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Influence of front light configuration on the visual conspicuity of motorcycles

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ABSTRACT

A recent study (Cavallo and Pinto, 2012) showed that daytime running lights (DRLs) on cars create "visual noise" that interferes with the lighting of motorcycles and affects their visual conspicuity. In the present experiment, we tested three conspicuity enhancements designed to improve motorcycle detectability in a car-DRL environment: a triangle configuration (a central headlight plus two lights located on the rearview mirrors), a helmet configuration (a light located on the motorcyclist's helmet in addition to the central headlight), and a single central yellow headlight. These three front-light configurations were evaluated in comparison to the standard configuration (a single central white headlight). Photographs representing complex urban traffic scenes were presented briefly (for 250 ms). The results revealed better motorcycle-detection performance for both the yellow headlight and the helmet configuration than for the standard configuration. The findings suggest some avenues for defining a new visual signature for motorcycles in car-DRL environments.

1. Introduction

Motorcycle[1] safety has become a critical issue in road safety over the past few years. Motorcycles have a considerably higher fatality rate than do automobiles. For instance, in the U.S. in 2007, the risk of a fatal accident per kilometer traveled was 37 times higher for a motorcyclist than for a car occupant (NHTSA, 2008). In France in 2009, the motorcycle fatality risk was 25 times higher than the car fatality risk (ONISR, 2009), and the number of motorcyclists killed was as high as 28% of the total number of road fatalities, even though motorcycles represent only 1.6% of the motorized traffic (IRTAD, 2011). Looking at France's death-toll statistics over the years, we can see that the total number of persons killed on the road went down by 44.8% in the seven years between 2002 and 2009, whereas the number of motorcyclists killed dropped by only 13.7% during that same period. Even worse, whereas in the USA the overall death toll from road accidents went down by almost 20% between 2000 and 2009, this figure rose by 54% for motorcyclists (IRTAD, 2011).

The two major scientific studies on the causes of motorcycle accidents in North America (the Hurt Report: Hurt et al., 1981) and Europe (the MAIDS Report: ACEM, 2009) concur in highlighting the poor detectability of motorcycles by other road users. This failure can be explained to a large extent by the relative lack of visual conspicuity of motorcycles as compared to bigger road users (Hancock et al., 1990; Olson et al., 1981), which has long been identified as one of the main risk factors in motorcycle accidents (e.g., Thomson, 1980; Hurt et al., 1981; Wulf et al., 1989; ETSC, 1997; Henderson et al., 1983). Most of these accidents occur in urban areas, in daylight and clear weather (ACEM, 2009; Hurt et al., 1981).

Visual conspicuity refers to an object's ability to attract attention by means of its physical characteristics. Object size is an important feature, as well as luminance and color in relation to the background (e.g., Engel, 1971, 1977; Connors, 1975; Cole and Jenkins, 1984). This notion is closely related to that of attention conspicuity (Hughes and Cole, 1984), defined as the propensity of an object to attract attention when it is unexpected. Attention conspicuity can be distinguished from search conspicuity by the fact that in the latter case the observer actively searches for an object. It has been shown that motorcycle detection is more critical when attention conspicuity is involved, while motorcycles are better detected when the observers directly search for them (Gershon et al., 2012).

Due to the critical role of conspicuity, a large body of research into the visual features of motorcycles and motorcyclists has been

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[1] By motorcycle, we mean all powered two- and three-wheel vehicles.

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conducted in an attempt to improve their detectability. Some investigators, for example, have studied the use of noticeable fluorescent and/or reflective accessories, whether on the motorcyclist's clothing (e.g., Olson et al., 1981; Donne et al., 1985; Dahlstedt, 1986; Hole et al., 1996), or helmet (e.g., Olson et al., 1981; Hole et al., 1996; Wells et al., 2004; Comelli et al., 2008), or the motorcycle itself (e.g., Wells et al., 2004; Rogé et al., 2010). Insofar as the effectiveness of these accessories depends upon the contrast between the motorcycle and its background (Gershon et al., 2012), many studies have focused on motorcycle lighting by examining luminance or headlight arrangement (e.g., Wulf et al., 1989; Tsutsumi and Maruyama, 2007). The most important safety measure implemented in a large number of countries over the past few decades is undeniably the law requiring motorcycles to use daytime running lights (DRLs). By enhancing the visual contrast with the background, DRLs make motorcycles more conspicuous (e.g., Olson et al., 1981; Zador, 1985). Many accident studies agree that DRLs improve motorcycle safety and help in significantly lowering fatal motorcycle accidents (Radin Umar et al., 1996; Krajicek and Schears, 2010). Moreover, a recent experimental study using a motorcycle-detection task clearly pointed out the effectiveness of DRLs (Smither and Torrez, 2010).

