Accident Analysis and Prevention 94 (2016) 119–126

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Improving motorcycle conspicuity through innovative headlight configurations

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ARTICLE INFO

Article history:
Received 29 September 2015
Received in revised form 4 May 2016
Accepted 12 May 2016
Available online 6 June 2016

Keywords:
Motorcycle
Conspicuity
Headlight ergonomics

ABSTRACT

Most motorcycle crashes involve another vehicle that violated the motorcycle's right-of-way at an intersection. Two kinds of perceptual failures of other road users are often the cause of such accidents: motorcycle-detection failures and motion-perception errors. The aim of this study is to investigate the effect of different headlight configurations on motorcycle detectability when the motorcycle is in visual competition with cars. Three innovative headlight configurations were tested: (1) standard yellow (central yellow headlight), (2) vertical white (one white light on the motorcyclist's helmet and two white lights on the fork in addition to the central white headlight), and (3) vertical yellow (same configuration as (2) with yellow lights instead of white). These three headlight configurations were evaluated in comparison to the standard configuration (central white headlight) in three environments containing visual distractors formed by car lights: (1) daytime running lights (DRLs), (2) low beams, or (3) DRLs and low beams. Video clips of computer-generated traffic situations were displayed briefly (250 ms) to 57 drivers. The results revealed a beneficial effect of standard yellow configuration and the vertical yellow configuration on motorcycle detectability. However, this effect was modulated by the car-DRL environment. Findings and practical recommendations are discussed with regard to possible applications for motorcycles.

1. Introduction

Despite the general improvement in road safety in Europe over the past few years, motorcycle[1] safety is still a major concern. Accident statistics have shown that motorcyclists are among the most vulnerable road users (NHTSA, 2012). In France, fatalities of motorized two-wheeler drivers represent 24% of all motorcyclists whereas they only represent 1.9% of all road users (ONISR, 2014). In the US, the risk of a fatal accident per kilometer travelled is 22 times higher for motorcyclists than for automobilists (NHTSA, 2012).

Typically, motorcycle crashes occur at intersections during the day and are often caused by right-of-way violations by another vehicle approaching head-on (MAIDS, 2009; Pai, 2011; Shaheed et al., 2013). Two kinds of perceptual errors contribute to the risk of such crashes: motorcycle-detection failures and/or motion-perception errors. In-depth studies of motorcycle accidents have noted a high frequency of detection errors (Hurt et al., 1981; Van Elslande and Jaffard, 2010; Pai, 2011). These errors are often referred to as "looked but failed to see" errors, where the car driver reports having looked in the right direction but having not seen the approaching motorcycle (MAIDS, 2004, 2009). This failure may be partly explained by the poor visual conspicuity of motorcycles, which results from their small frontal size, their irregular contour, and their often dark color. Visual conspicuity can be defined as the ability of an object to attract attention by means of its physical characteristics (Connors, 1975), such as size, brightness, color, outline, and motion. Environmental factors also come into play, as shown by several studies (Olson et al., 1981; Cavallo and Pinto, 2012; Gershon et al., 2012): the visual context determines the figure-background relationship and thus the motorcycle's brightness and color contrast levels. It may also contain competing visual elements that act as distractors.

In order to improve motorcycle safety, European motorcycle manufacturers will be using "digital conspicuity", i.e., intelligent transportation systems (ITSs) based on vehicle-to-vehicle communication. These technological solutions will solve problems related

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

http://dx.doi.org/10.1016/j.aap.2016.05.011
0001-4575/

to the limitations of visual perception and attention, but such systems are not likely to be operational for at least 15 years. Until reliable systems are available and all vehicles are equipped with them, other solutions are needed to improve motorcycle safety.

Within the past few decades, the use of daytime running lights (DRLs) by motorcyclists has been shown to improve the conspicuity of motorcycles (Olson et al., 1981; Smither and Torrez, 2010) and reduce motorcycle accidents (e.g., Muller, 1984; Zador, 1985). However, the now widespread use of DRLs on cars reduces the effectiveness of DRLs on motorcycles (Brendicke et al., 1994; Cavallo and Pinto, 2012). While car DRLs in the past consisted of turning on low beams during the day, dedicated DRLs with defined technical characteristics have become compulsory in many countries (in Europe since February 2011). Automobile manufacturers and suppliers presently favor the use of LED (light emitting diode) technology in designing car DRLs, not only to improve visibility but also to display their own visual signature. Having diversified shapes for car headlights might create "visual noise" for motorcycles and hamper their detection. In some countries, car DRLs are even turned on at the same time as low beams, thereby further increasing the number of potentially competing light sources.

In this context, Rößger and Lenné (2015) synthesized recent results on motorcycle conspicuity and discussed the various methods employed to assess the conspicuity of powered two-wheelers. Several studies conducted within the last decade have attempted to find new means of improving the visual conspicuity of motorcycles using innovative headlight configurations that increase the apparent size of motorcycles and/or provide them with recognizable visual features (Maruyama et al., 2009; Rößger et al., 2012; Gershon and Shinar, 2013; Pinto et al., 2014). Different methods such as photographs, computer graphics simulation, and video clips, as well as different visibility conditions (nighttime, dusk or daytime) have been used, which could explain why the results are sometimes discrepant.

