significantly closer to the obstacles than when sober.

These results are consistent with basic research indicating that alcohol can impair attention allocation in controlled situations that require complex choice reactions (Halloway, 1995; Moskowitz & Fiorentino, 2000). Indeed, Moskowitz (in Dewar et al., 2002) asserts that controlling a vehicle is inherently composed of complex choice decision tasks: "There is nothing in driving that is comparable to what a psychologist would consider a simple reaction time experiment." For example, in our hazard avoidance tasks, the task is considered complex because the participant must maintain speed and control of the bike while approaching the hazard and then respond immediately to the light and make the correct maneuver decision based on what they see. Moreover, this assumption corresponds to the conclusions by Kasantikul and Ouellet (2005) who observed that drinking riders were far more likely to be inattentive in the moments leading up to a crash than non-drinking riders.

4.1.1.3 Curve Circuit Task

The next scenario (curve circuit) required riders to control the lateral position and speed of the motorcycle through a loop circuit with curves marked by lane boundaries. This scenario included measures to assess the ability of the rider to maintain lane position and speed with consideration to perceived safety margins in relation to curve radius and lane width. The results from this scenario indicated that all levels of alcohol resulted in an increase in speed within the straight approach sections of the circuit. A similar effect was not evident in the curves, where the minimum speed was essentially the same at all BACs. Thus, without the natural constraints of road curvature, the straight sections afforded an opportunity for higher speed for riders in the alcohol conditions. This may imply that even at the levels of alcohol used in this study alcohol increased rider confidence, but once in a curve riders were able to recognize the need to adjust their speed to compensate for the physical characteristics of the curves that acted as natural constraints on speed choice. In contrast, the unconstrained nature of the straight sections gave riders in the alcohol conditions an opportunity to choose a faster speed than when sober.

The higher speeds that were achieved with alcohol in the straight sections also resulted in greater *variation* of speed. This may be expected since faster speeds on the straight sections would also necessitate greater reductions in speed to contend with the curves in the circuit. Once inside the curve, the effects of alcohol were manifest in poorer lane control, as evidenced by an increase in lane position variability and number of times riders crossed <u>outside</u> the lane boundaries in the BAC .08 condition. This impairing effect may be of particular importance given that speed and lane departures are fatal crash risk factors (Allen & Stein, 1987). In any case, riders in the alcohol conditions chose the higher speed range (25.5 mph on average in the BAC .08 condition versus 23.75 mph on average in the BAC .00 condition) and failed to comply with the performance standards to "not ride outside lane boundaries," which itself may be evidence of impairment.

4.1.1.4 Emergency Stop Task

The final scenario (emergency stop) required riders to brake rapidly while maintaining proper control to simulate an emergency stop situation. This scenario included measures to assess response time, braking intensity, stopping distance, and control of stopping path. The results from this scenario indicated the braking profile amongst riders in the BAC .08 condition indicated harder decelerations and faster maximum deceleration rates, although the response time and overall stopping distance was not affected by alcohol. The change in deceleration profile with alcohol may not be an indication of impairment by itself because it is consistent with efforts to comply with the performance standard to "stop quickly." However, there was evidence that alcohol increased the deviation in lateral position along the stopping path. To the extent that any deviation from a straight-line stopping path may exemplify reduced control and increase hazard exposure, the observed increase in lateral deviation while stopping may be considered to be evidence of impairment (in the context of the performance standard to “safely stop in the shortest distance possible”). For example, one rider braked so hard in the emergency stop in the BAC .08 condition that the front wheel locked up and he lost control of the motorcycle and tipped it onto the outrigger.

4.1.2 Coping Strategies

As discussed in the introduction, a driver can respond to the effects of alcohol by either of two active coping methods: (1) try harder and invest resources achieve the goal; and (2) lower performance goal by increasing tolerance margin (thereby reducing effort demand). The presumption is that these coping methods are triggered in response to the self-awareness of subjective intoxication (Figure 18) and performance impairment (Figure 19). This self-awareness may have mitigated these active coping strategies of investing more resources or reducing goal aspirations.

4.1.2.1 Resource Investment

If riders were not already overloaded, they could have adopted a general coping strategy of applying more effort to processing task information when intoxicated. That is, riders could have protected themselves from the impairment effects of alcohol just by “trying harder.” Specifically, riders could apply more resources (attention) to the riding environment to increase detection, decision, and response times. With low doses of alcohol this additional effort could be sufficient to maintain an overall RT similar to that observed when sober. The results of this study do lend some evidence that riders may have applied this strategy, especially because they were aware that they were part of a study where they tried to maximize their level of performance. The riders were also aware of their intoxication (Figure 18) which may have triggered effortful coping. Indeed, riders in the highest alcohol condition (BAC .08) did report exerting 30 percent more effort (Figure 17) than in the no alcohol condition (lowest alcohol condition). However, the amount of effort may not have always been sufficient to compensate for the amount of impairment. For example, the effort reported at the BAC .08 was not enough to overcome the apparent increase in reaction time in the hazard avoidance task (Figure 7). Thus, whereas the strategy of applying more effort may have overcome the impairment effects in some tasks at low alcohol levels, this same strategy was not sufficient to contend with the impairment resulting from the highest dose of alcohol.

Furthermore, riders could also apply additional effort in terms of response planning; that is, by anticipating the correct response in advance in order to prepare themselves to implement that response when needed. The advantage of “pre-loading” a response program is that the overall response time is reduced and there is no need for response deliberation. Instead, the perception of the relevant cues in the environment triggers the response automatically. Of course, this strategy is predicated on the assumption that the anticipated response is correct. If the planned response is incorrect, then the rider may make an error or the over all response time will increase as the rider is forced to cancel the erroneous planned response and initiate the correct one. The peril of this anticipatory strategy was observable in the hazard avoidance task wherein the highest alcohol condition (BAC .08) did result in more response errors (Table 7). In addition, the higher alcohol conditions (BAC .05, BAC .08) also resulted in slower reaction times overall (Figure 7) in the near hazard avoidance task.

