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Glancing and Stopping Behavior of Motorcyclists and Car Drivers at Intersections

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Abstract

For the past decade, motorcycle fatalities have risen while other motor vehicle fatalities have declined. Many motorcycle fatalities occurred within intersections after a driver failed to see a motorcyclist. However, little is known about the behavior of motorcyclists when they negotiate an intersection. A study was undertaken to compare the behavior at intersections of an experienced group of motorcyclists when they were operating a motorcycle with their behavior when they were driving a car. Each participant navigated a course through low-volume, open roads. Participants wore eye-tracking equipment to record eye-glance information, and the motorcycle and car were instrumented with an onboard accelerometer and Global Positioning System apparatus. Results showed that participants were more likely to make last glances toward the direction of the most threatening traffic before they made a turn when they were driving a car than when they were riding a motorcycle. In addition, motorcyclists were less likely to come to a complete stop at a stop sign than car drivers. These results suggested that motorcyclists were exposing themselves to unnecessary risk. Specifically, motorcyclists frequently failed to make proper glances and practice optimal riding techniques. The behavior of the motorcyclists was compared with the current Motorcycle Safety Foundation curriculum. The results suggested that threat-response and delayed-apex techniques should be added to the training curriculum.

According to the Fatality Analysis Reporting System, there were 38,444 fatal crashes in the United States in 2004 (1). Motorcycles were involved in 4,100 deaths and of these, 1,152 were intersection or intersection-related crashes. In 2008, fatal crashes dropped to 34,017 (–11.5%), yet fatal motorcycle crashes increased to 5,387 (+31.4%) and intersection-related crashes increased to 1,590 (+38%). In a study of motorcycle crashes by the motorcycle industry in Europe in 2003,500 of the 921 (54.3%) crashes investigated occurred at intersections (2). Clearly, intersection crashes involving motorcycles are on the rise.

This study examined the behavior of motorcyclists when they approach intersections and potential crash configurations. The research goal was to describe glancing and stopping

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behavior of drivers versus motorcyclists. The behaviors of the motorcyclists were compared with the current Motorcycle Safety Foundation (MSF) curriculum (3). A series of tactics and an overall strategy for safe intersection negotiation to supplement MSF training are proposed.

LIKELY CAUSES OF PROBLEM

Pradhan et al. examined the ability of novice and experienced drivers to anticipate hazards in several scenarios equating hazard anticipation with driver glances toward the potential hazard (4). The study hypothesized that experienced drivers were more likely to glance into an area of potential hazard in each of several scenarios. Pradhan et al. examined the glancing and stopping behaviors of drivers at two intersection configurations. One intersection scenario consisted of a stop sign, a stop line, and a pedestrian crosswalk (Scenario 6). However, the sidewalk on the right side of the road was difficult for the driver to see because it was concealed by a hedge. The researchers recorded driver glancing and stopping behavior. Specifical1y, three measures were collected as to whether (*a*) the driver glanced toward an area where a potential threat might emerge (such as a pedestrian or bicyclist emerging from the obstructed view to the right), (*b*) the driver came to a complete stop before the crosswalk area, and (*c*) the driver glanced toward the areas of conflicting traffic as he or she started forward into the intersection.

The second intersection configuration involved a driver who was making a left turn across a conflicting lane of through traffic (left turn across path–opposite direction, or LTAP-OD) at a site involving a limited sight line ahead (Scenario 9). Hypothetically, a vehicle traveling at high speed could emerge from the limited sight line ahead and present the turning driver with a dangerous situation. Every second that a driver glances toward his or her intended turn without checking toward the short sight line ahead gives opposing traffic an additional second to encroach and possibly collide with the turning driver's vehicle. A glance immediately before or after the commencement of the turn reduces that possibility.

To explain how a potential hazard may be neutralized, Scenario 6 from the research by Pradhan et al. may be used as an example (4). As a driver approaches the intersection, the most immediate potential hazard is a pedestrian or bicyclist emerging from behind the hedge to the right. Neutralizing the hazard would involve glancing toward the area of the hedge to ensure that a pedestrian does not emerge at the last moment and being prepared to stop if a pedestrian does emerge. Once a driver moves past the sidewalk, the next most immediate hazard becomes the approaching traffic or the potential for an approaching vehicle in the near lane (to the left in the United States). Therefore, most training publications suggest a last look left. However, if there were a very short sight line to the right, the most immediate hazard would be the traffic that may emerge from the right. When negotiating through an intersection, drivers who glance in the direction of the most immediate hazard and plan accordingly will be in an advantageous position to neutralize that threat.

