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Improving car drivers' perception of motorcyclists through innovative headlight configurations

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1. Introduction

Motorcyclists are very vulnerable road users and their safety has become a critical issue in many developed countries. In Europe in 2006, motorcyclists represented 18% of the total number of road fatalities (CARE, 2009) whereas they only represent 2% of the road users (EC, 2009). In France, two-wheelers represent now even 28% of the total number of road fatalities (IRTAD, 2011).

In-depth analyses (ACEM, 2009; Hurt, Ouellet, & Tom, 1981; Vis, 1995) show that in many motorcycle accidents the motorcyclists' right of way was violated by other vehicles (in 51 and 81%, as indicated by Hurt et al. and Vis respectively). The most typical accident happens at intersections where a car turns left and collides with an oncoming motorcycle.

Accident studies emphasise the high frequency of perceptual errors made by car drivers when colliding with motorcycles (in 60 or 70% of these accidents, according to Van Elslande & Jaffard, 2010, and Hurt et al., 1981, respectively). The errors are identified as non (or late) detections of the motorcycle on the one hand (e.g., Cavallo & Pinto, 2012), and as a misperceptions of the motorcycle's speed, distance (Tsutsumi & Maruyama, 2008; Gould, Poulter, Helman, & Wann, 2012), and time-to-arrival (Horswill, Helman, Ardiles, & Wann, 2005) on the other hand. Whereas detection problems in relation to motorcycle conspicuity have already been extensively studied, only very few investigations have addressed the second type of failures in relation to the perception of the motorcycle's motion. The present study was specifically dedicated to the latter question.

The misperception of the motorcycle's movement is related to its small size which in turn determines its low angular velocity, especially when the motorcycle is approaching head-on. Slow angular velocities are difficult to be perceived; they may even sometimes be below the perceptual threshold so that the motorcycle's motion is not perceived at all. The apparent size of the motorcycle, and thus its angular velocity, also depends on its distance from the observer: the motorcycle's movement is better perceived when it is close to the observer. Ambient lighting conditions are also likely to come into play insofar as they determine the visible extent of the motorcycle: whereas the whole outline of the motorcycle and the rider are visible at daytime, only the headlight is visible at night-time.

The use of innovative headlight configurations that visually increase the apparent dimensions of the motorcycle is likely to favour the perception of its speed, distance and time-to-arrival, as shown by Tsutsumi and Maruyama (2008). The authors had drivers on a test track making judgments of critical gaps to turn left in front of motorcycles. It was shown that motorcycles equipped with a headlight configuration that accentuated its vertical dimension led automobilists to accept larger gaps than when the motorcycles were equipped only with a standard headlight. A laboratory study (Gould et al., 2012) demonstrated an advantage of a tri-light configuration as compared to a single light for discriminating the speed of the approaching object. As could be expected, both studies found these significant improvements in nighttime conditions. More surprisingly, Tsutsumi and Maruyama observed them in daytime conditions as well, whereas Gould et al. did not notice any effect under these conditions.

The present series of experiments used a driving simulator to evaluate three innovative headlight configurations that accentuated the vertical and horizontal dimensions of the motorcycle. The gaps adopted by the drivers in a left-turn situation towards motorcycles equipped with these light configurations were compared to those adopted when facing a motorcycle with a standard headlight or a car. The first experiment was dedicated to nighttime conditions, and the second experiment to dusk and daytime conditions.

2. Experiment I

2.1. Methods

Participants

23 volunteers (7 women and 16 men) with a mean age of 31 years took part in the experiment. All had normal or corrected-to-normal vision, held a driving license for at least 2 years and were regular drivers.

Driving simulation

The study was conducted on a small-scale interactive driving simulator, comprising control devices (force-feedback steering wheel, gear lever, gas, clutch and brake pedals) as well as visual and auditive rendition systems. The visual scene and the scenarios were generated by an in-house software developed at Ifsttar. The image generation included HDR (High Dynamic Range) rendering. The road environment was displayed on 2 screens: one in front of the driver and the other one left to him. The central screen was a high fidelity LCD screen with specific light rendering features insuring high luminance levels (4000 cd/m^2) and high contrasts ($>20000:1$). The left screen was an ordinary high-fidelity LCD screen. The visual scene represented a rural intersection composed of a principal two-way road and a another two-way road going off 45° to the left. The traffic approached head-on and was presented on the central screen, whereas the off-going street was presented on the left screen.

Experimental design and procedure

The drivers were presented with a series of traffic scenarios and had to carry out a left-turn through the traffic stream when they considered they could safely carry out the turning maneuver. At the beginning of each scenario, the driver's car was stationary at the intersection and the driver watched the oncoming traffic flow. At each trial, a group of 3 vehicles was approaching at 40 or 60 km/h. The time gap between the first 2 cars was always 2,5 s; it was too short for turning. The time gap between the second and the third ("target") vehicle varied between 3 and 7 s. The target vehicles were motorcycles equipped with different headlight configurations as well as cars, vans and trucks. Four motorcycle headlight configurations were used (Fig. 1): "standard" (one central headlight), "horizontal" (one central light + 2 lights on the ends of the handlebar), "vertical" (one central headlight + one light on the helmet and 2 lights on the fork), "combined" (combining the horizontal and vertical configurations).

