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Improving car drivers' perception of motorcycle motion through innovative headlight configurations

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ABSTRACT

The most frequent cause of motorcycle accidents occurs when another vehicle violates the motorcycle's right-of-way at an intersection. In addition to detection errors, misperception of the approaching motorcycle's speed and time-to-arrival is another driver error that accounts for these accidents, although this error has been studied less often. Such misperceptions have been shown to be related to the small size of motorcycles and to their small angular velocity when approaching. In two experiments we tested the impact of different motorcycle headlight configurations in various ambient lighting conditions (daytime, dusk, and nighttime). The participants drove on a driving simulator and had to turn left across a line of vehicles composed of motorcycles and cars. The motorcycles were approaching at different speeds and were equipped with either a "standard" headlight, a "horizontal" configuration (added to the standard headlight were two lights on the rearview mirrors so as to visually increase the horizontal dimension of the motorcycle), a "vertical" configuration (one light on the rider's helmet and two lights on the fork were added to the standard headlight so as to increase the vertical dimension of the motorcycle), or a "combined" configuration (combining the horizontal and vertical configurations). The findings of the first experiment in nighttime conditions indicated that both the vertical and combined configurations significantly increased the gap car drivers accepted with respect to the motorcycle as compared to the standard configuration, and that the accepted gaps did not differ significantly from those accepted for cars. The advantage of the vertical and combined configurations showed up especially when the motorcycle's approach speed was high. The findings of the second experiment in dusk and daytime conditions indicated similar patterns, but the headlight-configuration effect was less pronounced at dusk, and nonsignificant during the day. The results are discussed with regards to possible applications for motorcycles.

1. Introduction

Motorcyclists[1] are very vulnerable road users and their safety has become a critical issue in many developed countries. In 2008, motorcyclists represented 17% of the total number of road fatalities in Europe, whereas they only represented 2% of the road users (EC, 2009). The number of motorcyclists killed or seriously injured has not decreased, contrary to other categories of road users. In Italy, France, and Switzerland, for instance, motorcyclists represented 30%, 26%, and 24%, respectively, of the total number of road fatalities in 2011 (IRTAD, 2013). In the USA, motorcycles accounted for 3.5% of the registered vehicles in 2011, yet for 14.2% of the road fatalities (NHTSA, 2011).

In-depth accident analyses have shown that the most typical automobile-motorcycle accidents happen at intersections where a car turns left[2] and hits an oncoming motorcycle (ACEM, 2009) and at T-junctions when a car pulls out of a side road onto the pathway of a motorcycle (Clarke et al., 2007). In the majority of cases, the motorcyclist's right of way was violated by other vehicles. These studies also report that most accidents are caused by perception failures on the part of other vehicle drivers (60% according to Van Elslande and Jaffard, 2010). Two kinds of perceptual errors have been identified: no (or late) detection of the motorcycle (e.g.,

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[1] By motorcycle, we mean all powered, two- or three-wheelers.

[2] In countries where vehicles drive on the right side of the road.

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Clarke et al., 2007), and misperception of the motorcycle's motion, i.e., speed and arrival time (e.g., Tsutsumi and Maruyama, 2008).

"Digital conspicuity", i.e., ITS-based vehicle-to-vehicle communication, as presently favored by motorcycle manufacturers, will be a technological solution that circumvents the problem of limits in visual perception and attention, but such systems are not likely to be operational for at least 15 years.[3] Until reliable systems are available and all vehicles are equipped with them, other solutions must be found. Innovative motorcycle headlight configurations could easily be implemented and could be an efficient means for improving motorcycle safety in the coming years.

When envisaging such new headlights for motorcycles, it is advisable to take into consideration the two kinds of perceptual errors made by other vehicle drivers, i.e., motorcycle-detection failures and motion-perception errors. Detection problems in relation to motorcycle conspicuity are already well known, and a number of recent studies have proposed novel motorcycle headlight configurations in order to improve motorcycle detectability (e.g., Binder et al., 2005; Maruyama et al., 2009; Röβger et al., 2010; Gershon and Shinar, 2013; Pinto et al., 2014). Errors in the perception of a motorcycle's motion are less well known and have rarely been investigated. The present study specifically addresses this issue, by evaluating different motorcycle headlight configurations likely to counteract these motion-perception errors.

The misperception of a motorcycle's motion is related to overestimation of the arrival time of small objects, called the "size-arrival effect". This effect was first evidenced by DeLucia (1991) and was then demonstrated more specifically for driving contexts and motorcycles (Caird and Hancock, 1994; Horswill et al., 2005). The consequence of the size-arrival effect is that drivers accept shorter gaps when interacting with motorcycles than with cars. Gould et al. (2012a,b); Gould et al. (2012a,b) showed that observers were also significantly less accurate in judging the speed of motorcycles as compared to cars.

