Accident Analysis and Prevention 72 (2014) 325–329

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Motorcyclist's lane position as a factor in right-of-way violation collisions: A driving simulator study

Bertrand Sager[a,b], Matthew R. Yanko[b], Thomas M. Spalek[b], David J. Froc[a], Daniel M. Bernstein[a], Farhad N. Dastur[a,*]

[a] Kwantlen Polytechnic University, Department of Psychology, 12666 – 72nd Avenue, Surrey, BC V3W 2M8, Canada
[b] Simon Fraser University, Department of Psychology, RCB 5246, 8888 University Drive, Burnaby, BC V5A 1S6, Canada

ARTICLE INFO

Article history:
Received 17 September 2013
Received in revised form 12 July 2014
Accepted 12 July 2014
Available online 8 August 2014

Keywords:
Motorcycle safety
Lane position
Gap acceptance

ABSTRACT

A driver turning left and failing to notice an oncoming motorcyclist until too late is the most common cause of motorcycle collisions. Consequently, much previous research has focused on motorcycle properties, such as size, shape, and color to explain its inconspicuousness. However, collision statistics remain largely unchanged, suggesting that the issue may not be related solely to the motorcycle's static properties. In the present study, we examined a different characteristic of the motorcycle, namely its trajectory of approach. Seventeen participants faced oncoming traffic in a high-fidelity driving simulator and indicated when gaps were safe enough for them to turn left at an intersection. We manipulated the size of the gaps and the type of oncoming vehicle over 135 trials, with gap sizes varying from 3 to 5 s, and vehicles consisting of either a car, a motorcycle in the left-of-lane position, or a motorcycle in the right-of-lane position. Our results show that drivers are more likely to turn in front of an oncoming motorcycle when it travels in the left-of-lane position than when it travels in the right-of-lane position.

1. Introduction

In 2011, in the United States, motorcycle collisions accounted for 14% of traffic fatalities, 81,000 injuries to motorcyclists, and 4,612 deaths (NHTSA, 2013). Motorcycle collisions frequently involve an oncoming car turning left, or otherwise violating the motorcyclist's right-of-way, with the driver of the car reporting that they did not see the motorcycle. Right-of-way violations account for nearly half of all car-motorcycle collisions (ACEM, 2009; Hurt et al., 1981). Early research concluded that motorcycles suffer from a lack of conspicuity (Hurt et al., 1981). Much of the motorcycle safety research conducted since has focused on making motorcycles more conspicuous, generally through various lighting treatments such as headlight modulators, additional lights, and bright reflective garments (Jenness et al., 2011; Olson et al., 1981). There is some debate, however, regarding the effectiveness of these measures (Cavallo and Pinto, 2012; Gershon et al., 2012; Hole et al., 1996), and it has been suggested that the problem may not be one of conspicuity at all (Olson, 1989). This view is supported by studies that manipulate the driver's attentional set (Most and Astur, 2007): Drivers searching for a traffic sign of a particular color are more likely to notice a motorcycle of that color. In addition, car drivers that also hold a motorcycle license seem to find motorcycles more conspicuous than non-riders, as they are less prone to collide with motorcyclists (Magazzù et al., 2006). A review of motorcycle right-of-way collisions reports two possible causes: Lack of motorcycle conspicuity, and difficulty in judging the velocity and distance of an oncoming motorcycle (Pai, 2011). Pai finds that research on motorcycle conspicuity is largely inconclusive, so here we focus on drivers' judgments about an oncoming motorcycle.

To date, dynamic determinants of right-of-way-violation collisions with motorcycles, specifically the motorcycle's approach path, have not been tested. The idea behind the present work is the proposition that the high incidence of motorcycle collisions may arise not from the detectability of the motorcycle but rather from the difficulty in judging its approach. One possibility is that a motorcycle approaching on a path coincident with the direct line of sight (see Fig. 1) may be inconspicuous because of a lack of apparent motion against the background. In this case, the perception of the approaching motorcycle would be mediated mainly by looming cues, which may be insufficient for accurate estimates of distance or time of arrival (but see Caird and Hancock, 1994).