The research presented in this study builds on the research by Pradhan et al. but differs in three aspects in that the current study

1. Was conducted in the southwest United States (Pradhan et al. conducted their research in Massachusetts),
2. Examined glancing and stopping behaviors by motorcyclists as well as drivers, and
3. Addressed the pavement glancing behaviors of drivers and motorcyclists.

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WHAT THIS RESEARCH EXAMINED

Glances Relative to Vertical Horizon (Pavement Glances)

Nagayama and Morita found that drivers' glance locations were more frequently at the horizontal line or above, wbereas motorcycle riders' glances were more frequently directed toward the road surface (5). Motorcyclists made 30% of their fixations toward the road surface. Drivers seldom glanced toward the road surface, preferring to look relatively far ahead at objects such as traffic signs.

The MSF basic rider handbook suggests that riders should "look well ahead, not down" (3, p. 37). This advice neglects the motorcyclists' concern when they encounter debris, potholes, or sand in the road. Road surface anomalies, although minor nuisances for a driver, are significant concerns for a rider. This study evaluated when pavement glances occurred and suggests occasions when maintaining a high visual horizon is most important for safety reasons.

Left Turns Across Conflicting Traffic

The MSF basic rider handbook utilizes the acronym SEE in its training: scan aggressively for hazards, evaluate the factors that create risk, and execute a margin of safety (3). The handbook offers specific rccommendations for turning: slow before entering the turn, look through the turn and keep the eyes moving, press the handlebar (countersteer), and roll on the throttle (keep from losing speed). A rider wbo looks toward the intended turn direction early and continuously glances toward his destination without glances to evaluate oncoming traffic would not be implementing the recommended SEE or look technique.

Sport bike training specialists Code and Chandler offer recommendations for negotiating curves that may be helpful if applied to turning (6). They suggest that riders continue straight longer, staying on the outside of the turn before steering more sharply toward the inside of the allowable turn. A gradual turn rather than a sharp turn requires the rider to be in the conflict area longer. Hough refers to this maneuver as "delayed apexing" (7). A rider who exhibits delayed apex turns and glances toward the direction of conflicting traffic at the last moment before turning limits the likelihood that another vehicle will close on his or her position before completion of the turn. A rider who starts the turn earlier and never glances toward impending traffic conflicts again will allow oncoming traffic additional time to encroach on his or her position, in contradiction of the MSF training. This study examines the frequency with which motorcyclists glance toward potential oncoming traffic.

Stopping for Stop Signs

As Pradhan et al. identified in their hidden-sidewalk scenario, drivers should be prepared for near-side pedestrians or bicyclists as they approach the stop line and before they move to the road edge (4). Stopping offers the side road driver more time to glance for traffic and leaves the area beyond the stop line as a safe zone for pedestrians and bicycles. Hole and Tyrrell showed that drivers who limit the scope of the search are more likely to miss the presence of an approaching motorcycle (8). Drivers who do not stop limit the search time and force themselves to process information concurrently rather than serially. A driver who fails to stop will be searching at the same time that he or she is negotiating through a turn in traffic and moderating speed. The current research compares the probability of stopping for drivers and motorcyclists.

Glance Sequence Before Intersection Entrance

Driver education programs often advocate a rule-based, left-right-left glance sequence at the entrance to an intersection. The left-right-left rule of thumb assumes that the most

immediate hazard will be in the nearest lane and to the left (in the United States). However, when subjects are taught a rule-based method, the ability to recognize hazards suffers when a single cue deviates from the normal pattern (9). In essence, if the most immediate hazard is anywhere other than to the left, driver performance will suffer and crash probability will likely increase.

Horrey et al. examined responses in a tactical command arena after participants were trained to respond to the most threatening event (10). When participants were encouraged to look toward one direction (a highlighted area), response times to threats in other areas were longer. Pritchett and Bisantz came to a similar conclusion when they examined aircraft radar detection tasks (11). Generalizing these findings to drivers suggests that when the most immediate hazard is anywhere other than to the left, the left-right-left search sequence will likely result in longer response times and more detection failures.