However, the advantage of using DRLs to increase motorcycle conspicuity is being questioned today due to the rising number of cars that also drive with their lights on during the day. Many countries have already passed laws making it mandatory for cars to keep their lights on during daytime driving. In Europe, a regulation in effect since February 2011 now requires automobile manufacturers to equip all new vehicles with lights that go on automatically when the vehicle is turned on. This measure should lead to the generalized use of DRLs by automobilists across Europe.

Many road-safety researchers and specialists have expressed their concern that car DRLs might decrease the beneficial effects of motorcycle DRLs (e.g., Brendicke et al., 1994; Cobb, 1992; FEMA, 2006; Hörberg and Rumar, 1979; Knight et al., 2006; Wang, 2008). The negative impact of car DRLs on the visual conspicuity of motorcycles was demonstrated recently in a study by Cavallo and Pinto (2012): car DRLs were shown not only to compete with motorcycle DRLs by creating "visual noise" that hindered motorcycle detection, but also to deprive them of their specific visual signature and thus impede their identification.

In this context, it is essential to seek new means of improving the visual conspicuity of motorcycles in a car-DRL environment. The idea is to add dissimilar features to motorcycles and thus give back to motorcycles their unique visual signature, one that clearly differentiates them from cars and helps other road users see them. Target/distractor dissimilarity is known to be a factor in improving visual searching (e.g., Duncan and Humphreys, 1989). The present experiment was designed to assess the effectiveness of three motorcycle-headlight configurations by focusing on the positioning and layout of front headlights on the one hand, and headlight color on the other.

Two configurations were used to vary the positions and layout of headlights. The first one is a *triangle* arrangement consisting of a standard front headlight plus two additional lights on the rearview mirrors. It is based on the assumption that humans have a dedicated "face" recognition process (for a survey on this question, see for example Chellappa et al., 1995) that might enhance motorcycle detection and identification (as shown in Maruyama et al., 2009). The second is a *helmet* arrangement, which consists of adding a light on top of the motorcyclist's helmet in order to accentuate the vertical dimension of the motorcycle and thus favor motorcycle detectability (Gershon and Shinar, 2013).

The *color* of the front headlight is thought to be another way to promote easy differentiation of motorcycles from other lit road users. Color can be used as a highlighting feature to attract attention to a specific limited area of the visual field (Fisher and Tan, 1989; Fisher et al., 1989). Color coding is the only coding mode known to be more effective than size, shape, and luminance in identification tasks (for a review, see for example Christ, 1975). Moreover, color coding has been shown to facilitate both visual search tasks and identification tasks (MacDonald and Cole, 1988), and the advantage of this coding mode tends to increase with the complexity of the visual scene (Christ, 1975; Kopala, 1979). Because the human eye is very sensitive to yellow and other similar hues, we decided to use this attention-getting color as part of the third lighting configuration for assessing motorcycle detectability in a white-light car-DRL environment. We hypothesized that human sensitivity to yellow, combined with the low prevalence of this lighting color in traffic, would enhance motorcycle conspicuity.

We used a detection task and conditions that brought search conspicuity into play, but also and especially attention conspicuity (see Cavallo and Pinto, 2012): several visual targets (cyclists and pedestrians in addition to motorcyclists) were presented in a complex urban environment and a constraining time limit was set for responding. These conditions seem to correspond the best to the demands of real-world driving, especially ones that trigger perceptual errors. The three new motorcycle front-light configurations were tested in a daytime environment in which all automobiles had their lights on, and compared to a *standard* lighting configuration consisting of a single white headlight. The distance and eccentricity of the visual targets, two features known to influence object detection (e.g., Engel, 1971; Rogé et al., 2009), were varied as well. Indeed, motorcycle detection in a car-DRL environment has been shown to be hampered when the motorcycle is far away and in the central part of the visual scene (Cavallo and Pinto, 2012). A positive effect of the new headlight configurations was expected to show up especially in these conditions.

2. Method

2.1. Participants

A total of 60 adult volunteers (27 women and 33 men) divided into 4 groups of 15 took part in the experiment. The mean age in each group was 28 years (SD around 3.55) and all participants had normal or corrected-to-normal eyesight (at least 8/10 binocular acuity). They were all licensed drivers and 7 participants also had a motorcycle license. Each of the 4 groups contained 1 or 2 motorcycle license holders. Participants exhibited normal visuo-attentional performance and signed an informed consent form prior to participation.