It is possible that this precise situation results from the way motorcyclists are generally trained to ride. Many North American

* Corresponding author. Tel.: +1 778 987 6515.
E-mail addresses: bsager@sfu.ca (B. Sager), myanko@sfu.ca (M.R. Yanko), tspalek@sfu.ca (T.M. Spalek), david.froc@kpu.ca (D.J. Froc), daniel.bernstein@kpu.ca (D.M. Bernstein), farhad.dastur@kpu.ca, mrdastur@yahoo.com (F.N. Dastur).

http://dx.doi.org/10.1016/j.aap.2014.07.012
0001-4575/

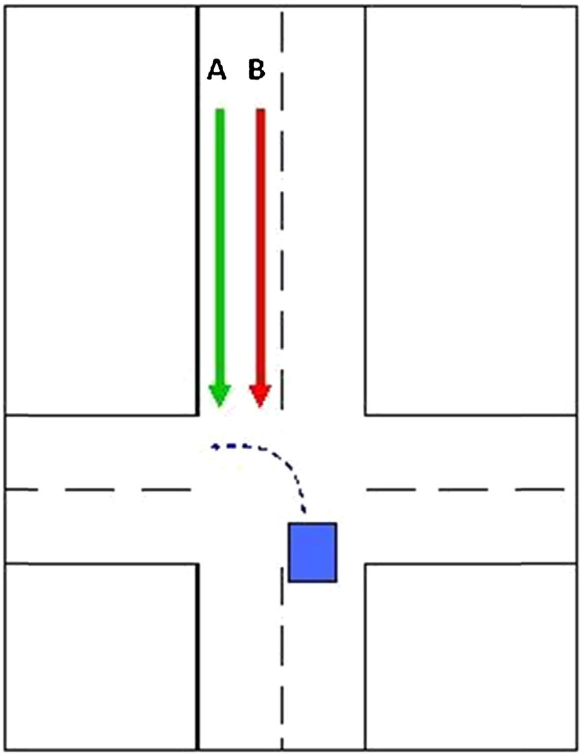

Fig. 1. Overhead view of a car preparing to turn left. Right (A) and left (B) lane position approaches are indicated by the arrows. A motorcycle approaching along path B offers fewer motion cues than a motorcycle approaching along path A.

training programs teach riders to travel in the left portion of their lane, close to the road's center line when driving on a single lane road (e.g., Insurance Corporation of British Columbia, n.d.; Motorcycle Safety Foundation, 2011). Instructors encourage this "dominant" or "blocking" lane position because it affords the best view of both lanes of traffic ahead, makes the motorcycle more visible to oncoming traffic, and ensures that other road users will not encroach on the motorcyclist's lane while overtaking them. According to the Motorcycle Safety Foundation (2011), "Many motorcyclists consider the left third of the lane—roughly the left tire track of automobiles—to be their default lane position, whether in traffic or waiting at an intersection" (p. 15). New riders, who are most vulnerable, may apply this rule without adapting it to the particular circumstances they face at a given time. While riding in the left-of-lane position generally affords a motorcyclist some advantages, from the perspective of an oncoming driver intending to make a left turn, a motorcycle approaching in the left-of-lane would be in their direct line of sight, thereby posing the kind of perceptual problems noted earlier.

Conversely, a motorcycle approaching from a right-of-lane position would offer several motion cues to an oncoming driver about to turn left. In addition to looming cues, these include motion against the background and a greater change in visual angle. Ouellet (1990) has speculated that a right-of-lane position might be safer when approaching an intersection, but, to date, the role of the motorcyclist's lane position has not been investigated empirically. We therefore designed the present work to assess the impact of lane position on drivers' decisions to turn left across the path of an oncoming motorcycle.

The design of the present experiment is similar to that of other studies that examined gap acceptance (Hancock et al., 1991; Lenné and Mitsopoulos-Rubens, 2011). In these studies, participants faced a stream of oncoming vehicles with gaps in the traffic of a predetermined size appearing randomly within the stream. Participants indicated via a button press which of those gaps would allow for a safe left turn across the traffic. In this experiment, we held the speed of oncoming traffic constant at 50 km/h, and vehicles were either cars or motorcycles. The critical difference between this and previous gap-acceptance studies is that approaching motorcycles were either in a left-of-lane or right-of-lane position. Based on the availability of the motion cues discussed previously, we expected that participants would accept fewer gaps in front of motorcycles approaching in the right-of-lane position and that the difference in accepted gaps would be most pronounced when it was uncertain whether the gap was safe.