Rather than uniformly suggesting that drivers make a last look to the left when they turn left, training should instead suggest that drivers neutralize the most immediate hazard last. Neutralizing involves dealing with the most threatening unit first (whether visible or not). This is still a rule but it offers more flexibility while addressing the varying needs of different circumstances. For instance, if the driver is attempting a left turn at a location with a limited sight line to the right, the last look should be to the right in order to reduce the likelihood that a vehicle will encroach on the driver's or rider's location without notice.

When a driver is negotiating an intersection, the key is to limit the amount of time that the most immediate hazard is not monitored before the turn. As an example, if a driver glances to the shortest sight line last, he or she will reduce the possibility that a vehicle could arrive at the driver's position undetected.

In their research on natural decision making, Bisantz et al. proposed a linear rule-based education by training rules first and then exceptions to each rule (12). In the case of the intersection glances, drivers and motorcyclists may be taught to consider the most-threatening rule. However, a more effective strategy for training may be to reinforce why a driver must look in a particular direction at each point during a turn and under what situations the last glance may be in one direction and in other situations in the other direction. In the current study it is hoped to extend the MSF basic training that informs drivers to keep the eyes moving by explaining what to look for and when.

HYPOTHESES

The current research examines intersection behaviors of a person riding a motorcycle and of one driving a car. The glance behaviors of each person were recorded as he or she approached the stop line and departed the stop line. In addition, it was noted whether a complete stop was made at a stop sign. The information collected may be used for driver and rider training, road design, and sign placement. A goal of the research was to gain an understanding of when driver behavior research may be generalized to motorcyclists and when the two tasks are notably different.

There were five hypotheses. Each of the hypotheses related to the behavior of drivers and motorcyclists, most notably as they approached or departed from an intersection. G hypotheses are related to driver and rider glances. Hypothesis S1 is related to whether the motorcyclists and drivers stopped for the stop sign. For each hypothesis, the location at which the information will be collected is given in Figure 1 and Table 1.

The five null hypotheses are as follows:

Hypothesis G1. Drivers are as likely as motorcyclists to look downstream (as measured by the average vertical fixation position). These data were collected at Locations 8 and 9 and glance distribution throughout the course.

Hypothesis G2. Motorcyclists are as likely as drivers to glance at the road surface when they travel across a sandy surface or when they make a right turn into a side road. These data were collected at Locations 1,3 and 7.

Hypothesis G3. Drivers and motorcyclists are equally likely to make a glance to the right while they are approaching the stop line. These data were collected at Locations 2, 3, 4, 5, and 6.

Hypothesis S1. Drivers and motorcyclists are equally likely to make a complete stop at a stop line. These data were collected at Locations 2, 3, 4, 5, and 6.

Hypothesis G4. Drivers and motorcyclists are equally likely to make a last glance when, or immediately after, they start into the intersection toward the area from which the most immediate potential hazard could appear. These data were collected at Locations, 1, 2, 3, 4, 5, and 6.

METHODOLOGY

This study seeks to acquire relevant information necessary to differentiate the behaviors exhibited by individuals riding a motorcycle as compared with these same individuals driving a car. The sought information includes glancing and stopping behaviors exhibited by panicipants when driving a car and when riding a motorcycle. The locations of interest were stop sign locations at T-intersections and locations where motorcyclists attempted left turns across opposing traffic.

Participants

Thirty-two driver-motorcyclists were recruited through advertisements in *Motorcycle Consumer News* and throughout the membership of the Southwest Association of Technical Accident Investigators. Participants included 26 men and 6 women with ages ranging from 20 to 69 years. Of these participants, 6 had obtained a motorcycle license or endorsement within the previous 5 years, 13 had been licensed or endorsed for 6 to 19 years, and 13 had been licensed for 20 or more years. The average rider in this research attended 1.7 training classes. Seven motorcyclists rode for less than 6,000 mi per year, eight rode 7,000 to 12,000 mi, and 10 rode more than 13,000 mi per year. Of these higher-mileage motorcyclists, four were riding instructors who rode more than 100,000 mi per year as part of their occupation. Of the 32 participants, equipment failures, lost eye calibrations, and experimenter error were related to the loss of some information. Eye-tracking data were collected from 23 people during both riding and driving sessions.

