Improving car drivers' perception of motorcycles: innovative headlight design as a short-term solution to mitigate accidents

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Abstract

The most frequent motorcycle accidents involve another vehicle violating the motorcycle's right-of-way at an intersection. The low visual conspicuity of motorcycles (especially because of their small size) is the primary reason why motorcycles are often not detected or seen or too late. The main safety measure in the past has been the use of daytime running lights (DRLs) by motorcycles, which became compulsory in the seventies in many countries. This conspicuity advantage of motorcycles as the only vehicles with DRLs is presently getting lost by the growing use of DRLs by cars as well. In a previous study (Cavallo & Pinto, 2012) we have shown that car DRLs are competing light patterns that create visual noise and decrease the detectability of motorcycles. In addition to detection errors, the misperception of the approaching motorcycle's speed and time-to-arrival also contributes to accident occurrence and severity.

In order to reduce motorcycle accidents, and especially to improve motorcycle perceptibility (both detection and speed perception) by other vehicle drivers, ITS based on vehicle-to-vehicle communication will probably provide effective long-term solutions (>15 years). But until then, other solutions have to be found and could quite easily be implemented, by considering innovative headlight configurations for motorcycles.

In two simulator studies, we tested various motorcycle headlight configurations, intended to remedy *simultaneously* the two perceptual errors made by other vehicle drivers. The impact of different headlight configurations (using colour coding and additional lights) was studied in the presence of visual distractors (car front lights: only LEDs, only dipped beams, LEDs and dipped beams) and in different illumination conditions (nighttime, dusk and daytime conditions).

The results indicate that headlight configurations comprising additional yellow lights on the fork and on the motorcyclist’s helmet significantly improve motorcycle perceptibility by other vehicle drivers. Furthermore, the simultaneous use of daytime running lights (LEDs) and dipped beams by cars, as frequently observed nowadays, has been shown to be particularly detrimental to motorcycle detectability.

1. Introduction

Motorcyclists are very vulnerable road users and their safety has become a critical issue in many developed counties. The number of killed and seriously injured motorcyclists has not been reduced these last years, contrary to other categories of road users. For instance, in Italy, France, and Switzerland motorcyclists represented as much as 30, 26, and 24 %, respectively, of the total number of road fatalities (IRTAD, 2013).

In-depth analyses (ACEM, 2009; Hurt, Ouellet, & Tom, 1981; Vis, 1995) show that in many motorcycle (MC)[1] 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 MC.

Perceptual errors made by car drivers are one of the main accident causation factors in collisions between cars and MCs (in 60 or 70% of these accidents, according to Van Elslande & Jaffard, 2010, and Hurt et al., 1981, respectively). The two kinds of perceptual errors are today well identified:

a) Non (or late) detections of the MC on the one hand, which are due to the low conspicuity (especially due to its small size, but also to dark colours and irregular contours) of MCs. The main safety measure in the past has been the use of daytime running lights (DRLs) by MCs, which became compulsory in the seventies in many countries and made them clearly distinguishable from other road users. This conspicuity advantage of MCs as the only vehicles with DRLs, which has been proven to effective in accident reduction, is presently getting lost by the growing use of DRLs by cars as well. In a previous study (Cavallo & Pinto, 2012), we have shown that car DRLs are competing light patterns that create visual noise and decrease the detectability of MCs.

b) The second, and less studied error, is a misperceptions of the MC's speed, distance (Tsutsumi & Maruyama, 2008; Gould, Poulter, Helman, & Wann, 2012), and time-to-arrival (Horswill, Helman, Ardiles, & Wann, 2005). This error is due to the small dimensions of the MC, which lead to low angular velocities when the MC is approaching. As a consequence, MC speed is underestimated and its arrival time overestimated. This misperception results in short temporal intervals and safety margins accepted by other vehicle drivers when they interact with MCs.