2. Methods

2.1. Participants

Eleven male and six female undergraduate Simon Fraser University (SFU) students (mean age 21.8 years, $SD = 2.38$) volunteered for the experiment in exchange for partial credit for a first-year course in introductory psychology, or ten dollars. All participants reported normal or corrected-to-normal vision and held a valid driver's license with a minimum of two years of driving experience.

2.2. Materials

We employed a DriveSafety DS-600 high-fidelity research driving simulator. Participants sat in the cockpit of a Ford Focus, which was mounted on a motion-platform. The simulation was authored using HyperDrive and rendered using Vection simulation software (DriveSafety Version 1.9.35).

2.3. Design

The experiment was a 3 (vehicle type: motorcycle-left, car, motorcycle-right) × (gap size: 3, 4, and 5 s) within-subjects design consisting of three experimental blocks with five trials per condition in each block. For each of the 135 randomized trials, participants indicated whether they would initiate a left turn in front of the target vehicle, which was either a motorcycle in the left-of-lane position, a car, or a motorcycle in the right-of-lane position. Motorcycles were positioned 1.25 m to the left or to the right of the center of the lane (see Fig. 2).

2.4. Dependent measure

We define a gap as a space between two vehicles in the stream of oncoming traffic. An accepted gap is one for which the participant indicates that they would perform a left turn across the flow of oncoming traffic, presumably because they consider it large enough. In the present experiment, the dependent measure was the proportion of gaps in each condition for which participants indicated that they would begin a left turn. This allows for the most direct test of the hypothesis that drivers accept fewer gaps in front of motorcycles approaching in the right-of-lane position than in front of motorcycles approaching in the left-of-lane position.

2.5. Headlights

In some ways, a simulated environment differs from a real-life driving scene. Most notably, headlights (especially on motorcycles) behave quite differently in a simulator than they do in real life. In a natural driving scene, a motorcycle's headlight is visible long before the vehicle can be identified as a motorcycle, but in the simulator, the headlight "turns on" once the motorcycle is close enough for the rendering engine to draw the pixels representing the headlight. In our simulator this happened when the motorcycle was 5 s away from the intersection. This sudden onset of the headlight caused

Fig. 2. Driver's view of the motorcycle in the left-of-lane position (top) and right-of-lane position (bottom).

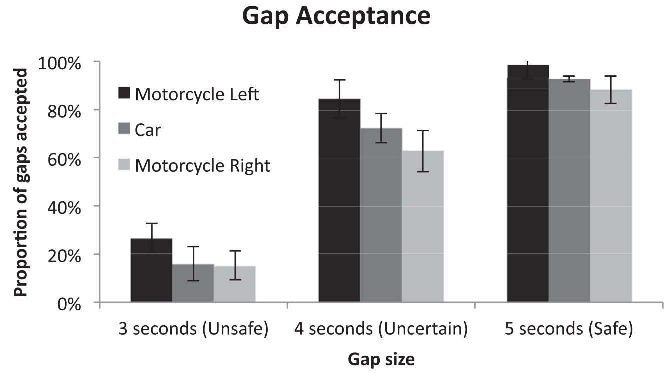

Fig. 3. Average number of gaps accepted per condition (out of a maximum of 15). Error bars indicate standard error of the mean.

the motorcycle to visually "pop out." To avoid this confound in the present experiment, we rendered all simulated vehicles with their headlights off.