4.1.2.2 Goal Aspirations

For those tasks that already demand high effort, the remaining coping strategy for riders is to cope by reducing performance goals. Performance goals are comprised of two components: (1) average (target) performance, and (2) tolerance margin for deviating from target performance (error). Tasks that are defined by high performance standards and narrow tolerance margins require most attention and effort because the information processing and motorcycle control demands are higher.

In this study, riders could have coped by reducing speed or tolerating higher fluctuations in speed and travel path before making corrective adjustments. However, several aspects of the task scenarios may have limited rider ability to reduce speed. First, riders may have avoided slowing because motorcycle stability is enhanced at higher speeds due to centrifugal forces. Second, the riders were instructed in some tasks to maintain a specific speed which may have contradicted their inclination to ride at a slower speed. Thus, assuming that riders were limited in their opportunity to reduce average speed, their remaining option was to accept wider tolerances for speed variation.

In the case that speed was not reduced, wider tolerances for travel path may also be expected if riding control and information processing is impaired. For example, larger path deviations may be expected with control and processing impairment when speed is not reduced because any deviations are exacerbated at higher speeds. A natural implication of accepting wider tolerances is a lowering of performance, especially when unexpected disturbances challenge the rider.

In the current study, there was no evidence that speed levels were reduced by alcohol. Indeed, the riders' speed levels were within the performance standards associated with the task instructions that specified a target speed. In fact, differences in speed that were significant were in the direction of *higher speeds* at all levels of alcohol during the circuit task (Figure 10). Simulation studies (e.g. Colburn, Meyer, Wrigley, & Bradley, 1993) and crash studies (Bédard, Guyatt, Stones, & Hirdes, 2002) also show that alcohol-related crashes and fatalities are associated with speed. As expected, the higher speeds in the circuit task were also associated with wider tolerance margins as demonstrated by a 6- to 9-percent increase in speed variation with alcohol (Figure 11) and a 342-percent increase in lane boundary violations at the highest alcohol level (Figure 12). The acceptance of wider performance margins (errors) may have also been the basis for the increased path deviation during the emergency stopping task at the higher alcohol levels (Figure 16) and the trend for more collisions with pylons in the offset swerve task (Figure 5).

The various effects of intoxication and the means that riders employ to protect stability and task performance are shown in Figure 23. In summary, in the present study the effects of alcohol on motorcycle control were most evident in those tasks requiring complex information processing with high time pressure and tight constraints on performance margins. For example, the inline weave task did not show any effects because it was simple, without time pressure, and was nearly unconstrained. In contrast, the effects of alcohol were apparent in the offset weave task that had the same time pressure, but imposed more constraints on performance standards. Similarly, reaction time was impaired by alcohol only when the hazard avoidance task induced a high time pressure.