Equipment

The experimental vehicles included a 2008 Kawasaki Ninja 650R and a 2009 Dodge Charger. The Ninja was selected because of its moderate size and upright riding position. Vericom 4000 triaxial accelerometers were mounted onboard each vehicle. On the motorcycle, string potentiometers monitored front and rear brake use. In the vehicle, string potentiometers recorded accelerator and brake pedal displacement.

A 2009 Mercury Marquis was used as the lead vehicle. Mock brake lights were mounted to the rear of the Marquis. The mock brake lights and light-emitting diode signals were

activated by a wireless system that was specifically designed for this research. The response results from the light stimuli will be reported in a separate paper.

Inflatable pedestrians were dressed and placed at the roadside of three locations on the route, and a researcher walked along the road edge at the far end of the course (opposite the command center). The purpose of the live pedestrian was to maintain the scene across trials and to provide drivers with some additional activity. A fourth vehicle, a 2009 Toyota Prius, was driven past the participants during the practice lap to reinforce the idea that the road was open to traffic.

Procedure

After verification of licensure and signing an informed consent, each participant completed a questionnaire regarding riding experience, rider training, and type of motorcycle normally ridden. The questionnaire also contained several questions to verify that a participant's performance was not negatively influenced by some confounding factor (such as drug use or health issues).

Each participant was fitted with the MobileEye eye-tracking system by Applied Science Laboratories. The MobileEye system is noted for its accuracy and mobility and has been utilized in more than 100 published studies. The MobileEye consists of safety glasses with a forward-facing camera and a camera aimed toward the corneal reflections of the eye. These two images are then overlaid during calibration. Before each drive, the eye-tracking system was focused and calibrated. To calibrate the system each rider was asked to fixate on 10 known points, which are then identified in the system software used to overlay crosshairs on the forward view. The crosshairs indicate the eye position of the participant. Once calibrated, the eye-tracking glasses and helmet were worn for both the riding and the driving portions of the experiment. The eye-tracking glasses were specifically designed for this experiment to perform as both an eye-tracking system and safety glasses.

After the eye-tracking system was fitted and calibrated, each participant was escorted to the car or the motorcycle. The order in which each participant completed the experiment was based on a randomized assignment design. Each participant drove both the car and the motorcycle for approximately 25 min. When riding or driving, participants traveled five laps around a housing development that had not yet been fully completed.

Figure 1 shows the layout of the course. The participants encountered 5 to 10 vehicles in the 50 min of driving and riding. The housing development had a few potential buyers driving through and construction workers. During both the motorcycle and car portions of the experiment, the participants traveled one 2-mi sighting lap to familiarize themselves with the car or motorcycle, followed by four laps through the course during which data were collected. Therefore, each participant traveled the course 10 times, 5 on a motorcycle and 5 in a car.

Participants were told to drive and ride as they normally would while obeying all laws. They were asked to follow the lead vehicle and were reminded that the roads were open to traffic. The tasks for each participant were to respond to light-emitting diode lights, which prompted the rider to swerve or brake to stop. Participants were also asked to tap the brakes when the brake lights of the lead vehicle were illuminated. The results of these tests are part of a sister study, but these tasks were a ruse for this experiment involving the examination of eye glance and stopping behaviors at each intersection.

Information was collected at seven locations. Six were intersections, and the seventh was a location in which sand had washed across the road. The layout of the course and the location

of each of these intersections are shown in Figure 1 and described in Table 1. The average eye fixation location and variance of eye fixation location data were collected throughout the course.

Data Collection

The MobileEye software plots crosshairs over the location in the video at which the participant was looking. At times the eye movements could not be recorded, and the crosshairs would not appear in the video. If there were intermittent crosshairs and one crosshair touched down in the proper area, a positive glance was recorded (value = 1). If crosshairs were seen but not depicted in the area of concern, no glance was recorded (value = 0). If there were no crosshairs at the time of concern, no result was recorded. During a turn, a look means that the driver–rider glanced to the extent of the sight line, not simply in that general direction.

When drivers and motorcyclists were approaching a left turn across traffic traveling in the opposite direction, the scoring of glances was slightly different. From the moment the motorcycle started to lean left or the car began to move left, it was determined whether the driver was looking forward or looked forward after that moment toward the direction of the opposing traffic. If there was such a glance, the glance was recorded (value = 1). If no glance was made at the start of the turn or immediately after the commencement of the turn, a failure to glance was recorded (value = 0). At each of these locations, the sight line ahead was limited and a fast-moving vehicle in the opposing lane could pose a danger if it materialized.