2.6. Gap sizes

To determine which gap sizes should be considered safe given the size of the intersection and the acceleration characteristics of the simulated vehicle, we ran a pilot study with five SFU students and two of the authors. Each participant made left turns at 12 intersections using the simulator. These intersections featured two single-lane roads intersecting at a 90° angle and were controlled by four-way stop signs. For the purpose of this pilot study, which aimed to establish how long it takes a driver to complete a turn in our simulator, these intersections were empty of any approaching traffic. We needed to know the mean delay between the beginning of a turning maneuver and the moment the participant's vehicle cleared the intersection. Pilot testing determined this delay to be 3 s ($M = 3.09$, $SD = .42$). Consequently, we deemed that a three-second gap in a stream of oncoming traffic would not allow for the safe execution of a left turn, that a four-second gap would allow for the safe execution of a left turn, but leave very little safety margin, and that a five-second or more gap in the stream of traffic would allow for the execution of a left turn and leave a reasonable safety margin. Importantly, even if the left-turning car had enough time to clear the motorcyclist's path, accepting a gap that did not leave a sufficient safety margin would likely cause the motorcyclist to over-react and crash their motorcycle due to overenthusiastic braking (Ouellet, 1990).

2.7. Procedure

Participants sat in the driver's seat of the simulator, with the simulated vehicle positioned at a three-way intersection on the main road, ready to make a left turn onto the intersecting roadway (Fig. 1). Participants viewed a stream of oncoming vehicles (white cars and red motorcycles) traveling at 50 km/h. One hundred thirty-five experimental trials (15 per condition) were separated by either three or four cars at two-second intervals and consisted of a three-, four-, or five-second gap closed by a motorcycle in the left-of-lane position, a car, or a motorcycle in the right-of-lane position. As would be expected in a real-life situation, the size of the motorcycle was proportional to the distance from the driver. Therefore, the motorcycle was rendered smaller when it approached from a right-of-lane position as compared to when it approached from a left-of-lane position. Specifically, at the time that the motorcycle entered the intersection, the right-of-lane and left-of-lane motorcycle subtend 2.04 and 2.10° of visual angle, respectively.

Participants indicated the moment when they would begin a left turn across the stream of oncoming traffic by pressing a button positioned on the right backside of the steering wheel. Because participants were required to make responses for 135 left turns in a short time, we judged that pressing a button would be more practical and result in less motion sickness than completing the left turn on each trial. Participants were encouraged to accept as many safe gaps as possible. To keep participants on task, a simulated vehicle waiting behind them honked whenever three consecutive trials ended without the participant accepting a gap. Participants completed three blocks of 45 randomized trials (five per condition) lasting about 15 min each.

To reduce fatigue and boredom during the experiment (due to sitting at an intersection for 15 min, observing oncoming traffic and pressing a button), participants drove a simulated route through a rural area after the first and second blocks. This route was the same for all participants, took about 3 min to traverse, and ended at an intersection where the next block of trials began.

3. Results

For each of our nine conditions, we calculated the proportion of gap-accepted trials for each participant. We then entered these proportions into an analysis of variance (ANOVA) with two within-subject factors: vehicle-type (motorcycle in a left-of-lane position, car, motorcycle in a right-of-lane position) and gap size (3, 4, and 5 s). This method of analysis matches how others have examined similar data in the past (e.g., Crundall et al., 2012). The ANOVA revealed a significant main effect of gap size, $F(2,32) = 102.34$, $p < .001$, partial $\eta^2 = .87$, and of vehicle type, $F(2,32) = 10.07$, $p < .001$, partial $\eta^2 = .39$. The interaction was not significant, $F(4,64) = 1.01$, $p = .41$. Fig. 3 depicts the means for each condition.

Because we found no interaction between vehicle type and gap size, we collapsed data across gap size, and performed post hoc planned pairwise comparisons. The results showed that participants accepted a greater proportion of gaps in front of motorcycles in the left-of-lane position (M = .70, SEM = .04) than in front of cars (M = .60, SEM = .05), $t(16) = 3.40$, $p < .01$ and motorcycles approaching from the right-of-lane position (M = .55, SEM = .06), $t(16) = 3.61$, $p < .01$. There was no significant difference in the proportion of gaps accepted in front of cars as compared to those in front of motorcycles approaching from the right-of-lane position, $t(16) = 1.73$, $p = .10$.