2.2. Task

Participants had to detect the presence of vulnerable road users (a motorcyclist, bicyclist, or pedestrian) on color photographs displayed on a large screen. If one was detected, they had to identify it.

2.3. Experimental design

A mixed experimental design was employed, with motorcycle *front-lighting configuration* as a between-subject variable (standard, triangle, helmet, yellow), and three within-subject variables: the targeted *vulnerable road user* (VRU) (motorcyclist, bicyclist, or pedestrian), the *distance* of the VRU in the scene (far vs. near), and the VRU's *eccentricity* (central vs. off-centered). Each of the four lighting configurations was tested in 12 experimental conditions resulting from the combination of the three within-subject variables. Three different photographs were presented in each of

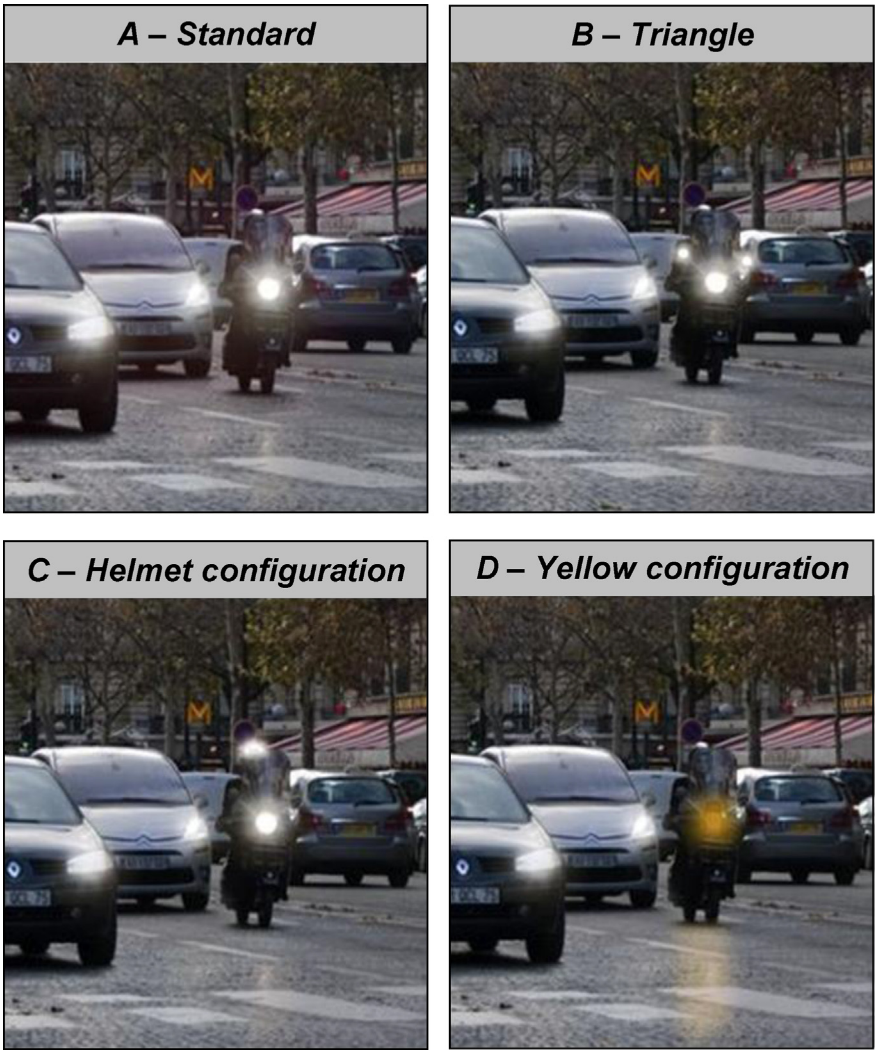

Fig. 1. Example of the four motorcycle lighting configurations studied: (A) standard; (B) triangle; (C) helmet; and (D) yellow.

these 12 experimental conditions, making a total of 36 experimental items. Nine distractors containing a VRU (located at different distances from those used in the experimental trials) were added, which gave us a total of 45 items containing a target. In order to obtain a balanced design with 50% of the trials containing a target, 45 distractors with no target were added. Performance on distractor items was not analyzed, nor was performance on pedestrian or bicyclist detection. The reason for choosing three different targets was to vary the visual situations and prevent the observers from looking specifically for motorcycles.