When making right or left turns from a side road, a driver or rider should have two concerns. First, he or she should be concerned with pedestrian and bicycle traffic, particularly pedestrian and bicycle traffic coming from the right, giving the driver limited time to respond. Once stopped, drivers should devote attention to vehicles that might strike them when they were pulling out. The scoring of a proper glance (value = 1) occurred if the operator glanced right before arriving at the stop line and glanced left when starting from the stop line or later (regardless of whether he or she stopped). If the operator did not glance both right and left at the proper times, no glance was recorded (value = 0).

There were three raters. If there was a difference in scores between the first and second rater, the third rater reviewed the eye-tracking tapes, and in the opinion of that rater, the score that best reported the glance performance was used. The objective was to evaluate whether the operators looked at the extent of the sight line and within the road (a 28-ft width). During pavement glances, a glance was recorded if the driver or rider glanced toward the pavement anywhere near the inside corner of the turn immediately before or during his or her turn right. Because of the relatively large areas that defined a proper glance, less than 1% of the scores were different between raters.

RESULTS

A repeated-measure analysis of variance was utilized to test the effects of both mode of transportation and threat. There were two transportation mode factors: motorcycle and car. There were five threat conditions: LTAP-OD, left turns, right turns, not making a pavement glance, and stops. Participants' behavior relative to both threats (F_4 = 8.011, P = .001) and transportation mode (F_1 = 23.096, P = .000) were statistically different. A Bonferroni adjustment for multiple comparisons was applied and showed that left-turn glances were significantly different from LTAP-OD [standard error (SE) = 0.71, P = .001], right turns (SE = 0.71. P = .14), and no pavement glance (SE = 0.91, P = .024). Performances across the

five threat conditions were statistically dissimilar for riders and drivers (SE = 0.048, $P = .000$).

Glances

Nineteen of the 23 participants made fewer glances toward the area of the most significant potential hazard immediately before turning when they were riding the motorcycle compared with when they were driving a car. When they were making an LTAP-OD, drivers made a last glance toward the restricted sight line ahead 60% more often than motorcyclists did ($t_{22} = 2.42$; $P = .025$) (Locations 2 and 5). Participants made 50% more glances to the right when they were approaching the stop sign while driving ($t_{22} = 2.21$; $P = .039$) (Locations 2, 3, 4, 5, and 6). When making a left turn from the area of a stop line, drivers were 23% more likely to make a last glance toward the direction of the most immediate potential hazard (the direction of a short sight line) (Locations 2, 3, 4, 5, and 6). Drivers made a last glance toward the most dangerous area 79% of the time and motorcyclists glanced in those directions 64% of the time, yet the difference was not significant ($t_{22} = 1.6$; $P = .124$) (see Table 2).

Motorcyclists made considerably more glances toward the pavement than drivers ($t_{22} = 3.47$; $P = .00$) (Locations 1, 3, and 7). A driver's search area is restricted by the car's A-pillars, rear-view mirror, dashboard, and roof. A rider has no similar structural limitations. Another observation was that drivers tend to recline backward, whereas motorcyclists tend to remain erect or lean slightly forward (the posture of riders may differ on other motorcycles and with other drivers). However, motorcyclists compensated for their more forward head angle. The average vertical fixation location for motorcyclists and drivers did not differ significantly when the head angle difference was accounted for ($t_{22} = 0.02$; $P = .96$). Therefore, even though riders in this research were leaning forward, they apparently leaned their heads back further to compensate.

Motorcyclists made more pavement glances yet did not have a significant different vertical glance position. These results suggest that the variance of glances for motorcyclists must have been larger, which it was. Motorcyclists' search area was nearly 10 degrees larger both vertically and horizontally. The search area was measured from the 16th-percentile glance coordinate to the 84th-percentile glance coordinate (one standard deviation) both vertically and horizontally. The larger horizontal variance of the search area for motorcyclists was nearly significant ($t_{22} = 1.79$; $P = .09$). The vertical variance was significant ($t_{22} = 2.58$; $P = .02$). Overall, the rider search area (width by height) was larger than that of the driver ($t_{22} = 2.09$; $P = .05$). The average driver's glance location was 1 degree to the right of the average motorcyclist glance location, which was not significant ($t_{22} = 0.587$).