4. Discussion

Our results showed that participants were more willing to turn left in front of a motorcycle in a left-of-lane position than in front of a car or in front of a motorcycle in a right-of-lane position. While we did not find a significant interaction, possibly due to a lack of statistical power, numerically the data suggest that this effect might be most pronounced for small gap sizes where the success of the maneuver is uncertain (see Fig. 3). This seems intuitive, because it is likely that, as gaps increase in size to the point where they are obviously safe, they will be accepted regardless of the type of vehicle closing the gap. These results are consistent with our hypothesis that the right-of-lane position offers more motion cues to an oncoming driver and is therefore more likely to deter oncoming drivers from crossing in front of a motorcyclist's path as they approach an intersection. However, our findings are inconsistent with some motorcycle rider training which motorcyclists generally leave with the belief that they should always ride in the left portion of the lane. Our results suggest that the right-of-lane position may be a safer riding position when entering an intersection.

Ouellet (1990) proposed that, for a motorcyclist, adopting a lane position that is furthest removed from an immediate right-of-way-violation threat was a more effective way to avoid a collision than trying to apply emergency braking or swerving. Most riders do not brake efficiently when confronted with an emergency, and swerving takes more time than is usually available. Ouellet's mathematical reconstructions show that a motorcyclist one lane removed from the threat has more time to react, and that the portion of their trajectory where a collision is unavoidable is the smallest compared to other lane positions. The present study shows that a right-of-lane position also decreases the probability of an oncoming driver violating the motorcyclist's right-of-way and making a left turn.

Some limitations to our experiment should be noted. The first of these is that motorcycles close half the gaps of interest in our simulation. In the real world, motorcycles are much less frequent; it seems possible that a lower motorcycle-to-car ratio would increase the effect of lane position on gap acceptance, but this remains untested. A second limitation is that in the present experiment, all traffic flowed at 50 km/h; it is currently unknown whether the effect of lane position on gap acceptance becomes more or less pronounced as speed increases. A third limitation is that the subject vehicle is stationary at the intersection; future experiments should attempt to replicate our findings at intersections that the participant approaches at speed. A last, albeit minor, limitation is that all the simulated motorcycles were red, and all the simulated cars were white. This does not affect the comparison between motorcycles in the left-of-lane and motorcycles in the right-of-lane, but it could be argued that the effect we observed is specific to these colors. Although our simulator renders only one type of motorcycle, we replicated our findings in an identical experiment that varied the color and type of the cars (a yellow VW Golf, a red Toyota Tacoma, and a purple Toyota Celica).

Right-of-way violations caused by oncoming drivers turning left or by drivers crossing on a perpendicular road account for nearly half of all car-motorcycle collisions (Hurt et al., 1981). Because the driver of the other vehicle took no corrective action in 65% of these cases (ACEM, 2009), it is in the motorcyclist's best interest to employ defensive countermeasures. Such countermeasures should not be strictly passive or static, such as the use of a headlight modulator or the wearing of a bright yellow jacket. These countermeasures, while sometimes effective, may lull a motorcyclist into a false sense of security (for a discussion of risk homeostasis, see Wilde, 1994). Our results suggest that if motorcyclists adopt a right-of-lane riding position as they approach intersections, they might find themselves in fewer situations where an oncoming driver violates their right of way and turns left across their path. Even if motorcyclists do find themselves in such a situation, based on Ouellet (1990), they will have more time to react. Therefore, contrary to common motorcycle driving practice, it seems that a right-of-lane position might be more effective than a left-of-lane position when approaching intersections.

Acknowledgments

We thank Elisabeth Kreykenbohm and Vince DiLollo for helpful comments on earlier drafts of this work. This work was supported by the Canada Research Chairs Program (950-228407), a Katalyst Grant from Kwantlen Polytechnic University to Daniel M. Bernstein, Farhad N. Dastur, and David J. Froc, as well as a Canada Foundation for Innovation (7540) New Opportunities Grant and a grant from the British Columbia Knowledge Development Fund to Thomas M. Spalek.

References

Association de Constructeurs Europeens de Motocyclettes (ACEM), 2009. In-depth investigations of accidents involving powered two wheelers (MAIDS), Retrieved from: http://www.maids-study.eu/pdf/MAIDS2.pdf

Caird, J.K., Hancock, P.A., 1994. The perception of arrival time for different oncoming vehicles at an intersection. Ecol. Psychol. 6 (2), 83–109, http://dx.doi.org/10.1207/s15326969eco0602_1.