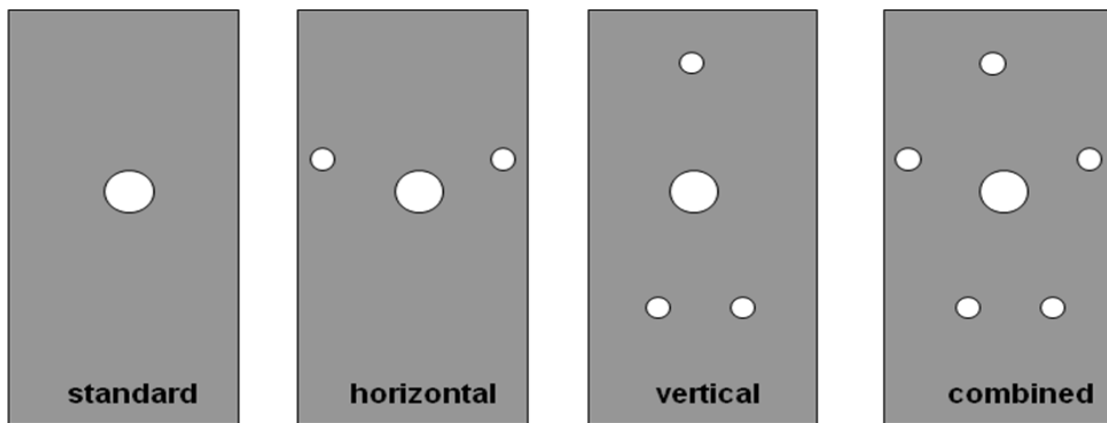


Figure 1. Schematic presentation of the four motorcycle headlight configurations tested

Data processing

The median accepted time gap per participant, speed and headlight configuration/vehicle type was calculated via a logistic regression function that determined the point of transition between the decision to turn or not to turn. The median accepted time gaps were analysed by ANOVAs. Post-hoc comparisons used Scheffé test.

2.2. Results

Statistical analyses revealed a significant main effect of headlight configuration and type of vehicle (Fig. 2). The accepted gaps towards motorcycles were significantly longer for the vertical and combined headlight arrangements when compared to the standard configuration. Interestingly, there was no significant difference between the gaps afforded by these two configurations that increase the vertical dimension of the motorcycle and those adopted towards cars.

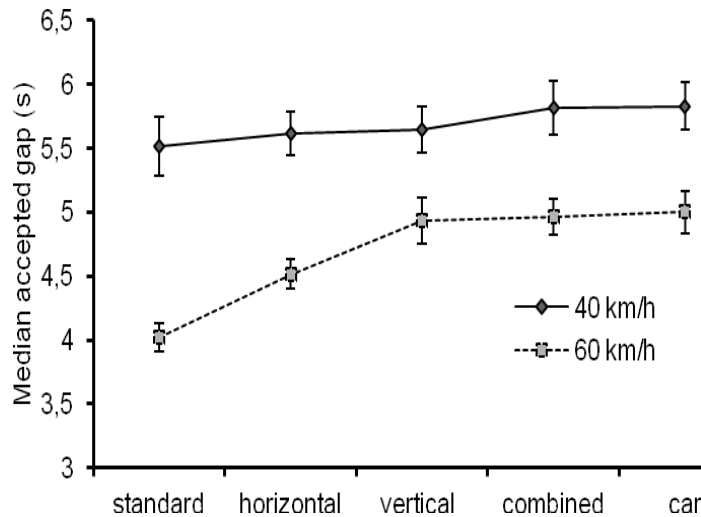


Figure 2. Median accepted time gaps for motorcycles equipped with different headlight configurations and for cars, at nighttime conditions (vertical bars represent standard deviations)

The findings also showed a significant main effect of speed, with longer accepted gaps at 40 km/h than at 60 km/h.

The significant interaction between headlight configuration and speed (Fig. 2) indicates that the light configurations did not significantly influence the accepted time gaps when motorcycles approached at lower speed (40 km/h), but only at higher speed (60 km/h). At the higher speed, no significant difference was observed between vertical and combined configurations, and cars.

These findings suggest that the vertical and combined configurations provided an advantage over the standard configuration only when the motorcycle drove at higher speed. This difference may be due to the fact that the distance of the motorcycle, at the moment when the decision to turn was taken, was shorter at the lower speed (about 65 m) than at the higher one (about 85 m). The greater proximity of the motorcycle at lower speed may have led the driver to adopt more conservative judgments. This kind of influence of object distance on accepted gaps and time-to-arrival judgments has already been observed in many studies (see, for example, Cavallo, Mestre & Berthelon, 1997). Moreover, for a given time-to-arrival, the angular velocities are higher when vehicles approach at low as compared to high speeds, and it can be assumed that the angular velocity of the motorcycle could be easier analysed when it approached at 40 km/h.