The glance performance of participants with 5 years of licensure or less was compared with that of participants who were licensed for more than 5 years. Those two experience groups did not differ significantly in pavement glances, glances in left turns, glances in right turns, or vertical position (when they were driving or riding). Experienced motorcyclists maintained an average glance location 2 degrees to the left of straight ahead, whereas those with less than 5 years of riding maintained an average fixation location nearly 9 degrees to the right. This relationship was significantly different ($F_1 = 6.281$). On U.S. roads, this result means that the experienced riders were attending to traffic ahead and oncoming traffic more effectively and that inexperienced riders spent more time glancing at objects off the road to the right. There was no difference in horizontal glance position of drivers ($F_1 = 0.773$).

Stops

Only 2 of 22 participants came to a complete stop more often when they were riding the motorcycle. Drivers came to a complete stop at the same stop signs 77% more often than motorcyclists. Sixty-nine percent of drivers made a complete stop, whereas only 39% of the motorcyclists did (t_{22} = 2.74: P = .012). Most motorcyclists exhibited a desire to remain upright, some weaving the front tire left and right to do so.

DISCUSSION OF RESULTS

Glances

The participants in this research were recruited from magazines for motorcycle enthusiasts. Therefore, there were several avid riders, including a few instructors. The participants in this research were relatively well trained and experienced compared with what would be expected of the average rider. The relative experience of this group may be most evident in the analysis of the average vertical glance locations for drivers and motorcyclists, which were nearly identical. The same result would not be expected if a less sophisticated group was being tested. However, even with these motorcyclists, search areas were more than 5 degrees larger than those for drivers for both breadth and height. A search area that is 5 degrees larger has considerable safety implications. For example, if the drivers maintain a fixation position 4 s ahead, the left and right road edges would be within 6 degrees of straight forward. Given that motorcyclists maintained glances out to 10 degrees suggests that there were many more off-road glances by motorcyclists.

Without a constrained search area, and with more concern for roadway imperfections, motorcyclists made many more glances toward the pavement when they were riding the motorcycle. Most motorcyclists would glance at the pavement at the inside of a right turn, presumably for sand or debris. Motorcyclists made 30% more pavement glances at right turns and when approaching sand across the road surface. The right-turning movement by vehicles has been associated with a high incidence of pedestrian and bicyclist crashes that approach from the right (13).

Motorcyclists are much more vulnerable than drivers, so one may assume that they would be more cognizant of approaching traffic. However, when faced with the same scenarios on a motorcycle as with driving a car, the motorcyclists in this research made significantly fewer glances toward areas of potential conflict immediately before they started a turn. One possible cause of this relatively poor performance is that many of these motorcyclists reported that they were taught to follow your nose when they were making a left turn. The rider's concern for motorcycle control may be at the expense of intersection safety. Motorcyclists using a delayed apex turning path (later glance, later turn, and less time to turn) reduce their time of exposure without an anticipatory glance in three ways (7). First, a sharper turn reduces their time across the opposing lane of traffic by a small time increment (about 0.1 s). Second, the time the rider moves forward reduces the exposure time by ¼ to 1 s depending on the speed of the turn and the distance moved forward. Last, and most important, a rider who looks toward his or her destination seconds before beginning the turn without looking for approaching traffic will give approaching traffic additional time to close on the rider's position. All three factors associated with the concept of a delayed apex reduce the time the rider is vulnerable to oncoming traffic. Therefore, although the current training does not apply a delayed apex to intersection turning, it appears that the training may generalize to intersections. A later turn also separates the braking and turning more clearly, reducing the chance that overlapping friction demands will overwhelm available friction, causing a crash. The current research is consistent with that by Pradhan et al. (4) (see Table 3).

These motorcyclists failed to glance toward oncoming traffic for 2 s and up to 6 s before they initiated a turn. A vehicle traveling 50 mph will travel 440 ft in 6 s. A delayed apex turn allows for a later, timelier glance and shorter exposure to conflicting traffic. Also, by the time a rider becomes aware of an oncoming vehicle, he or she may be in a significant lean. The MSF trains motorcyclists to first straighten the bike before they brake hard (3). Therefore, response options and handling when the motorcycle is leaning are limited. As a means of reducing the probability that an oncoming vehicle will sneak up on a motorcyclist, the rider needs to limit his or her exposure. Riders can limit their exposure to conflicting traffic if they implement the MSF training and also consider the tactics developed in this research. Therefore, a proper turn would include slowing, glancing toward the intended destination to ensure that it is clear, moving forward, glancing ahead immediately before turning, and initiating a sharper turn toward the side road.