Cavallo, V., Pinto, M., 2012. Are car daytime running lights detrimental to motorcycle conspicuity? Accid. Anal. Prev. 49, 78–85, http://dx.doi.org/10.1016/j.aap.2011.09.013.

Crundall, D., Crundall, E., Clarke, D., Shahar, A., 2012. Why do car drivers fail to give way to motorcycles at t-junctions? Accid. Anal. Prev. 44 (1), 88–96.

Gershon, P., Ben-Asher, N., Shinar, D., 2012. Attention and search conspicuity of motorcycles as a function of their visual context. Accid. Anal. Prev. 44 (1), 97–103, http://dx.doi.org/10.1016/j.aap.2010.12.015.

Hancock, P.A., Caird, J.K., Shekhar, S., Vercruyssen, M., 1991. Factors influencing drivers left turn decisions. Hum. Factors Ergon. Soc. Annu. Meet. Proc. 35 (15), 1139–1143, http://dx.doi.org/10.1177/154193129103501525.

Hole, G.J., Tyrrell, L., Langham, M., 1996. Some factors affecting motorcyclists' conspicuity. Ergonomics 39 (7), 946–965.

Hurt, H.H., Ouellet, J.V., Thom, D.R., 1981. Motorcycle accident cause factors and identification of countermeasures, vol. 1: Technical Report, Traffic Safety Center, University of Southern California, Los Angeles.

ICBC (n.d.). Roadsense Tip Lane Position When Riding a Motorcycle. Retrieved from http://apps.icbc.com/rs-tips/lanepositionwhenridingamotorcycle/lanepositionwhenridingamotorcycle.html

Jenness, J., Huey, R., McCloskey, S., Singer, J., Walrath, J., Lubar, E., Lerner, N., 2011. Perception of approaching motorcycles by distracted drivers may depend on auxiliary lighting treatments: a field experiment. In: Proceedings of the Sixth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Lake Tahoe, CA, pp. 2–8.

Lenné, M.G., Mitsopoulos-Rubens, E., 2011. Drivers' decisions to turn across the path of a motorcycle with low beam headlights. Proc. Hum. Factors Ergon. Soc. Annu. Meet. 55 (1), 1850–1854, http://dx.doi.org/10.1177/1071181311551385.

Magazzù, D., Comelli, M., Marinoni, A., 2006. Are car drivers holding a motorcycle licence less responsible for motorcycle–car crash occurrence? A non-parametric approach. Accid. Anal. Prev. 38 (2), 365–370, http://dx.doi.org/10.1016/j.aap.2005.10.007.

Most, S.B., Astur, R.S., 2007. Feature-based attentional set as a cause of traffic accidents. Vis. Cogn. 15 (2), 125–132, http://dx.doi.org/10.1080/13506280600959316.

Motorcycle Safety Foundation, January 2011. Motorcycle operator manual (16th ed.), Retrieved from: http://msf-usa.org/downloads/mom_v16_color_hi_res.pdf

NHTSA, 2013. Traffic Safety Facts, 2011 Data. DOT HS811753. National Highway Traffic Safety Administration, Washington, DC, http://www-nrd.nhtsa.dot.gov/Pubs/811753.pdf
Olson, P.L., Halstead-Nussloch, R., Sivak, M., 1981. The effect of improvements in motorcycle/motorcyclist conspicuity on driver behavior. Hum. Factors 23 (2), 237–248.
Olson, P.L., 1989. Motorcycle conspicuity revisited. Hum. Factors 31 (2), 141–146.
Ouellet, J.V., 1990. Lane positioning for collision avoidance: an hypothesis. In: Proceedings: The Human Element: 1990 International Motorcycle Safety Conference, vol. 2, Orlando, Florida, pp. 9.58–9.80.
Pai, C.W., 2011. Motorcycle right-of-way accidents–A literature review. Accid. Anal. Prev. 43 (3), 971–982.
Wilde, G.J., 1994. Target Risk: Dealing with the danger of death, disease and damage in everyday decisions. PDE Publications, Toronto.