2.4. *Apparatus and stimuli*

The stimuli were photographs of urban traffic at intersections (mainly in Paris) in overcast weather (see Fig. 1). They were presented on a 40″ LCD flat-panel display (Samsung SyncMaster PXn), which offered high-quality visual rendering (image contrast ratio of 1200:1, 1366 × 768 resolution, brightness 500 cd/m^2, 16.7 million colors). The images displayed on the screen subtended a visual angle of approximately 32° × 18°. Digital photographs of more than 20 intersections were taken using a Nikon D90 camera with a 35-mm lens, from different vantage points. A large number of traffic situations of similar visual-scene complexity were included to prevent participants from using a fixed search strategy or heuristic (see for more details on the stimuli, Cavallo and Pinto, 2012).

2.4.1. *Experimental stimuli*

The experimental stimuli contained at least one set of three to six cars stopped at or approaching a red light, and a single VRU (a motorcyclist, bicyclist, or pedestrian). The VRU was the target the participants had to detect. Target distance was controlled by the VRU's height in the image: 6 cm (angular size 2.15°) or 4 cm (angular size 1.43°) for the near and far conditions, respectively. For the eccentricity variable, a target was considered central if it was located in the central third of the visual scene, and off-centered otherwise. Vehicle front lights were edited into the pictures: a bright-headlight image was selected among the photos, and this texture was applied to all lit vehicles so that the lighting was the same for all light sources. Realistic halos and reflections on the road surface were created and added to each lighted vehicle. Finally, in order to raise and equalize photograph brightness for each urban intersection, the automatic mode of Photoshop was applied to one photograph, and then these parameters were copied and applied to the whole selection. Four motorcycle lighting configurations were created: *standard* (one white front headlight), *triangle* (standard headlight + two lights on the rearview mirrors), *helmet* (standard headlight + one light on the helmet), and *yellow* (one yellow front headlight) (see Fig. 1 A–D).

2.4.2. *Distractor stimuli*

Forty-five of the distractor stimuli had no target. They could contain a visual scene (a) without any approaching traffic, (b) with vehicles some or all of whose headlights were on and off, (c) with vehicles at very different distances than in the experimental stimuli (in the foreground or background of the scene), or (d) with vehicles in all kinds of positions with respect to the observer's viewpoint (turning right or left, etc.). Lastly, nine of the distractor stimuli contained one VRU but it was of greater apparent height than in the experimental stimuli, which substantially increased its visibility.

2.5. *Procedure*

All participants first passed the visual acuity test (Ergovision) and Part 3 of the UFOV test (Ball et al., 1993), and then read the instructions. Depending on their age and UFOV score, they were assigned to one of the four lighting-configuration groups (standard, triangle, helmet, or yellow). Once seated 160 cm from the LCD monitor, participants performed a practice block of eight trials (four target trials and four no-target trials) to get familiar with the procedure. The 90 stimuli were then presented in three blocks of 30, each containing 12 experimental and 18 distractor items. The presentation order of the trials within the blocks was random for all participants, and the order of the blocks was counterbalanced across participants. The stimuli were presented for 250 ms. This allowed participants only "one glimpse" at the scene, which simulated the amount of time a driver might have when glancing in the direction of oncoming traffic (Crundall et al., 2008).

The trial presentation procedure was as follows. Displayed on the LCD monitor were (1) a fixation point in the center of the screen (1500 ms), (2) the stimulus (250 ms), and (3) the question "Apart from the four-wheel vehicles, did you see any other road users?" The answer choices were (a) a pedestrian, (b) a motorcyclist, (c) a bicyclist, (d) none of the above. No feedback on response accuracy was given. The inter-trial interval was 500 ms. Participants were allowed breaks between the blocks. The whole experimental session lasted between 25 and 30 min.

2.6. *Data analysis*

Correct detections, identification errors, false alarms, and misses were determined for the motorcyclist stimuli, and false alarms and correct rejections were counted for the no-target distractor trials. Only the analysis of correct detections of motorcyclists is presented here.

Correct detections were analyzed using the generalized estimating equations (GEE) approach, which takes the dependency between the repeated measurements into account (for more details, see Liang and Zeger, 1986). Because of the binary structure of the dependent variable, a logit link function and a binomial distribution were chosen. The structure of the correlation matrix was set at exchangeable. Results were obtained using SPSS® software. The overall data are presented first. Then the main effects and interactions given by the GEE procedure are detailed (see Table 2). Bonferroni corrections were applied to the analysis of pairwise comparisons. An α-level of .05 was chosen for all statistical tests.