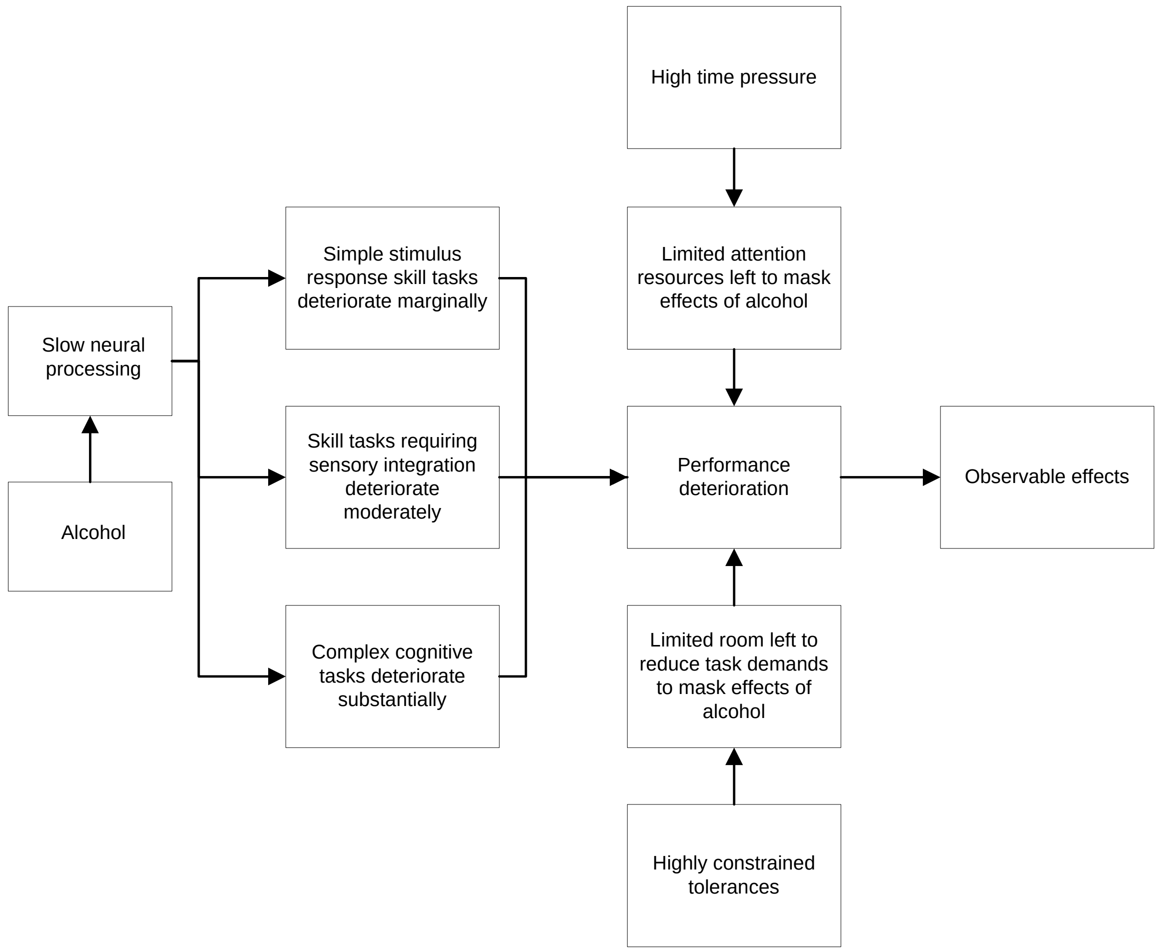

Figure 23. A general representation of the factors that influence observable changes in rider behavior. The largest effect occurs for the most complex task when little time is available for sensory integration, decision making, and control initiation especially.

Generally, it appears that the observed effects of alcohol can be accounted for by one governing principal mechanism, namely that riders trying to maintain stability of the motorcycle at higher BACs are less able (and therefore less willing) to engage in rapid steering corrections, especially at slow speeds. At the higher alcohol levels, the effort to maintain motorcycle stability reduces the ability of the riders to achieve the required performance standards for each task. The proposed mechanism of this trade-off between stability and task performance is represented schematically in Figure 24. The mechanism depicted includes the rider awareness of intoxication, the assignment of goal priority, and the acceptance of tolerance margins. With this formulation, rider awareness of intoxication (and performance impairment) is fundamental to the rider's decision to adopt a strategy to cope with impairment.

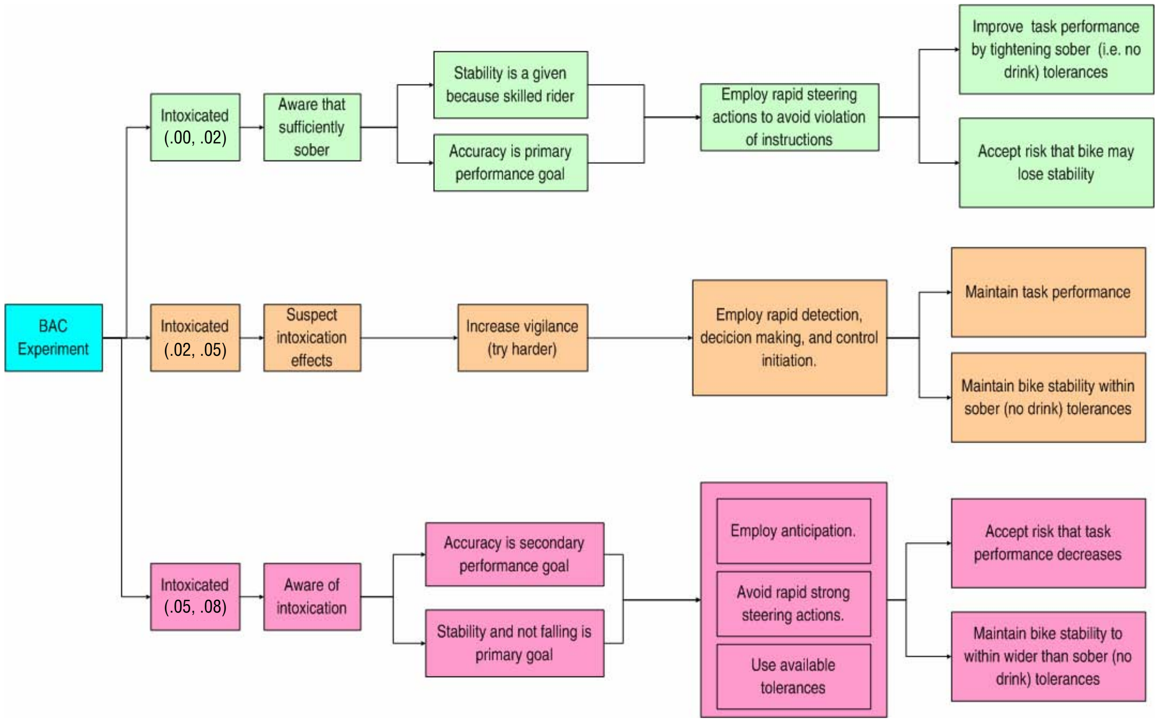

Figure 24. A general overview of the proposed mechanism governing the tradeoff between task performance and motorcycle stability for three levels of intoxication.

4.2 Rider Awareness

In addition to measures of objective performance, this study also included measures of rider subjective awareness of the effects of alcohol as summarized in Table 10. The results of this study demonstrated that riders were able to perceive differences in subjective intoxication and impairment as a function of alcohol level. Levels of reported intoxication and impairment were highest in the BAC .08 condition, although significant levels of impairment were also evident in the BAC .05 condition. Moreover, significant levels of intoxication were evident in the lowest alcohol condition (BAC .02). Indeed, subjective awareness was more sensitive to alcohol level than objective performance measures as evident from the larger effect sizes (7- to 46-percent variance accounted for by BAC effect). This is consistent with a meta-analysis of several studies that demonstrated that in general alcohol effects are more significant for subjective measures than for objective tasks (Halloway, 1995).

The riders responded to this perceived intoxication and impairment by reporting significantly more effort to cope with the riding tasks in the BAC .08 condition (Figure 17).[7] There was also evidence of intended self-regulation of behavior given that riders reported they would be significantly less willing to ride for a

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[7] Notably, more effort was not reported in the BAC .05 condition which may suggest an absence of active coping in response to the perceived increase in performance impairment.

gratifying (see Figure 20) or important reason in the BAC .05 and .08 conditions. When the situation related to their willingness to ride for an urgent reason (see Figure 22), riders were significantly less willing to ride for that reason only in the BAC .08 condition. Presumably, this decision was based on their perceived level of impairment. These results suggest that motorcycle riders are aware of the effects of alcohol and are able to exercise some judgment regarding their performance impairment when making decisions to ride. However, research shows that factors in the real world may inhibit riders' desires to exercise this judgment when they feel impaired; for example they are unwilling to leave their motorcycle behind after drinking (Syner & Vegega, 2001).