Rößger et al. (2012) used photographs of daytime traffic scenes at intersections and found that subjects recognized a motorcycle with a T-shaped headlight configuration (additional lights on the fork and handlebars, forming a T) more quickly than with a standard headlight. Gershon and Shinar (2013) examined the effect of an alternating blinking-light system (ABLS) using video clips shot at daytime and at dusk. The ABLS was a 24-cm high helmet-mounted device with two vertically positioned lights that blinked alternately and created apparent motion. The findings showed that the ABLS increased motorcycle detection rates, especially at dusk. Maruyama et al. (2009) tested a much simpler headlight arrangement with a triangular design (one standard light and two additional lights on the rear view mirrors) called "face design". The effectiveness of this configuration on motorcycle detection was observed in nighttime conditions using computer graphics simulation. However, Pinto et al. (2014) found no benefit of this configuration under more realistic conditions where photographs of complex urban traffic scenes (presence of cars with DRLs) and daytime visual conditions were used, probably because the additional lights on the motorcycle were confused with headlights of cars. Rather than with the triangular configuration, Pinto et al. (2014) showed significant benefits when the motorcycles had yellow headlights, and also when the motorcyclists had an additional light on their helmet. It can be assumed that color coding and/or a high-mounted (helmet) light represent quite simple, ergonomically realistic solutions likely to be accepted more easily by motorcycle riders than the T-shape light configuration (Rößger et al., 2012) or the ABLS (Gershon and Shinar, 2013).

Other studies have also addressed the impact of innovative headlight configurations on the perception of an approaching motorcycle's speed and time-to-arrival (Tsutsumi et al., 2008; Gould et al., 2012a,b). A recent study (Cavallo et al., 2015) pointed out that increasing the vertical dimension of the motorcycle had a beneficial effect on the perception of the approaching motorcycle's motion: longer time gaps were accepted for motorcycles equipped with this vertical configuration, especially in low-visibility conditions where the approach speed was high.

Based on previous research into motorcycle detectability (Pinto et al., 2014) and perception of motorcycle motion (Cavallo et al., 2015), we assume that innovative motorcycle headlight configurations can be designed that benefit both kinds of visual mechanisms and thus globally improve motorcycle perceptibility. While the present experiment is devoted specifically to motorcycle conspicuity and detectability, the choice of configurations to be evaluated also took into account their potential for improving the motorcycle's speed and time-to-arrival.

Our experimental approach consisted of testing three innovative motorcycle headlight configurations in visually complex car-headlight environments in daytime conditions. The configurations, which involve color coding and/or accentuation of the motorcycle's vertical dimension, were: (1) the "standard yellow" configuration, consisting of a central yellow headlight instead of a conventional white one; (2) the "vertical white" configuration, combining a central white headlight, an additional white light on the helmet, and two additional white lights on the fork; (3) the "vertical yellow" configuration, combining a central yellow headlight, an additional yellow light on the helmet, and two additional yellow lights on the fork. These innovative configurations were compared to a "standard white" central headlight. The four motorcycle headlight configurations were evaluated in three car headlight environments: cars with DRLs only on, cars with low beams only turned on, and cars with both DRLs and low beams turned on.

We used a target detection task under time constraints. Short computer-generated video clips were presented to the participants. Compared to static images, these dynamic sequences added visual motion cues likely to affect conspicuity (Itti and Baldi, 2005). The visual targets were vulnerable road users (cyclists, pedestrians, and motorcyclists). The visual targets' distance and eccentricity in the visual scene were also varied because it has been shown that these variables affect motorcycle detection performance (Engel, 1971; Rogé and Pébayle, 2009; Cavallo and Pinto, 2012; Pinto et al., 2014).

We expected the innovative headlight configurations to improve motorcycle detection, and the visually complex car-light environments to be detrimental to motorcycle conspicuity.

2. Method

2.1. Participants

A total of 57 adults (12 women and 45 men) participated in the experiment. They were divided into three groups of 19 participants. Each group of participants had to detect vulnerable road users in a different car-light environment. The groups were matched on age (Group 1: 30.78 ± 7.42; Group 2: 30.79 ± 6.41; Group 3: 29.71 ± 6.01, $p = 0.853$), gender (15 men and 4 women) and driving experience (Group 1: 10.79 ± 6.45; Group 2: 11.21 ± 6.29; Group 3: 9.01 ± 6.31, $p = 0.530$). All participants were licensed drivers and had normal or corrected-to-normal vision (at least 6/10 binocular acuity). All participants underwent the useful field of view (UFOV) test (Ball et al., 1993) and all exhibited normal visuo-attentional performance. Each of the three groups included two or three motorcyclists. Written informed consent was obtained before participation in the study.