3. Results

3.1. *Descriptive results*

The rates for the different response categories as a function of lighting-configuration group are displayed in Table 1. The d' values for correct detections was between 1.7 and 2, indicating that the participants' responses in each group were likely to differ significantly from chance.

Table 1
Rates of correct detections, identification errors, misses, false alarms, and correct rejections for the standard, triangle, helmet, and yellow lighting-configuration groups.

<table>
<tr><td></td><td></td><td colspan="8">PRESENTATION</td></tr>
<tr><td></td><td></td><td colspan="4">Motorcycle Stimuli</td><td colspan="4">No-target distractors</td></tr>
<tr><td rowspan="9">RESPONSE</td><td rowspan="6">Detections</td><td colspan="4">Correct detections</td><td colspan="4">False alarms</td></tr>
<tr><td>Standard</td><td>Triangle</td><td>Helmet</td><td>Yellow</td><td>Standard</td><td>Triangle</td><td>Helmet</td><td>Yellow</td></tr>
<tr><td>54</td><td>62</td><td>71</td><td>74</td><td rowspan="4">5</td><td rowspan="4">6</td><td rowspan="4">9</td><td rowspan="4">6</td></tr>
<tr><td colspan="4">Identification errors</td></tr>
<tr><td>Standard</td><td>Triangle</td><td>Helmet</td><td>Yellow</td></tr>
<tr><td>7</td><td>3</td><td>3</td><td>7</td></tr>
<tr><td rowspan="3">Non-detections</td><td colspan="4">Misses</td><td colspan="4">Correct rejections</td></tr>
<tr><td>Standard</td><td>Triangle</td><td>Helmet</td><td>Yellow</td><td>Standard</td><td>Triangle</td><td>Helmet</td><td>Yellow</td></tr>
<tr><td>36</td><td>35</td><td>26.0</td><td>19</td><td>95</td><td>94</td><td>91</td><td>94</td></tr>
</table>

Table 2
GEE analysis results.

Variables	DF	χ^2	p
Lighting	3	7.94	.047
Eccentricity	1	93.95	.0001
Distance	1	64.67	.0001
Lighting*Eccentricity	3	7.30	.063
Lighting*Distance	3	17.92	.0001
Eccentricity*Distance	1	19.90	.0001
Lighting*Distance*Eccentricity	3	11.35	.010

Although bicyclist and pedestrian detections were not analyzed further, we found detection rates comparable to those in Cavallo and Pinto (2012): the motorcyclists had a higher detection rate (63%) than pedestrians (53%) and bicyclists (35%).

3.2. *GEE analysis*

3.2.1. *Effect of lighting configuration*

The GEE analysis revealed a significant effect of lighting configuration (see Fig. 2). Pairwise comparisons showed that the yellow configuration was detected significantly better than the standard configuration (74% vs. 54%; $p < .05$) and that the helmet configuration also tended to be detected more often than the standard headlight (71% vs. 54%; $p = .056$), whereas the triangle configuration (62%) was not significantly different from the standard headlight

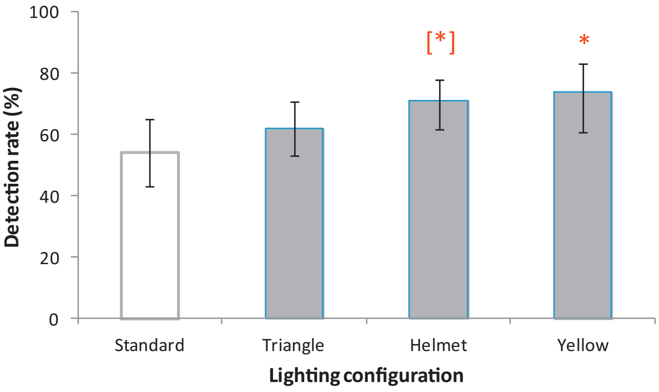

Fig. 2. Mean and confidence interval of the motorcycle-detection rate as a function of lighting configuration. There was a significant difference between the standard and yellow configurations (labeled with an asterisk); the helmet-configuration advantage tended to reach significance (asterisk in brackets).