MC manufacturers bet on “digital conspicuity”, i.e., ITS based vehicle-to-vehicle communication that will probably provide effective solutions in the long term (at least >15 years). These technological solutions will circumvent the problem related to the limits of visual perception and attention, but until having reliable systems at our disposal, other

[1] By motorcycle, we understand all powered two- and three-wheelers.

solutions have to be found. Innovative MC headlight configurations could quite easily be implemented and could be an efficient means for improving MC safety in the coming years.

An increasing number of studies carried out in the last 7-8 years highlight a renewal of research interest for MC headlight ergonomics. Several investigations have been devoted to the definition of a new visual signature for MCs to indicate the presence of these road users and favour their detectability. A T-shaped light configuration (additional lights at the fork and the handlebars forming a T) (Röβger, Hagen, Krzywinski, & Schlag, 2012) as well as an alternating-blinking light system on the motorcyclist's helmet have been shown to be effective (Gershon & Shinar, 2013), but are difficult to implement. Pinto, Cavallo and Saint-Pierre (2014) examined much simpler light arrangements and showed significant benefits when motorcycles had yellow headlights, and also when motorcyclists had an additional light on their helmet. Contrary to Maruyama, Tsutsumi and Murata (2009), Pinto et al. did not find a detection benefit for triangle headlights (with two additional lights on the MC's handlebar).

Other studies addressed the influence of innovative MC headlights arrangements on the perception of the MC's speed and arrival time. Tsutsumi and Maruyama (2007) have demonstrated that headlight configurations that vertically enlarge the MC (with additional lights on the handlebar and the fork) afford longer accepted gaps than motorcycles equipped with just a standard front light, and this in night-time as well as in daytime conditions. Gould et al. (2012), on the contrary, found an improved MC speed perception when the MC was horizontally enlarged that when it was vertically enlarged. These authors also noted improved speed discrimination when MCs were equipped with a triangle configuration.

All of these studies have focused on only one of the two kinds of perceptual errors. But the motorcyclist who equips his MC with additional light wants to prevent both kinds of perceptual errors made by other vehicle drivers. The present study is the first one that investigated headlight configurations that effectively counteract detection errors, and at the same time reduce motion perception errors. The tested headlight configurations therefore combined design characteristics that are efficient for motorcycle detection on the one hand, but that have also been proven efficient for motorcycle motion perception. We have specifically chosen colour coding (yellow) and MC vertical enlargement which features seemed to have the highest potential for improving MC perception.

Our study consisted of two simulator experiments. The first one evaluated the effect of several headlight configurations on MC motion perception, by measuring the gaps accepted by drivers when turning left in front of a MC. The best performing configurations were chosen for the second experiment, in which we tested their capacity of improving MC detectability.

2. Experiment 1

2.1. Method

Participants. Three groups of 23 volunteers took part in the experiment. The groups were matched with regard to age (31 years), gender (7 women and 16 men in each group), and driving experience. All had normal vision and were regular drivers.

***Driving simulation*.** A small-scale interactive driving simulator was used, comprising control devices (force-feed-back steering wheel, gear lever, gas, clutch and brake pedals) as well as visual and auditive rendition systems. The road environment was displayed on two 47'' high fidelity LCD screens: one in front of the driver and the other one left to him. The visual scene represented a rural intersection with a road going off 45° to the left (Figure 1). The traffic (MCs, cars, vans, trucks) approached head-on at different speeds (40 and 60 km/h at night-time; 60 and 90 km/h at dusk and daytime) and with different time gaps between the vehicles (3 – 7 s). The MCs were equipped with four different headlight configurations (Figure 2). The participants' task was to turn left through the traffic stream when they judged that turning was safe.