3. Experiment II

3.1. Methods

The methods used were similar to experiment I. The only difference pertained to the use of dusk and daylight conditions on the one hand, and to the use of higher approach speeds, 60 and 90 km/h, on the other hand. The choice of different speeds was made because no effect of headlight configuration was observed for the lower speed of 40 km/h in the first experiment. Furthermore, motorcycle accidents often happen at quite high speeds and it was important to evaluate the potential of innovative motorcycle headlight configurations under these conditions.

Two groups of 23 participants, matched with regard to age, gender and driving experience, took part in the experiment. Each group consisted of 7 women and 16 men (mean age: 31 years).

3.2. Results for dusk conditions

Analysis of variance indicated a significant main effect of headlight configuration and vehicle type, with longer accepted gaps for the vertical and combined configurations than for the standard and horizontal configurations. The gaps accepted for the vertical and combined light arrangements were not significantly different from gaps accepted when facing cars.

A significant main effect of approach speed on the accepted time gap was found: shorter gaps were observed at high speeds as compared to low speeds.

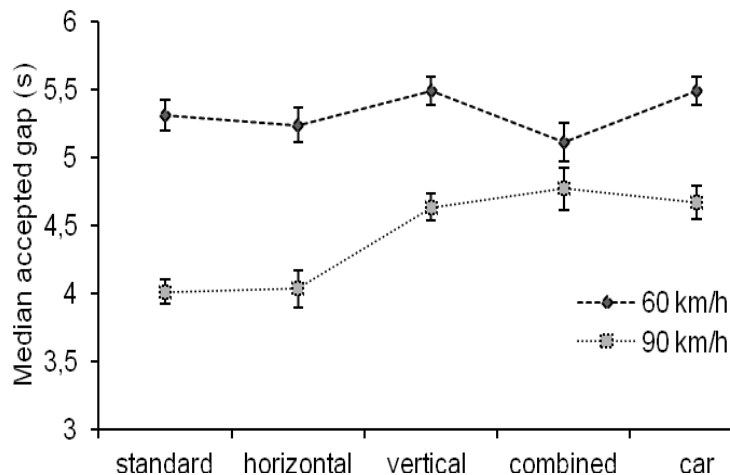


Figure 3. Median accepted time gaps for motorcycles equipped with different headlight configurations and for cars, at dusk conditions (vertical bars represent standard deviations)

The significant interaction between headlight configuration and speed (Fig. 3) indicated that headlight ergonomics had no effect on accepted gaps at 60 km/h, but only at 90 km/h. At the higher speed, the time gaps were significantly shorter when the motorcycle was only

fitted with a standard headlight as compared to motorcycles fitted with the vertical or combined configurations, or when turning in front of a car. At the higher speed, no significant difference was found between vertical and combined configurations, and cars. This pattern of results was similar to the one observed at nighttime conditions, showing greater benefits of configurations that accentuate the vertical dimension of the motorcycle when its approach speed is high.

Surprisingly, no effect of motorcycle headlight design was found at 60 km/h. This finding is contrary to the one obtained at nighttime conditions where headlight ergonomics influenced accepted gaps at the speed of 60 km/h. This difference could be due to the visibility of the motorcycle/motorcyclist outline at dusk conditions which may have facilitated the processing of the motorcycle's angular velocity. It can be assumed that the outline in dusk conditions was easier discernible when the motorcycle was approaching at 60 km/h than at 90 km/h, because at the lower speed the motorcycle was closer and its angular size bigger. Further investigations are necessary to study the influence of the angular size of the motorcycle and the motorcycle/background contrast.

3.3. Results for daytime conditions

Statistical analysis revealed no effect of headlight design on accepted gaps which were found to be similar for all motorcycles, whatever their headlight configuration. Furthermore, the gaps accepted in front of motorcycles did not differ from those accepted in front of cars. Only a significant effect of speed was observed, with longer gaps at 60 km/h than at 90 km/h.

4. Conclusions

The findings of the present study indicate that innovative motorcycle headlight ergonomics can improve motorcyclist safety by increasing the gaps accepted by automobile drivers when they turn left in front of a motorcycle. Among the headlight configurations tested, only light arrangements that accentuated the vertical dimension of the motorcycle/motorcyclist outline, i.e., the vertical and combined configurations, provided substantial improvements as compared to motorcycles equipped with only standard headlights. Interestingly, the time gaps accepted in front of these configurations were equivalent to those accepted in front of cars.

The beneficial effect of configurations that accentuate verticality was found to be modulated by ambient lighting conditions and the motorcycle's speed of approach: the configurations were found to be all the more effective that ambient lighting was reduced and the motorcycle approach speed high, i.e., in conditions where the perception of the motorcycle's motion was particularly difficult. Whereas these configurations provided no safety improvement at daytime, they afforded longer accepted gaps in dusk and nighttime conditions: at nighttime, they were effective already at motorcycle speeds of 60 km/h (and

motorcycle distances around 85 m), whereas at dusk they provided a safety benefit only at speeds of 90 km/h (and motorcycle distances around 120 m).

In terms of application, the use of the vertical configuration is without doubt preferable to the combined configuration, because it requires less additional lights and may be easier accepted by motorcycle riders.

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