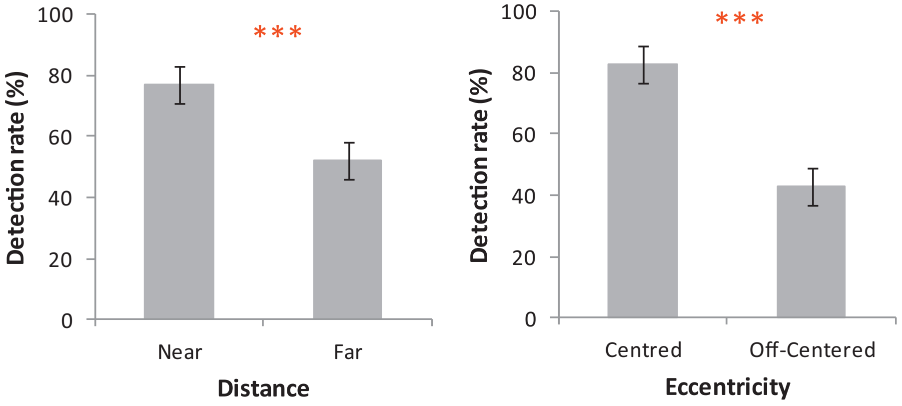

Fig. 3. Mean and confidence interval of the motorcycle-detection rate as a function of distance (on left) and eccentricity (on right) (***$p < .0001$).

(54%). No significant difference between the yellow and helmet configurations was noted.

3.2.2. *Effects of distance and eccentricity*

GEE statistics revealed significant main effects of distance and eccentricity: motorcycles were more often detected when located in the near (77%) and central (83%) positions of the visual scene rather than in far (52%) and off-centered (43%) positions (see Fig. 3).

The significant interaction between distance and eccentricity indicates that the effect of distance was significant only when the motorcycle was located in off-centered positions in the visual scene ($p < .0001$): in that case, the difference between the detection rates at near distances (65%) and far distances (23%) was as much as 42 percentage points, whereas this difference was only 6 percentage points when the motorcycle was in the central part of the visual scene (86% and 80% at near and far distances, respectively). Moreover, the effect of eccentricity was more pronounced at far distances than at near ones: a significant difference of 57 percentage points ($p < .0001$) between centered and off-centered locations was found when the motorcycle was far away, and a smaller but also significant difference of 21 percentage points ($p < .0001$) between centered and off-centered locations when the motorcycle was nearby. It appeared clearly that detection performance was impaired the most when the motorcycle was in a far-away, off-centered location.

3.2.3. *Effects of lighting configuration as a function of distance and eccentricity*

The GEE analyses revealed a significant lighting-by-distance interaction (see Fig. 4): whereas no significant differences between the four lighting configurations were found when the motorcycle was at a near distance, the helmet (68%, $p < .0001$) configuration was detected significantly more often (by 35 percentage points) than the standard configuration (33%) when the motorcycle was far away. Although an improvement of 24 percentage points was also observed for the yellow configuration as compared to the standard configuration at a far distance, this difference failed to reach significance ($p < .1$).

The interaction between lighting and eccentricity fell short of significance (see Fig. 5). The lighting configuration had no significant effect when the motorcycle was in an off-centered location in the visual scene, whereas in the central part, motorcycles tended to be detected better when equipped with a yellow headlight (92%, $p = .089$) than with a standard white one (71%). This improvement amounted to 21 percentage points for the yellow configuration.

A significant triple interaction between lighting configuration, distance, and eccentricity was also found. We examined whether the positive effect of the yellow and the helmet configurations depended on one of the four distance-by-eccentricity conditions. We found that the yellow and the helmet configurations, as compared to the standard headlight, were ineffective when the motorcycle was in near, off-centered locations, whereas these configurations tended to improve detection performance when the motorcycle was far away and centered, far away and off-centered, or near and centered. However, none of the lighting-configuration differences were significant in any of the four distance-by-eccentricity combinations.

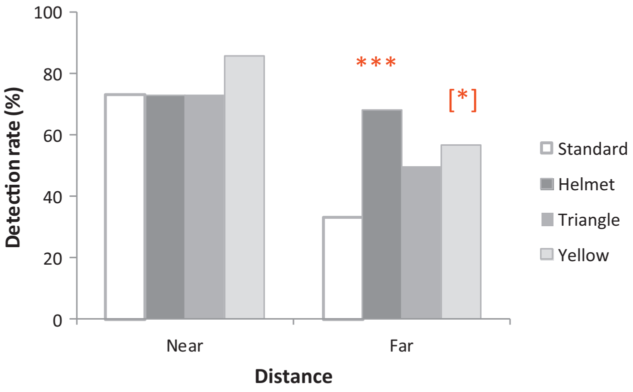

Fig. 4. Mean motorcycle-detection rate (in %) as a function of lighting configuration and distance (***$p < .0001$; [*]$p < .1$).