Table 12. Summary of Alcohol Effects on Subjective Response.

Subjective Measure	Question	Expected Alcohol Effects	BAC	Results
NASA RTLX	**Mental Demand:** How much thinking, deciding, calculating, remembering, looking, searching did you need to do?	Participants at higher BACs may report that more mental demand was required to attend to the tasks and remember task requirements.	.02	
			.05	
			.08	
	Physical Demand: How much physical activity was required?	Participants at higher BACs may feel physically less able to ride the motorcycle and may report that more physical effort was required to complete the course due to the physical sensations that accompany impairment (e.g., nausea, dizziness).	.02	
			.05	
			.08	
	Time Pressure: How much time pressure did you feel due to the pace of the tasks?	Participants at higher BACs may report feeling less able to make rapid responses in the tasks requiring a quick decision in response to stimulus because alcohol impairs complex reaction time.	.02	
			.05	
			.08	

	Performance: How successful do you think you were in accomplishing the goals of the tasks set by the experimenter?	Participants at higher BACs may report that their performance was not as good, particularly if they report feeling impaired.	.02	
			.05	
			.08	
	Effort: How hard did you have to work mentally and physically to accomplish your level of performance?	Participants at higher BACs may report more effort was required to complete tasks and overcome any impairment effects they report feeling.	.02	
			.05	
			.08	Participants in this condition reported significantly more effort required to complete the riding tasks.
	Frustration Level: How insecure, discouraged, irritated, stressed and annoyed during the task?	Participants at higher BACs may report more frustration with the tasks because of interference from impairment effects.	.02	
			.05	
			.08	
Riding Capability	How intoxicated do you feel at this moment?	Participants at higher BACs should report higher levels of perceived intoxication compared to BAC .00 and lower alcohol conditions.	.02	Participants in this condition reported feeling significantly more intoxicated than the BAC .00 condition.
			.05	Participants in this condition reported feeling significantly more intoxicated than the BAC .02 and .00 conditions.
			.08	Participants in this condition reported feeling significantly more intoxicated than the BAC .05, .02 and .00 conditions.
	How impaired do you feel your	Participants at higher BACs may	.02	

	performance would be riding a motorcycle right now?	report poorer perceived performance, particularly if they report feeling more impaired at higher levels.	.05	Participants in this condition reported feeling their performance was significantly impaired at this alcohol level compared to BAC .02 and .00 conditions.
			.08	Participants in this condition reported feeling their performance was significantly impaired at this alcohol level compared to BAC .02 and .00 conditions.
	How willing would you be to operate a motorcycle right now for an unimportant though gratifying reason (e.g., ride to a party).	Participants at higher BACs may report that they would not be willing to ride for an unimportant reason if they report feeling intoxicated and having impaired performance.	.02	
			.05	Participants in this condition reported being significantly less willing to ride for this reason compared to the BAC .02 and .00 conditions.
			.08	Participants in this condition reported being significantly less willing to ride for this reason compared to the BAC .02 and .00 conditions.
	How willing would you be to operate a motorcycle right now for an important, but avoidable reason (e.g., give a friend a ride home who feels mildly ill, when they could get a taxi)?	Participants at higher BACs may report that they would not be willing to ride for an important reason if they report feeling intoxicated and having impaired performance.	.02	
			.05	Participants in this condition reported being significantly less willing to ride for this reason compared to the BAC .00 conditions.
			.08	Participants in this condition reported being significantly less willing to ride for this reason compared to the BAC .02 and .00 conditions.
	How willing would you be to operate a motorcycle right now	Participants at higher BACs may report that they	.02	

	for an urgent purpose (e.g., ride to a hospital to help a sick relative who has no one else to contact)?	would not be willing to ride for an unimportant reason if they report feeling intoxicated and having impaired performance.	.05	
			.08	Participants in this condition rated their willingness to ride for this reason significantly lower than the BAC .02 and .00 conditions.

4.3 Study advantages

There are a number of advantages to the methodology used in this study. The methodology was based on a robust experimental design that isolated the effect of alcohol from other confounding factors. In particular, the use of a balanced incomplete block design removed the learning effects by randomizing alcohol levels across test days (and participants) to provide a non-confounded estimate of alcohol effects. In addition, extensive practice periods were included such that performance could stabilize (asymptote). The analysis included covariates for relevant individual differences such as riding skill (baseline performance, riding experience) and exposure to alcohol (drinking history).[8] This covariate analysis provided a test for the effects of alcohol without interference from these individual difference variables. Furthermore, a single-blind alcohol administration protocol was used to equalize expectancy effects across all alcohol conditions. Drinking was completed in a group recreational setting to include the social influences on alcohol intoxication (Smiley, Noy, & Tostowaryk, 1987; Ward & Dye, 1998). Most important, the test environment was based on a valid set of scenarios to measure riding skills that are relevant to motorcycle safety. In conjunction with specified performance standards for these scenarios, it was possible to define "impairment" in terms of a relevant set of measures to characterize motorcycle control.