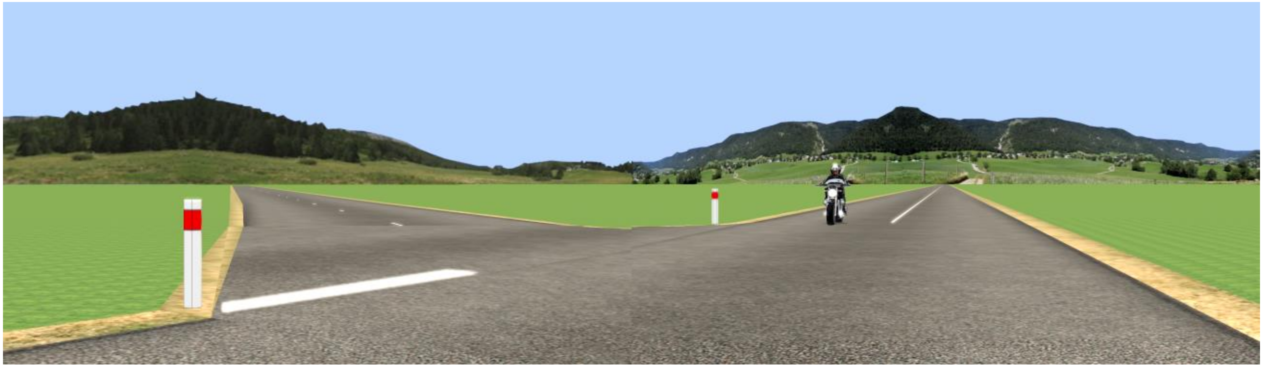

Figure 1. MC with the vertical configuration approaching the intersection at daytime.

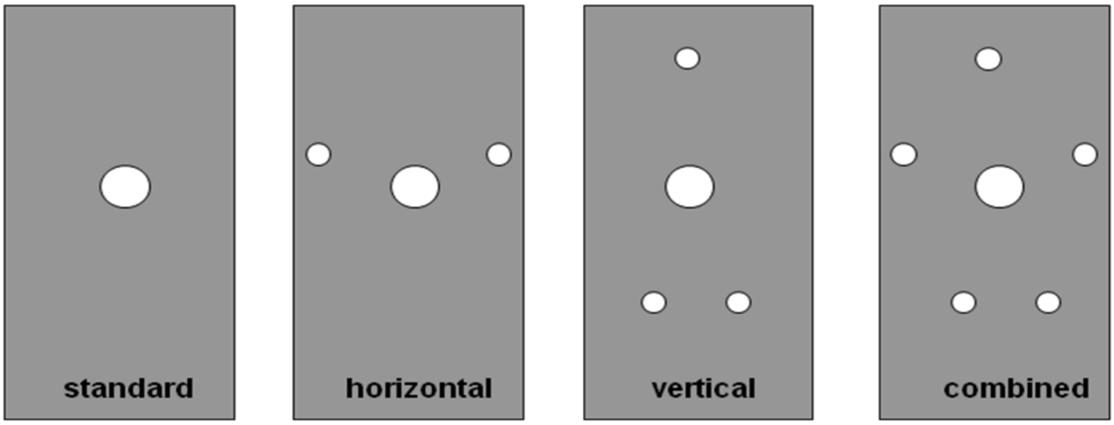

Figure 2. The four MC headlight configurations tested in a left-turn situation.

2.2. Results

Night-time. The Figure 3 shows that the vertical and the combined configurations afforded longer accepted gaps at night-time, when the MCs approached at the higher speed (here, 60 km/h). The chosen gaps were equivalent to those accepted toward cars. At 60 km/h, the time gain for the vertical and combined arrangements as compared to the standard headlight was .91 s and .94 s, respectively. This means an additional safety distance of about 15 m, which is a sizable asset when cars interact with motorcycles.