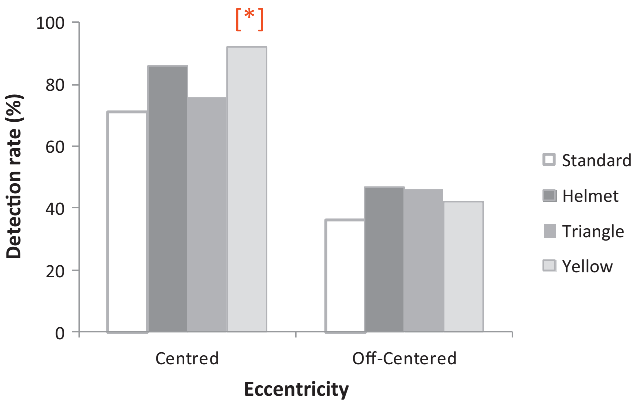

Fig. 5. Mean motorcycle-detection rate (in %) as a function of lighting configuration and eccentricity ([*]$p < .1$).

4. Discussion

The purpose of this experiment was to study some new motorcycle front-light configurations likely to increase their visual conspicuity and thereby improve their detectability in a car-DRL environment. The results obtained are encouraging, since both the *yellow* and *helmet* conditions gave rise to better overall detection performance than the standard condition did. The yellow configuration tended to be beneficial when the motorcycle was in the central area of the scene, whereas the helmet configuration was particularly effective when the motorcycle was far away.

Regarding the use of color coding—and in line with our hypothesis—the results showed that having a yellow headlight significantly increased the dissimilarity between motorcycles and surrounding white-light sources, and thereby provided motorcycles with an easy-to-recognize visual signature. The enhanced conspicuity afforded by the yellow light tended to appear when the motorcycle was located in the central area of the visual scene. Given that detection is not critical in this condition, it can be assumed that the yellow light specifically improved motorcycle identification by clearly distinguishing it from other light sources. This finding is consistent with studies on the role of color in visual search and identification tasks, which have shown that compared to shape- or size-based coding, color coding reduces search time and increases the number of correct answers (Christ, 1975; Nowell, 1997). This benefit is known to be even greater when the number of "noisy" or background items of the same color as the target(s) drops (Christ, 1975; Carter, 1982; Nagy and Sanchez, 1990). This applies perfectly to a traffic environment where cars have white DRLs.

Among the two new white headlight arrangements tested here (triangle and helmet), only the one with a light on the helmet was significantly more effective than the standard lighting pattern. The helmet configuration was found to be particularly effective when the motorcycles were far away. This result can be explained by the fact that the positioning of a light source on the highest point of the motorcyclist also introduced an element of dissimilarity in terms of height in the visual field, between the motorcycle and other road users. A helmet light thus creates a new visual signature that helps distinguish motorcyclists from other road users, particularly in situations where they are more difficult to perceive due to their distant location and small angular size. Because of its high position, this configuration has the additional advantage of lowering the motorcyclist's risk of being hidden behind other vehicles, thereby ensuring optimal visibility.

In contrast, the triangle configuration did not significantly improve motorcycle conspicuity in a car-DRL environment, even though this configuration can be assumed to evoke a human face and activate our automatic face-recognition ability. This lack of improvement suggests that, unlike the other two lighting configurations, the triangle does not offer any truly distinctive features, perhaps because the additional lights on the rearview mirrors remain in the area lit up by surrounding cars and may therefore be confused with car headlights. These results run counter to the conclusions drawn in Maruyama et al.'s study (2009), where the detection rate for the triangle configuration was 2.4 times greater than that of the standard configuration (single central headlight). Note, however, that Maruyama et al.'s experimental situations were quite different from ours since they used computer-generated images and nighttime conditions. We can assume that their images were much less complex than the photographs of real daytime traffic used in our experiment, which naturally contained more distractions. In the same way as motorcycles equipped with a single white headlight have a lower detectability level in a complex urban environment with car DRLs (Cavallo and Pinto, 2012), the lights in the triangle configuration may tend to be mistaken for car lights. Perhaps this configuration could improve motorcycle detection in situations with fewer car DRLs or at night (as in Maruyama et al., 2009), when there are not so many distracting elements in the scene. But in our visually complex experimental situation with motorcycles embedded in an environment of multiple light sources, the triangle configuration does not seem to have offered a conspicuity advantage.