Stops

Although it would be preferable to address search patterns and stopping separately, it is clear that they are entwined. At times, motorcyclists appeared to want to do anything to avoid putting their foot to the ground when they were approaching a stop sign. Some riders implemented a weave technique to allow them to remain erect while moving at a low speed. Clearly this maneuver added effort to remain erect, reduced time and cognitive resources available for searching, and was associated with fewer glances toward areas of the greatest potential hazard. In this study, the area of greatest potential hazard was toward the short sight line (if the sight line was less than 300 ft) or to the left at locations of longer sight lines.

Drivers in the current study made a complete stop 66% of the time. These results are consistent with previous research, which shows that drivers made complete stops 61%, 76.9%, and 73.4% at various intersections (4, 14, 15). In comparison, motorcyclists stopped at only 39% of the stop signs.

The most common explanation by turning operators involved in intersection crashes was that they looked but failed to see (16, 17). It is common to hear about drivers failing to see motorcyclists. However, if the rider fails to stop and looks but fails to see, the rider will be giving the main road driver less time to respond to his or her actions. Rider training should stress the need for motorcyclists to put a foot down and make a complete stop.

SUMMARY

Among a group of rather experienced motorcycle riders, the frequency of safe glancing and stopping behaviors at intersections paled in comparison with the behavior in driving the same route in a car. Motorcyclists made more glances at the pavement (Hypothesis *G*2). On the basis of the significantly larger search areas exhibited by motorcyclists, it is apparent that they made many more off-road glances than car drivers did. In addition, motorcyclists made more glances toward the pavement and fewer glances toward areas of potential pedestrian and bicycle conflicts. Motorcyclists who perform as they did in this study place themselves in a precarious situation relative to detecting other vehicles, bicycles, and pedestrians in an intersection.

Hypothesis *G*1 was related to the ability of drivers and motorcyclists to maintain a glance position far downstream. The base of a motorcyclist's viewing window is lower than that of a car driver. Motorcyclists lean forward and are not constrained by a dashboard like drivers. Despite these factors, the rather experienced group in this study maintained a similar downstream glance position when riding and when driving.

When making left turns across conflicting traffic, motorcyclists were significantly less likely to make a last glance ahead (toward potential conflicting traffic) (Hypothesis *G*4). Instead, motorcyclists tended to look toward the side road, in the direction they wanted to go, and to negotiate the corner gradually without making an effort to look ahead for several seconds. Motorcyclists were also less likely to make a glance to the right before arriving at the stop line (Hypothesis *G*3).

Last, motorcyclists were much less likely to stop at a stop line (Hypothesis *S*1). Once a rider fails to stop, he or she must process multiple tasks at once. The rider must attend to his or her search for traffic while also attending to vehicle guidance and control. Motorcyclists who fail to stop are placing themselves in a more difficult situation. Stopping also offers motorcyclists and drivers more time to glance for traffic and a better opportunity to assess the environment.

The participants had a range of experience and training. However, the current study measured the performance of a rather experienced group of participants at a specific location and on a specific motorcycle. If the experience of the motorcyclists, the test location, and motorcycle are changed, the results may be different.

Since this was one of the first studies involving rider eye tracking, the possibility cannot be eliminated that the light-traffic location and the use of a lead vehicle influenced the results. However, the encouraging result was that these drivers exhibited similar glancing and stopping behavior to that of drivers in previous research that was conducted in various traffic conditions (4, 14, 15, 18).