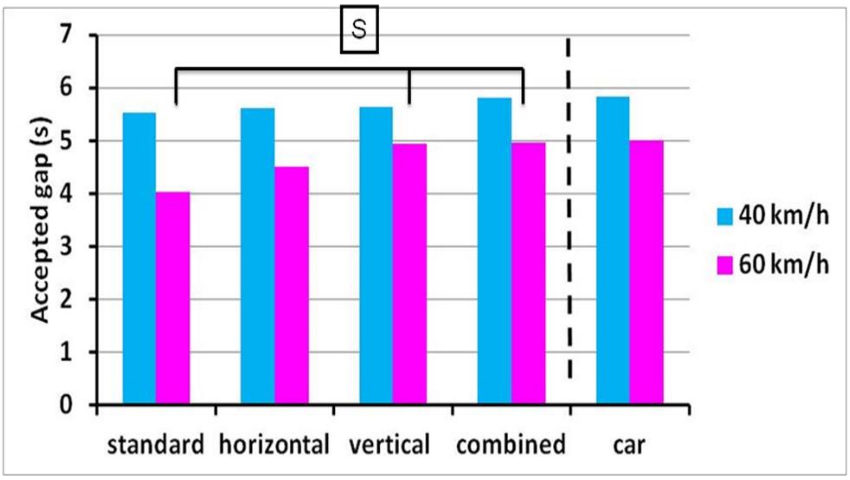

Figure 3. Accepted time gaps (in s) according to approach speed, for motorcycles equipped with different headlight configurations and for cars, at nighttime conditions.

Dusk. Figure 4 reveals similar results at dusk conditions. At the higher speed (here, 90 km/h), the vertical and the combined configurations led drivers to accept time gaps towards MCs which were notably longer than for MCs fitted with the standard headlight, and which were equivalent to cars. The horizontal configuration afforded the same time gaps as the standard headlight and did not provide any advantage.

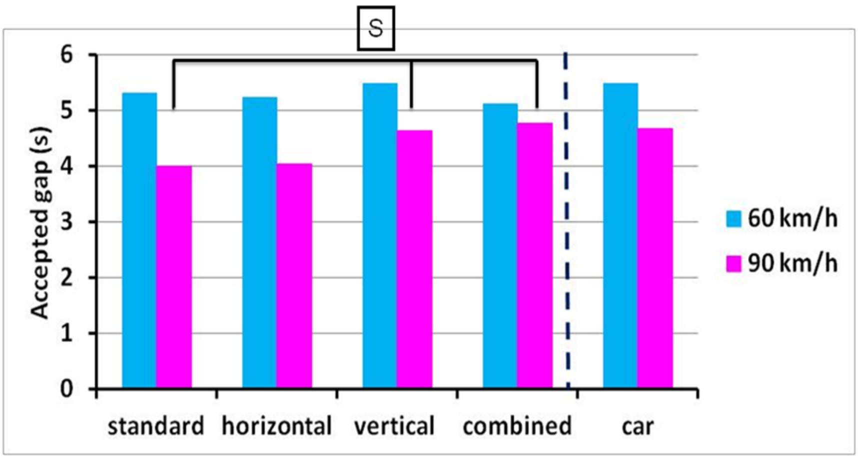

Figure 4. Accepted time gaps (in s) according to approach speed, for motorcycles equipped with different headlight configurations and for cars, at dusk conditions.

The time gain for the vertical and combined configurations at dusk was .62 s and .76 s with respect to the standard headlight, and .60 s and .74 s with respect to the horizontal arrangement. These time increments correspond to additional safety distances between 15 and 19 m at dusk, when turning left in front of motorcycles equipped with these light arrangements.

Daytime. Figure 5 shows a similar pattern at daytime, with time gains for the vertical and combined configurations at the higher speed (here, 90 km/h) of about .50 s, but none of these time benefits were statistically significant.