4.4 Study limitations

The experimental control afforded by the research methodology does also present some limitations to the study. First, a fully balanced experimental design and protocol are cumbersome to implement. As a result, only a limited number of participants could be recruited in the time period and budget of this project. Although this sample size was sufficient to detect significant alcohol effects for some measures, a larger sample size would logically provide more power to

[8] Interestingly, only riding performance in the baseline condition demonstrated a consistent correlation with measures in the test conditions (Appendix I). Notably, riding experience (years with license) did not function as a consistent covariate. Given that age and riding experience are correlated, the absence of a correlation between riding experience and riding measures is consistent with the absence of an effect of age (and drinking experience) on riding performance observed by Moskowitz et al. (2000).

potentially detect effects across a wider set of measures. Second, rider behavior was measured for a set of simplistic scenarios to assess basic riding skills and to minimize risk to study participants. The necessary use of simple scenarios may not have been sufficiently challenging and may not have utilized a sufficiently broad range of skills to provide a comprehensive and sensitive assessment of alcohol impairment. Third, an experienced sample of riders was recruited and ample practice given to reach asymptotic performance. This was a deliberate effort in order to reduce learning effects in this study. The unintended effect of this regime may have been to reduce the potential range of performance impairment that could be observed and may have restricted the conclusions of this study to highly-experienced riders riding in highly familiar environments. Overall, the calculated effect sizes (Eta^2) for the significant main effect of alcohol are small (2-8 percent of variance accounted for by the alcohol effect). Thus, emergency reactions to truly unexpected hazards could not be evaluated. Furthermore, participants in this study were probably motivated to perform optimally in the context of the experiment (and attempted to conceal evidence of impairment). However, these same factors imply that any impairment effects may be <u>underestimated</u>, especially for consideration of alcohol impairment in novice riders and complex riding scenarios.

5 CONCLUSION

This study demonstrates some changes in riding behavior in response to alcohol consumption that may be construed as impairment relative to standard performance and the self-assessment of riders. Most of the impairing effects on riding performance was evident at the per se alcohol limit of BAC .0.08. However, many of these same impairing effects were also evident in the lower BAC .0.05 condition. Although the participants' self-reports suggest that riders may be aware of the intoxicating and impairing effects of alcohol, this study cannot conclude that corollary self-regulation would be sufficient to mitigate crash risk. Admittedly, the effect sizes (Eta^2) calculated for the significant main effect of alcohol may be considered small. These small effect sizes may be attributable to the use of experienced riders performing well-practiced tasks with low to moderate alcohol doses. Larger impairments may be expected with less experience riders, on less familiar roads, with more complex and novel tasks at higher alcohol doses. Similarly, the practical significance of these results must be interpreted in the context of the contrived experiment conditions. For example, the 50 ms delay found in the hazard avoidance task in reaction time on a real road traveling at 70 mph translates into a relatively small increase in stopping distance of 1.50 m. However, the magnitude of this effect must be viewed in the context of the constrained test environment. It is likely that in the real world – with concurrent distractions and without the motivation to perform for an experiment – that impairment effects would be larger. Thus, more research is needed to determine real-world implications of BAC during the riding experience.

6 FUTURE RESEARCH

This study demonstrated significant alcohol effects on motorcycle riding performance within the confines of a test course with simplified tasks that measured fundamental riding skills. Based on our experience and results, we would suggest the following opportunities for future research:

- Future research should examine the basis upon which riders perceive their impairment; that is, is the perception of impairment based on self-awareness of a subjective state (intoxication) or self-assessment of observed performance. This research could then suggest methods to encourage safe riding decisions.
- Future research should consider increasing the demands of the riding tasks by increasing time urgency or difficulty of controlling the motorcycle.
- Future research should transition from measuring performance on sequential tasks in terms of discrete skills to measuring performance on continuous rides along a test track to examine the effect of alcohol on complex riding behaviors that are not artificially constrained. This should include dynamic situations with scripted traffic events.
- Future research should include a naturalistic study of motorcycle riders including a data acquisition system that can safely measure breath alcohol content and integrate this information with the riding performance dataset.

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APPENDIX A – RECRUITMENT SCREENING

Name:____________________ Phone:_______________ Email:______________________

CRITERIA DESCRIPTION	INCLUDE IF	OK
Gender _________	Male	
Age ________Yrs	21 – 50	
Motorcycle Operator's License ________Yrs	> 5 years experience (ask when received license)	
Good Health	Check NOT Diabetic, Asthmatic, Migraines	
No Medication, regular or intermittently	Check NO Antihistamines, Blood Pressure, Caffeine-based medication	
Wears Glasses/Contact Lenses?	Ensure are able to comfortably wear a full motorcycle helmet with face shield	
No heart, liver or kidney disorders	Check	
No Allergic reactions to alcohol	Check	
Any food allergies?	List:	
Height ________ft	Record	
Weight ________lbs	Record	
BMI _________	Record (calculate later)	
Weekly consumption of alcohol _______units	< 15 (f), < 20(m)	
Prepared to commit for 3 full days of testing (5-8 hours per day)	Positive	
Prepared to consume alcohol at about 10:00 a.m.	Positive	
Able to get to MHSRC without driving (we will provide a ride home, but they need to get to the test site)	Positive	

Remind Participants:

NO alcohol 24 hours prior to study
No eating for four hours before the study
No caffeine (coffee, tea, chocolate) on day of study
No medications on day of study
No energy drinks on day of study
We will provide box lunch for the participant on the study day

APPENDIX B – CAGE (ALCOHOLISM SCREENER)

Please respond honestly to the following questions about your alcohol drinking habits. State 'YES' or 'NO' in response to each of the following questions:

Have you ever felt you should *cut* down on your drinking?	Yes / No
Have people *annoyed* you by criticizing your drinking?	Yes / No
Have you ever felt bad or *guilty* about your drinking?	Yes / No
Have you ever had a drink first thing in the morning to steady your nerves or get rid of a hang-over (*eye-opener*)?	Yes / No

APPENDIX C – PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

For most people, physical activity (*involved in riding a motorcycle)* should not pose any problem or hazard. The Physical Activity Readiness Questionnaire has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of (*riding*) activity most suitable for them.