Both the distorted perception of arrival time and the higher speed discrimination thresholds are due to motorcycles' small size, which determines their small angular size in the observer's visual field and in turn, their low angular velocity, especially when the motorcycle is approaching head-on. Slow angular velocities are difficult to perceive; they may even sometimes fall below the perceptual threshold in such a way that the motorcycle's motion cannot be discerned, especially when the viewing time is short. In addition, ambient lighting conditions play an important role insofar as they determine the motorcycle's visible contour: whereas the whole outline of the motorcycle and the rider are visible during the day, only the headlight is visible at night. The motorcycle's distance from the observer also comes into play because it determines the motorcycle's angular size, and thus its angular velocity: the motion of the motorcycle is easier to perceive when it is close to the observer than when it is far away.

The use of innovative headlight configurations that visually increase the apparent size of the motorcycle is likely to favor the perception of its motion. Tsutsumi and Maruyama (2008) had drivers on a test track make judgments of critical gaps for turning left in front of a motorcycle. It was shown that motorcycles equipped with a headlight configuration that comprised two additional lights on the fork and two other lights on the ends of the handlebars (the "LONG" system) caused automobilists to accept larger time gaps than when the motorcycles were equipped with a standard headlight only. Two laboratory studies (Gould et al., 2012a,b) demonstrated an advantage of a tri-light configuration (two additional lights on the handlebars) over a single headlight, for discriminating the speed of an approaching motorcycle. Both studies found significant improvements in nighttime conditions, where the motorcycle outline was invisible. More surprisingly, Tsutsumi and Maruyama (2008) observed such improvements in daytime conditions as well, whereas Gould et al. (2012b) did not note any effect under these conditions.

The present series of experiments used a gap-acceptance task (turning left at an intersection) on a driving simulator to evaluate three innovative headlight configurations that accentuated the motorcycle's vertical and horizontal dimensions, or both. Our choice of which configurations to test took previous studies on motorcycle detectability into account, in particular studies showing detection benefits of a triangular light arrangement (Maruyama et al., 2009) or an additional light on the helmet (Pinto et al., 2014). The first configuration tested (called "horizontal") produced maximal horizontal enlargement of the motorcycle. While this configuration has been shown to improve motorcycle speed discrimination (Gould et al., 2012a,b), its effect on gap acceptance has never been tested before. The second light arrangement (called "vertical") added the motorcyclist's helmet to the front-light configuration and thus produced maximal vertical enlargement of the motorcycle, bigger than that obtained by the LONG system (Tsutsumi and Maruyama, 2008). The third configuration (called "combined") was a combination of the other two; it increased not only the motorcycle's visible dimensions, but also its implied surface area. The enhancement of both the motorcycle's dimensions and its surface area is generally considered to be beneficial in helping drivers perceive its time-to-arrival and subsequently accept the appropriate gaps, but to our knowledge, no study has attempted to compare their effectiveness in affording larger gaps towards motorcycles.

In sum, the aim of the present experiment was to compare the gaps accepted by drivers with respect to motorcycles equipped with these light configurations to those accepted when encountering a motorcycle with a standard headlight or a car. We hypothesized that the three innovative headlight configurations would afford larger gaps than the standard configuration and thus provide a safety benefit. More specifically, the largest accepted gaps were expected because of the increase in the motorcycle's vertical dimensions, which produces the maximal possible enhancement of the motorcycle's angular velocity. We also expected a greater increase in accepted gaps for the innovative headlight configurations at low illumination conditions, where the motorcycle outline was invisible or difficult to discern.

Our first experiment was run under nighttime conditions; the second dealt with dusk and daytime conditions.

2. Experiment I: nighttime conditions

2.1. Method

2.1.1. Participants

Twenty-three volunteers (8 women and 15 men) with a mean age of 31 years (SD = 8.03) took part in the experiment. All had normal or corrected-to-normal vision, held a driving license for at least two years, and were regular drivers.

2.1.2. Material

The study was conducted on a small-scale, interactive driving simulator comprising various control devices (force-feedback steering wheel; gear lever; gas, clutch, and brake pedals) as well as visual and auditory rendition systems. The visual scene and the scenarios were generated by in-house software developed at IFSTTAR. Image generation (60 Hz) included HDR (high dynamic range) rendering. The road environment was displayed on two

[3] Based on the example of motorcycle ABS introduced in 1988 and its present equipment rate of 30% in France, one can expect that digital conspicuity will need more than 25 years to become reality.