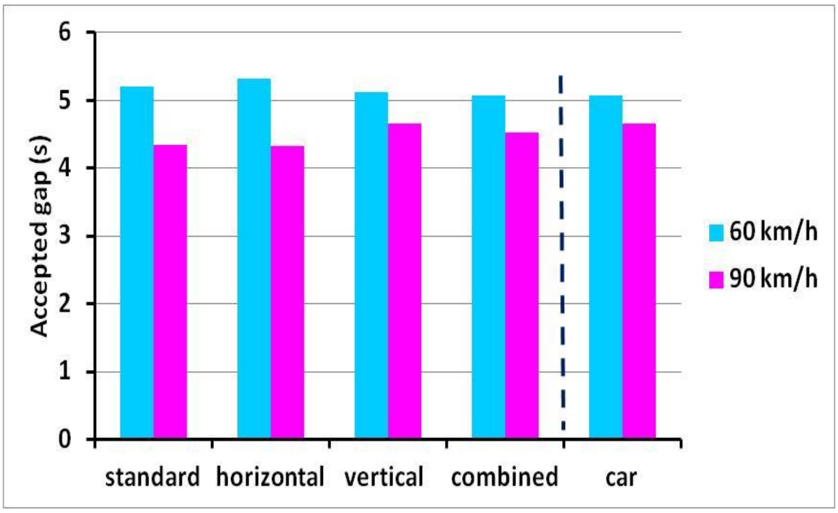

Figure 5. Accepted time gaps (in s) according to approach speed, for motorcycles equipped with different headlight configurations and for cars, at daytime conditions.

2.3. Discussion

The findings of the first study indicate that only light arrangements that accentuated the vertical dimension of the MC/motorcyclist, i.e., the vertical and combined configurations, provided substantial improvements as compared to MCs equipped with only standard headlights or with the horizontal arrangement ("triangle"). Interestingly, the time gaps accepted in front of MC fitted with 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 approach speed: these two configurations were found to be all the more effective that ambient lighting was reduced and the MC approach speed high, i.e., in conditions where the perception of the MC's motion was particularly difficult.

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. The vertical configuration was then tested in the second experiment regarding its capacity of improving MC detectability.

3. Experiment 2

3.1. Method

Participants. Three groups of 19 volunteers took part in the experiment. The groups were matched with regard to age (30 years), gender (4 women and 15 men in each group), and driving experience. All had normal vision and were regular drivers.

***Driving simulation*.** Only the central screen of the driving simulator (see Experiment 1) was used. The participants were presented with sequences of 250 ms displaying daytime traffic scenes with cars and MCs approaching four lanes intersections at constant speed (50 km/h). Cars were fitted with (1) LEDs, (2) dipped headlights, or (3) LEDs *and* dipped headlights lit together (Figure 6). These three environmental conditions were introduced in order to evaluate the effect of visual distracters, consisting in car DRLs, on MC detection. Four MC headlight configurations were tested (see Figure 7). The participants' task was to detect whether vulnerable road users (MCs, cyclists, pedestrians) were present in the traffic scene. The vulnerable road users appeared at different distances and eccentricities.