1. Has your doctor ever said you have heart trouble?

    Yes or No (circle)

2. Do you frequently suffer from pains in your chest?

    Yes or No (circle)

3. Do you often feel faint or have spells of severe dizziness?

    Yes or No (circle)

4. Has a doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by a (*riding*) exercise, or might be made worse by a (*riding)* exercise.

    Yes or No (circle)

5. Is there a good physical reason not mentioned here why you should not be involved in a (*riding*) program even if you wanted to?

    Yes or No (circle)

6. Are you over 35 and not accustomed to vigorous (*riding)* activity?

    Yes or No (circle)

Referenced from The American College of Sports Medicine, <u>Guidelines for Exercise Testing and Prescription, Fifth Edition.</u>

For Experimenter: Answering "yes" to questions 1, 2, or 3 means participant cannot participate in this study.

APPENDIX D – TEST MOTORCYCLE INSTRUMENTATION

Sensor Specifications

The DGPS system, the Microstrain IMU (attached to the helmet), and the crossbow IMU (attached to the motorcycle) represent the Safebike sensors for which performance specifications are relevant.

Navcom S F-2050 G DGPS System

RTK Positioning <10kms (Software option) (RMS):
Horizontal: 1 cm + 1ppm
Vertical: 2 cm + 1ppm
Data Latency:
Position Velocity Time: < 20 ms at all rates
Raw measurement data: < 20 ms at all rates
Velocity:
0.01 m/s

The Intelligent Vehicles Lab has developed a means to determine the dynamic accuracy of DGPS systems, and has published results [1]. From Table 1, it is shown that Dual Frequency, Carrier Phase DGPS systems offer accuracies better than 10 cm at speeds of 30 MPH:

Table 1. Position error for LONG baseline RTK

SPEED MPH	Mean error, cm	Standard Deviation, cm	Average Latency, mSec
10	7.9	3.8	42.4
20	9.6	8.3	46.0
30	8.9	7.8	39.5

Crossbow IMU (Motorcycle IMU)

The inertial measurement unit used on the motorcycle is a Crossbow IMU 400, six degree of freedom unit providing three axes of acceleration (lateral, longitudinal, and vertical) and providing three axes of rotational rates (roll, pitch, and yaw). The performance specifications for this IMU are provided in Figure 1.

Specifications	IMU400CD-100	IMU400CD-200	Remarks
Performance			
Update Rate (Hz)	> 100	> 100	Continuous Update Mode
Start-up Time Valid data (sec)	< 1	< 1	
Angular Rate			
Range Roll, Pitch, Yaw (°/sec)	± 100	± 200	
Bias: Roll, Pitch, Yaw (°/sec)	<± 1.0	<± 1.0	
Scale Factor Accuracy (%)	< 1	< 1	
Non-Linearity (% FS)	< 0.3	< 0.3	
Resolution (°/sec)	< 0.025	< 0.05	
Bandwidth (Hz)	> 25	> 25	-3 dB point
Random Walk ($°/hr^{1/2}$)	< 2.25	< 4.5	Typical
Acceleration			
Range X/Y/Z (g)	± 4	± 4	
Bias: X/Y/Z (mg)	<± 12	<± 12	
Scale Factor Accuracy (%)	< 1	< 1	
Non-Linearity (% FS)	< 1	< 1	
Resolution (mg)	< 0.6	< 0.6	
Bandwidth (Hz)	> 75	> 75	-3 dB point
Random Walk ($m/s/hr^{1/2}$)	< 1.0	< 1.0	
Environment			
Operating Temperature (°C)	-40 to +71	-40 to +71	
Non-Operating Temperature (°C)	-55 to +85	-55 to +85	
Non-Operating Vibration (g rms)	6	6	20 Hz - 2 KHz random
Non-Operating Shock (g)	1000	1000	1 ms half sine wave
Electrical			
Input Voltage (VDC)	9 to 30	9 to 30	
Input Current (mA)	< 250	< 250	
Power Consumption (W)	< 3	< 3	at 12 VDC
Digital Output Format	RS-232	RS-232	
Analog[1] Range (VDC)	± 4.096	± 4.096	Pins 8, 9, 10, 12, 13, 14
	0 to 5.0	0 to 5.0	Pins 5, 6, 7
Physical			
Size (in)	3.0 x 3.75 x 3.2	3.0 x 3.75 x 3.2	Ind. mounting flanges
(cm)	7.62 x 9.53 x 8.13	7.62 x 9.53 x 8.13	Ind. mounting flanges
Weight (lbs)	< 1.4	< 1.4	
(kg)	< 0.64	< 0.64	
Connector	15 pin sub-miniature "D" male		

Figure 1. Crossbow (motorcycle) IMU specifications.

Microstrain IMU (Helmet)

The Microstrain IMU is also a six-axis sensor; three axes of acceleration, and three axes of rotational rates. The performance specs for the Microstrain IMU are provided in Table 2.

Table 2: Microstrain IMU (Helmet) specifications.

Range	yaw: ± 180 degrees
	pitch: ± 180 degrees
	roll: ± 70 degrees
A/D Resolution	12 bits
Digital Filter	Infinite Impulse Response (IIR) User programmable weighted moving average
Angle Resolution (no digital filtering)	Pitch: 0.30 degrees (typical)
	Roll: 0.25 degrees (typical)
	Yaw: 0.50 degree (typical)
Angle Resolution (most aggressive digital filtering)	Pitch: < 0.1 degrees
	Roll: < 0.1 degrees
	Yaw: < 0.1 degrees
Resolution specs. taken during static motions	
Accuracy	Pitch: ±0.93 degree typical (yaw from 0 - 360 degrees & roll=0 degrees)
	Roll: ±0.33 degree typical (yaw from 0 - 360 degrees & pitch =0 degrees)
	Yaw: ±1.0 degrees typical (pitch & roll=0 degrees)
Accuracy is defined as the square root of the sum of the errors squared (non repeatability, temperature coefficients & nonlinearity)	
Angle measurement nonlinearity (pitch & roll)	±0.23% F.S.
Angle measurement repeatability	Pitch: 0.07 degrees (typical)
	Roll: 0.07 degrees (typical)
	Yaw: 0.26 degrees (typical)

APPENDIX E – TEST COURSE PRACTICE

This table describes the evaluation of subjective performance to determine error-free performance on the practice rides. The participant received audio instructions over the helmet headset during each ride and the research provided verbal feedback after each ride regarding course instructions and observed performance.