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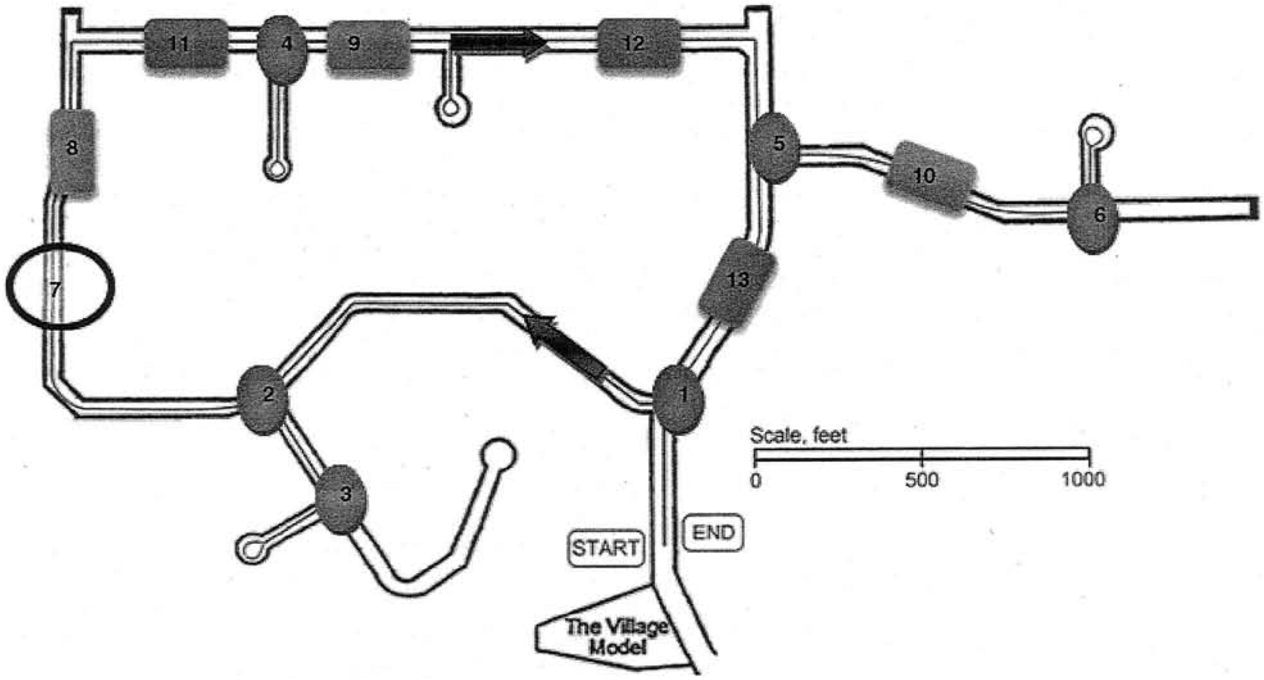

FIGURE 1.

Download from VBOX Global Positioning System recording ovarlaid onto image of survey map showing coordinates of course driven by eaeh participant; starting and ending point = (0, 0).

TABLE 1

Description of Station Numbers

Station Number	Behavior	Data Collected
1, 3, 4, 6	Right turn	Does driver or rider glance right (for pedestrians or bicycles), left, then right when turning?
2, 5, 6	Left turn across oncoming traffic	Glance for opposing traffic immediately before turning left into side road from main road.
2, 3, 5	Left turn	When exiting side road, did driver (*a*) glance right when approaching the stop line and (*b*) glance left after starting forward?
1, 3, 4, 6, 7	Pavement glances	Right turn: did driver or rider glance at pavement when turning or crossing sandy road?
8, 9, 10	—	Locations where pedestrians were placed along the roadside.
13	—	Location was unrelated to this research.
9, 11, 12	Eye glance distributions	Locations where road glances were recorded.
2, 3, 4, 5, 6	Stopping at stop sign	Did driver or motorcyclist make complete stop before entering intersection?

NOTE: — = not applicable.

TABLE 2

Intersection Glancing and Stopping Results

	Car			Motorcycle		
Behavior	***N***	**Percentage**	**SD (%)**	***N***	**Percentage**	**SD (%)**
LTAP-OD[a]	102	48	33	94	30	29
Right[a]	101	58	36	107	39	34
Left	80	79	27	69	64	37
All turns[a]	283	60	25	270	42	27
Pavement[a]	112	50	33	99	73	28
Stop[a]	119	66	37	109	39	36

NOTE: SD = standard deviation.

[a]Significant relationship ($\alpha \leq .05$).

TABLE 3

Comparison of Results of Current Research with Those of Pradhan et al. (4)

Behavior	Car (%)	Motorcycle (%)	Car (4), Average of Younger and Older (%)
LTAP-OD	48	30	52
All turns	60	42	49
Stop	66	39	61

NOTE: Turns in Scenarios. 1, 3, 5, 6, 7, 9, 10, and 14; stops in Scenarios 6b and 11b.