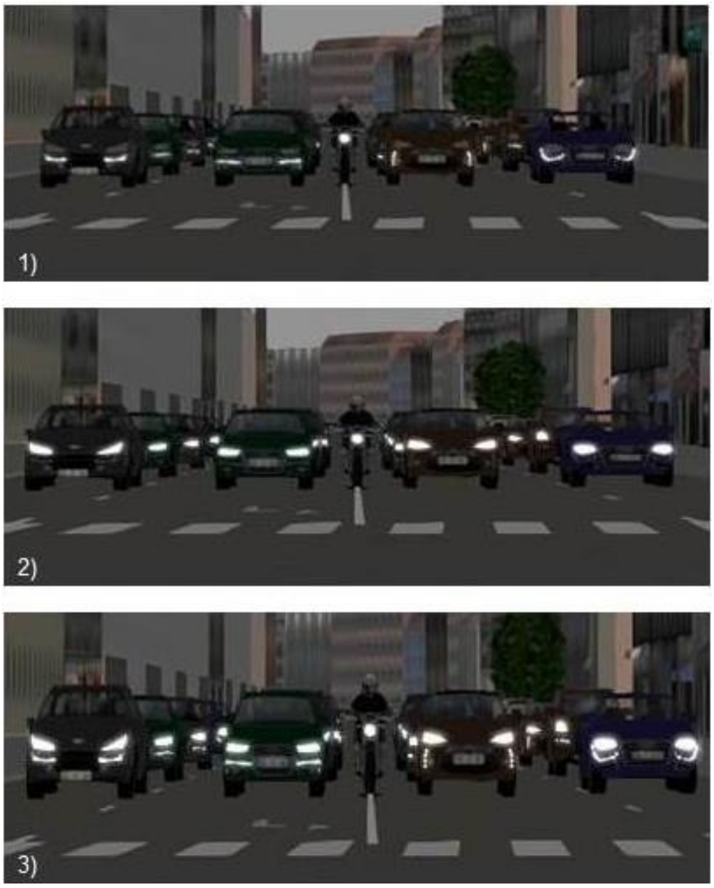

Figure 6. The three environmental conditions comprising different kinds of visual distactors.

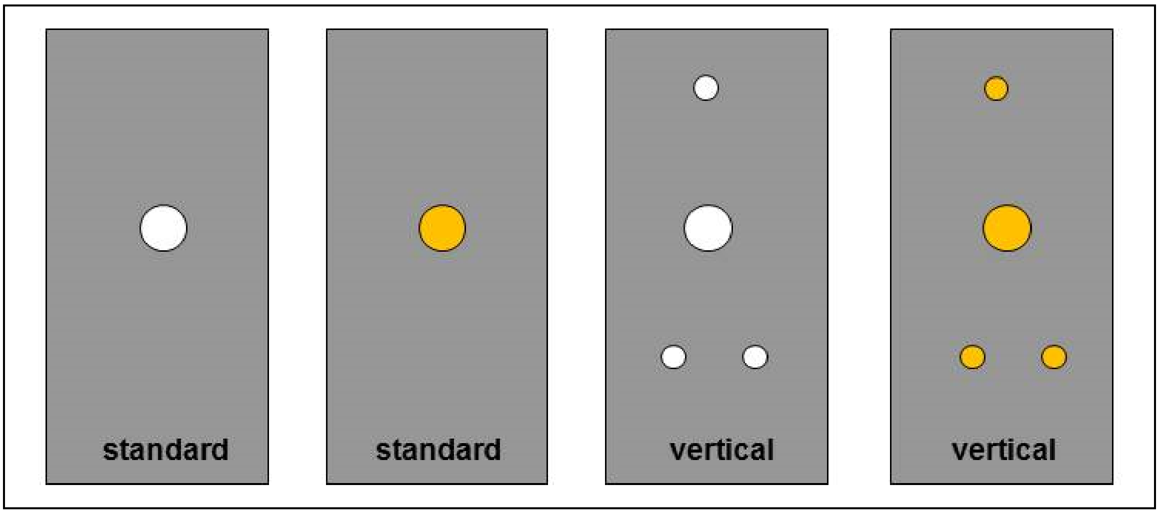

Figure 7. The four MC headlight configurations tested for their detectability in a traffic environment with visual distractors.

3.2. Results

Effect of headlight configuration. Figure 8 clearly indicates that the MCs were better detected when they were fitted with configurations comprising yellow lights. The increase in detectability, compared to the standard headlight, was considerable, 29 and 19 % points for the yellow vertical and the yellow standard configurations, respectively. The yellow vertical arrangement amounted to almost 90 % of correct detections.

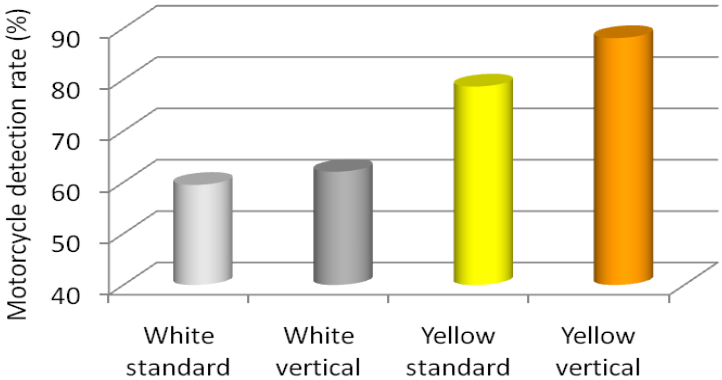

Figure 8. Motorcycle detection rates (%) as a function of motorcycle headlight configuration.