For each of the lighting configurations tested, we found the classic effects of distance and eccentricity, namely that distant and off-centered objects are detected significantly less well. Faraway objects have a smaller angle size and are therefore less conspicuous (e.g., Engel, 1971; Jenkins and Cole, 1986); objects that are not in the middle of the visual scene are also known to be detected less well (e.g., Carrasco and Chang, 1995; Engel, 1977). With regards to these effects on motorcycle detection, our results are also in line with Rogé et al. (2009) and Gershon and Shinar (2013), who found better performance for central objects and faraway distances, respectively. Taking these variables into account allowed us to determine the conditions in which the tested conspicuity enhancements were the most effective. It is interesting to note that the yellow and helmet configurations turned out to be beneficial precisely in situations where car DRLs have been shown to have the most damaging effect (Cavallo and Pinto, 2012), i.e., when the motorcycle is far away and/or in the middle of the visual scene. The results of the present study seem to confirm that the effects observed by Cavallo and Pinto were actually due to competing light patterns, whose adverse effects were reduced in this experiment thanks to the conspicuity enhancement produced by the yellow and helmet configurations. In other words, when it was difficult to see a motorcycle because of its small angular size at its distant location in a car-DRL environment, adding a visual signature like a yellow headlight or a helmet light enhanced motorcycle conspicuity and improved detection. In the central part of the visual scene, where motorcycles were easily detected, we can assume that the yellow light acted as a conspicuity feature that especially improved motorcycle identification.

In terms of application, the present findings indicate several ideas for defining a new visual signature for motorcycles that could make them significantly safer. The yellow and the helmet configurations were both shown to be effective at improving motorcycle detectability in a car-DRL environment. As compared to more complex solutions, such as the T-shape headlighting suggested by Rößger et al. (2012), the yellow and helmet configurations represent quite simple, ergonomically realistic solutions likely to be more readily accepted by motorcycle riders. In particular, the yellow headlight seems to have a good potential for offsetting detrimental effects of car DRLs and to be technically simple to implement.

The advantage of the helmet configuration is that only one auxiliary lighting source is needed to improve detection. The number and types of auxiliary lights are known to have an impact on the electrical power system of a motorcycle, and consequently affect fuel consumption. However, as long as LED technology is used, as in the current dedicated DRLs, battery issues are not at stake. The very low power demands of this technology, together with the small installation space required, make it possible to add batteries to the helmet, without too much extra weight (Müller et al., 2011). Regarding the helmet configuration, future research should determine whether there are significant safety-gain differences between a continuous headlight as in the present experiment, or an alternating-blinking headlight as studied by Gershon and Shinar (2013). The combination of a helmet light and color coding (i.e., a yellow helmet light) could also been considered to associate the benefits of the two systems.

5. Methodological considerations and perspectives

Regarding the validity of our study, the present findings need to be confirmed by further research using additional methods. In particular, the impact of movement information (like that present in dynamic visual scenes) is worth investigating, since target motion is regarded as a conspicuity factor (Itti et al., 2003). Higher contrast and luminance levels (as obtained in real-world conditions) should also be studied in greater detail. To do so, experiments could be conducted in real driving situations or on a driving simulator, although both of these methods have some shortcomings. Experiments run on test tracks have the advantage of offering real levels of luminance (albeit hard to reproduce), but it is difficult to set up situations as complex as in the present experiment. On the other hand, the visual rendering systems used on simulators (projection screens) do not generate realistic contrasts or light sources, both of which are important factors of object salience. However, new display methods (with a "high dynamic range") are now providing a better rendering of contrasts and light sources, and are thus able to recreate the salience of objects in a more realistic way (Petit and Brémond, 2010). The use of these innovative techniques in future investigations should improve the validity of studies on the conspicuity of motorcycles.

Another crucial point for future studies is that research on the ergonomics of motorcycle headlights and the definition of a new visual signature should not only be aimed at improving car drivers' detection and identification of motorcycles, but also their perception of the motorcycle's movement, i.e., its speed, distance, and time-to-arrival. Accident analyses (Tsutsumi and Maruyama, 2007) and experimental studies (Horswill et al., 2005) have suggested that poor perception of motorcycle movement is also a frequent cause of accidents, in addition to non-detection or late detection. Giving motorcycles a new visual signature could also help automobilists to better assess the movement of approaching motorcycles and to accept time windows large enough to keep motorcyclists out of danger. A number of studies considering the effect of headlight configuration on the perception of motorcycle motion are already in progress (e.g., Gould et al., 2012a,b; Maruyama et al., 2009; Tsutsumi and Maruyama, 2007).

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