Task	Observed Behavior	Verbal Discussion Points after Each Practice Ride
Inline Weave	1. Ensure rider does not touch any cones with motorcycle tires 2. Ensure rider does not put feet down 3. Ensure rider keeps motorcycle inside yellow lines	1. Encourage rider to stay as close to cones as possible 2. Encourage rider to choose a speed that allows completion of both swerves that helps them avoid braking and putting feet down in course 3. Remind rider to stay inside yellow lines
Offset Weave	1. Ensure rider does not touch any cones with motorcycle tires 2. Ensure rider does not put feet down 3. Ensure rider keeps motorcycle inside yellow lines	1. Encourage rider to stay as close to cones as possible 2. Encourage rider to choose a speed that allows completion of both swerves that helps them avoid braking and putting feet down in course 3. Remind rider to stay inside yellow lines
Hazard Avoidance	1. Observe speed as rider approaches barrier (subjective) 2. Ensure rider went in direction indicated by light 3. Ensure rider passes between the cones making up the exit lane	1. Question what speed rider was doing and ask them to confirm correct speed for task (12 mph) 2. Remind rider to respond immediately to light and to go in direction indicated
Curve Circuit	1. Observe speed in circuit 2. Ensure rider completes two laps of circuit 3. Watch to see that rider keeps motorcycle inside yellow lane boundaries	1. Question what speed rider was going in straight segment (before first curve) and ask them to confirm the correct speed (20-25 mph) 2. Remind rider to choose a consistent speed for circuit (not including straight) that allows them to complete all curves and stay inside lines

		3. Remind rider to complete two laps of circuit
Emergency Stop	1. Observe speed on approach to target zone. 2. Observe stop to ensure rider stops fully and under control.	1. Question what speed rider was doing on approach to target zone (12-18 mph) 2. Remind rider not to anticipate horn by slowing down or choosing a speed slower than the minimum 3. Remind rider to respond immediately to horn by stopping quickly and safely in shortest distance possible

APPENDIX F – NASA RTLX

NASA RTLX

Think about the experimental task or tasks you just completed. Please place a vertical line through each scale for the six characteristics summarized below:

Example:
Happiness
How much happiness did you feel during the task?

LOW — HIGH

Mental Demand

How much thinking, deciding, calculating, remembering, looking, searching, did you need to do?

LOW — HIGH

Physical Demand
How much physical activity was required?

LOW — HIGH

Time Pressure
How much time pressure did you feel due to the pace of the tasks?

LOW — HIGH

Performance
How successful do you think you were in accomplishing the goals of the task set by the experimenter?

GOOD — POOR

Effort
How hard did you have to work mentally and physically to accomplish your level of performance?

LOW — HIGH

Frustration Level
How insecure, discouraged, irritated, stressed and annoyed during the task?

LOW HIGH

APPENDIX G – RIDING CAPABILITY QUESTIONNAIRE

How intoxicated do you feel at this moment?

Please mark the line to indicate your feelings

Not at all ________________________________ Extremely

How impaired do you feel your performance would be riding a motorcycle right now?

Please mark the line to indicate your feelings

Not at all ________________________________ Extremely

How willing would you be to operate a motorcycle for an unimportant though gratifying reason? (e.g., ride to a party)

Please mark the line to indicate your feelings

Not at all ________________________________ Extremely

How willing would you be to operate a motorcycle for an important, but avoidable reason? (e.g., give a friend a ride home who feels mildly ill, when they could get a taxi)

Please mark the line to indicate your feelings

Not at all ________________________________ Extremely

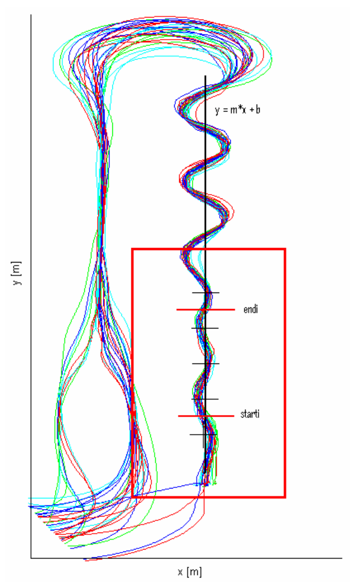
How willing would you be to operate a motorcycle for an urgent purpose? (e.g., ride to a hospital to help a sick relative who has no one else to contact)

Please mark the line to indicate your feelings

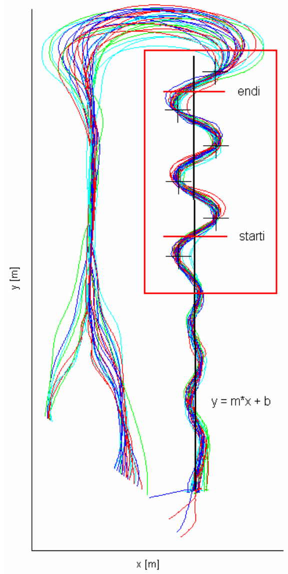
Not at all ________________________________ Extremely