***Effect of car DRLs in the visual environment*.** Figure 9 illustrates the detrimental effect of visual distracters formed by car DRLs, especially when numerous light sources were present around the MC. This happened when cars had their dipped lights and LEDs lit simultaneously. The difference in correct detections between the most MC-friendly environment, when cars were lit by LEDs only, and the most detrimental environment, when cars lit LEDs and dipped headlights at the same time, is about 11 % points. In the most distracting visual environment (LEDs + dipped beams), only the yellow vertical configuration provided a significant benefit as compared to the white standard headlight.

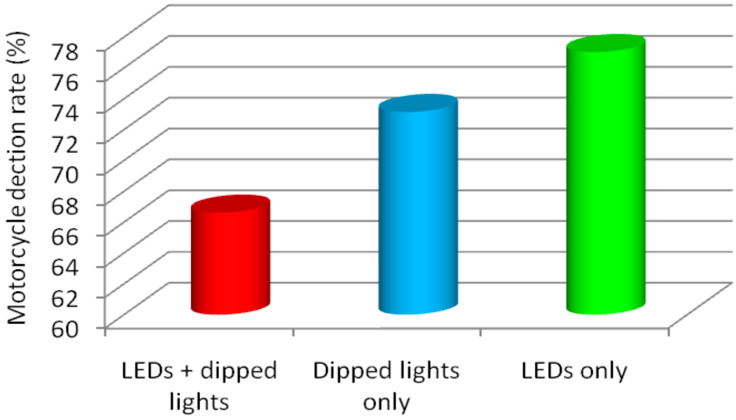

Figure 9. Motorcycle detection rates (%) as a function of lit car lights in the environment.

3.3. Discussion

The findings emphasize the beneficial effect of the yellow standard lights, and even more, the yellow vertical configuration. They suggest that colour coding (here, the yellow colour) improved MC detection and identification, by clearly distinguishing it from other vehicles that all have white front lights. These results are in line with earlier findings that demonstrated a clear benefit of a yellow MC headlight over a conventional white headlight (Pinto et al., 2014).

The conspicuity advantage of the yellow configurations also depended on the visual complexity of the MC's environment. When many car light sources are visible in the vicinity of the MC, then only the yellow vertical configuration guarantees a real detectability improvement as compared to the white standard headlight.

4. Conclusions

We have shown that the yellow vertical configuration is the most beneficial one: it improves the perception of the MC's motion as well as its detection and identification. This configuration brings together the characteristics of the two best performing arrangements: the enlargement of the MC's vertical dimension and the colour coding.

In terms of application, it is probably not realistic to assume that MC could be equipped with yellow frontal headlights, because they are less efficient for lighting the street and may produce colour distortions in road sign perception. We rather recommend a MC lighting configuration that combines a white central front light and 3 additional yellow lights, one on the helmet and two on the fork. Using the LED technology for these additional lights could be a good solution to limit power demands.

The recommended light arrangement is less complex than the T-configuration suggested by Rössger et al. (2012) and also more realistic than an alternating-blinking light on the helmet as suggested by Gershon &Shinar (2013). Incidentally, both light arrangements have been tested only with regard to MC detection, but not regarding MC motion perception.

The yellow vertical arrangement has also been shown to be much more effective than the triangle configuration advised by Gould et al. (2012). The triangle configuration has also the favour of the MC manufacturers, but we have proven that it does not improve MC motion perception at all. A slight benefit in terms of detectability of the triangle configuration could be expected if the additional 2 lights on the handle bar are of a different colour (yellow, orange) than car lights, but this effect has not been evidenced yet.

Finally, it should be noted that MC detectability suffers from distracting light sources on cars, especially when cars simultaneously light dipped beams and dedicated DRLs. A better separation of these two functions, involving improved car lighting regulations, could help making MCs easier to detect by other vehicle drivers.

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