APPENDIX H – DELINEATION OF MEASUREMENT WINDOWS FOR RIDING TASKS

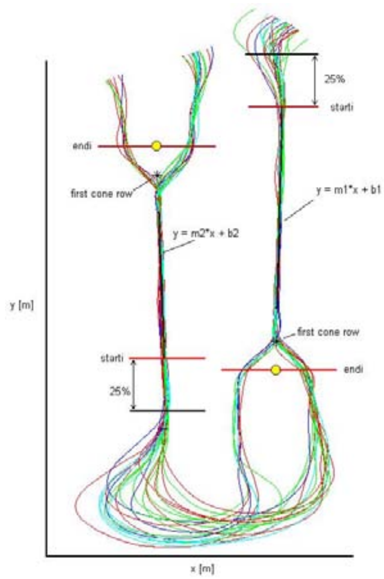
For each of the six riding tasks within the test course (see Figure 2), start and end points were established using the GPS position data for the motorcycle based on the first location where all riders were ready for the task (e.g., on the straight section approaching the light box in the decision task) and the last location where all riders were consistently performing the task at hand (e.g., had not yet initiated the turn around to align for the next task). The data between the start and end points for each task are shown in this Appendix H. The region bounded by these points delimited the spatial and temporal windows over which the dependent measures were computed (see Section 2.4.2.3). In addition, all recorded data was referenced to distance in 10 cm increments along the path of the test course in order to compare performance of participants at different locations across trials.



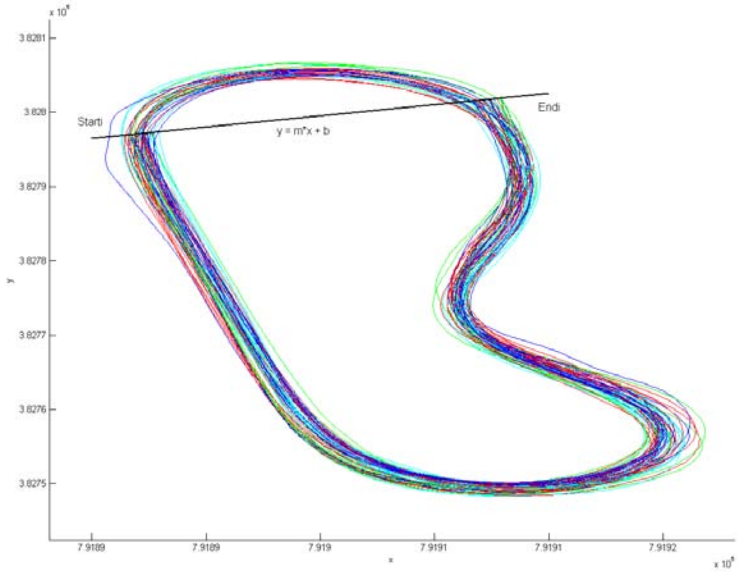
Inline weave task measurement window.



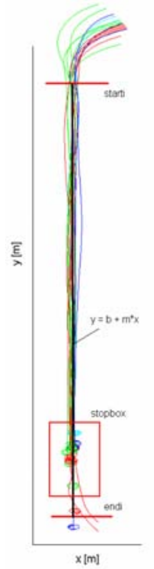
Offset weave task measurement window.



Hazard avoidance measurement windows.



Curve circuit task measurement windows.



Emergency Stop task measurement window.

APPENDIX I – RESULTS FOR COVARIATES USED IN ANALYSIS

The F and p-values for each covariate in the model are listed for variables that had a significant main effect of BAC. The Pearson correlation (r) and associated p-value are listed for the covariates correlation with overall performance in the BAC conditions. (NS = Not significant; N/A means "not applicable" because variable cannot be computed using the ANCOVA model)

			Covariates		
Tasks	**Measures**	**BAC**	Baseline	Drinks per Week	Years of Riding Experience
Inline Weave	Missed or Hit Pylons	NS			
	Minimum Passing Distance between Motorcycle and Pylons	NS			
	SD Passing Distance between Motorcycle and Pylons	NS			
	Number of Times Lane Boundaries Crossed	NS			
	Number of Times Feet Came off Pegs	NS			
Offset Weave	Missed or Hit Pylons	N/A			
	Minimum Passing Distance between Motorcycle and Pylons		F(1,112)=33.58, p<0.0001; r=0.42, p<0.0001	NS	NS
	SD Passing Distance between Motorcycle and Pylons	NS			
	Number of Times Lane Boundaries Crossed	NS			
	Number of Times Feet Came off Pegs	NS			
Hazard Avoidance 1.5s	Mean Speed at Light Ignition	NS			
	Reaction Time		F(1,112)=23.51, p<0.0001; r=0.35,	NS	NS

			p<0.0001		
	Passing Distance to Obstacle	NS			
	Braking Events	N/A			
Hazard Avoidance 2.5s	Mean Speed at Light Ignition	NS			
	Reaction Time	NS			
	Passing Distance to Obstacle		F(1,112)=13.03, p<0.0001; r=0.27, p=0.001	F(1,112)=6.04, p=0.02; r=-0.26, p=0.0014	NS
	Braking Events	NS			
	Incorrect Direction Choice (both tasks)	N/A			
Curve Circuit	Maximum Speed (Straight)		F(1,112)=629.47, p<0.001; r=0.87, p<0.0001	NS	NS
	Minimum Speed (Curves)	NS			
	SD of Speed (Total Circuit)		F(1,112)=483.7, p<0.0001; r=0.86, p<0.0001	NS	F(1,112)=4.22, p=0.042; r=0.19, p=0.02
	Number of Times Lane Boundaries Crossed	NS			
Emergency Stop	Speed at Horn Trigger	NS			
	Reaction Time to Horn	NS			
	Elapsed Time to Maximum Deceleration		F(1,112)=104.6, p<0.0001; r=0.23, p=0.006	NS	NS
	Stopping Distance	NS			
	Deviation in Stopping Path		F(1,112)=10.07, p<0.002; r=0.60, p<0.0001	NS	NS

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