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Errors in judging the approach rate of motorcycles in nighttime conditions and the effect of an improved lighting configuration

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ABSTRACT

One of the key contributory factors for accident involvement is misjudgment of approach speed (Department for Transport, 2010). Past research has indicated that individuals can use the rate of visual looming in order to the judge time to passage (TTP) of approaching vehicles, and that smaller vehicles loom to a lesser extent than larger vehicles (e.g., Horswill et al., 2005). However, the judgment of TTP in nighttime conditions has received little attention. This paper explores drivers' abilities to make judgments of motorcycles and car approach speeds in nighttime driving conditions, when only the headlights are visible, as well as the effectiveness of a tri-headlight configuration on the accuracy of motorcycle speed judgments. Results showed that individuals were significantly more accurate at judging the speed of two car headlights compared with the standard solo headlight motorcycle. However, the inclusion of a tri-headlight formation on a standard motorcycle frame significantly improved these judgments. A further investigation demonstrated that tri-headlight configurations with separation between headlights on the horizontal and vertical axes are most effective for yielding accurate speed judgments. The implications of the results for road safety and motorcycle design are discussed.

1. Introduction

In 2008, the volume of motorcycle traffic in the UK had increased by approximately 44% compared with figures from the 1990s (Department for Transport, 2010). Furthermore, despite accounting for just 1% of all road users in the United Kingdom, motorcyclists accounted for 19% of all road traffic fatalities and 21% of all serious road injuries (Department for Transport, 2010). In combination these figures suggest that motorcyclists represent the automobile group that is at the greatest risk of injury.

A large percentage of the motorcycle literature has focused on the error classification of "Look But Fail To See" (LBFTS) accidents, where an individual pulls out into the path of an oncoming motorcyclist and claims not to have seen them approaching (Herslund and Jørgensen, 2003). In response, a number of studies have stressed the need to improve the conspicuity of the motorcycle and motorcyclist (Williams and Hoffman, 1979; Olson et al., 1981; Hole et al., 1996; Rößger et al., 2011). However, while statistics have indicated that the leading contributory factor to accident involvement is a failure to look properly, the second most common contributory factor is a failure to correctly judge the path or speed of another vehicle (Department for Transport, 2010).

When a driver is at a junction waiting to pull out, they need to judge whether the time to passage (TTP) of the approaching vehicles on the main carriageway is sufficient to allow them to pull out and join the line of traffic. If asked about how they are making those judgments, most drivers would say that they are judging the distance of oncoming vehicles and their speed. Distance and speed, however, are metric properties of the 3D scene that are not directly available to the observer (Gibson, 1979). Distance can be inferred from cues such as height in the scene, scaled by eye-height, but this is very unreliable in natural road contexts. For example, a vehicle that is travelling at 30 mph and situated 65 m away from the observation point will have a TTP of 5 s. However, an increase or decrease in the slope of the road by just 1° could mean that this depth cue would indicate that the vehicle is approximately 266 m away or just 37 m away respectively. Additionally, cues to absolute distance such as binocular disparity are not effective for the distances typically encountered in road scenes (Tresilian et al., 1999). The most reliable cue to distance for an approaching vehicle is its optic size on the retina, $\theta(t)$, whereas the rate of change of optic size, $\dot{\theta}$ is correlated with speed of approach, and the ratio of the two can indicate TTP without the requirement to judge actual distance, $z(t)$ or speed, $v(t)$ (Lee, 1976):

$$\mathrm{TTP} = \frac{z(t)}{v(t)} = \frac{\theta(t)}{\dot{\theta}(t)} \quad (1)$$

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A problem arises with Eq. (1), however, because the rate of expansion (looming: $\dot{\theta}(t)$) is dependent upon vehicle size (S), as seen in Eq. (2) below:

$$\dot{\theta}(t) = \frac{Sv(t)}{z^2(t)} \quad (2)$$

This means that a larger sized vehicle will loom at a greater rate compared to a smaller vehicle, and as a consequence a smaller vehicle could be travelling at a faster speed and still be perceived to be approaching slower. If the ratio of optic size to looming rate (tau: Eq. (1)) is used then vehicle size should not be an issue, but a particular problem can occur if $\dot{\theta}(t)$ drops below the threshold for its detection in which case TTP in Eq. (1) tends towards infinity and the vehicle will be seen as small and almost static in the visual scene.

Research has supported the assertion that visual looming can lead to the underestimation of speed for smaller objects if the observer does not compensate for relative object size (DeLucia and Novak, 1997; DeLucia et al., 2003). More specifically, in a study involving the use of video footage, Horswill et al. (2005) noted that judgments of TTP for motorcycles were less than those for cars that were travelling at the same speed in daylight conditions. Furthermore, the authors noted that there was a linear trend for vehicle size on TTP judgments across all of the stimuli tested (shortest TTP judgments for small motorcycles, then large motorcycles, cars and largest TTP judgments for vans). This effect supported previous research whereby the accuracy of TTP judgments declined across a full-size car, a compact car and a motorcycle (Caird and Hancock, 1994). An interesting issue is that the vertical extent of a motorcycle and rider is often equivalent to a standard full-size car; thus it appears that individuals may be more sensitive to detecting looming along the horizontal axis compared with the vertical axis.

While it is clear that vehicle profile can bias speed and TTP judgments, there has been relatively little research conducted into judging car and motorcycle speeds in nighttime conditions where only very basic perceptual information is available. Nighttime conditions may exacerbate the effect of Eq. (2). If a motorcycle is approaching a junction along an unlit carriageway then the area discernable by an observer at a junction is the headlight of approximately 20 cm in diameter. By comparison a car also has a 20 cm headlight diameter, but has two lights separated by approximately 1.6 m and the main cue to its approach speed would appear to come from their separation. Tresilian (1991) proposed that TTP could be extracted from the divergence of two features, using a method equivalent to Eq. (1), with θ defined by the optical gap between two edges. At a cortical level, however, this is not a straightforward issue. A closed illuminated contour that is expanding provides a strong and direct percept for most animals (e.g. Sun and Frost, 1998) and is responded to in equivalent sub-cortical areas in humans (Billington et al., 2010), but there is no equivalent evidence that neural systems respond in a direct manner to the separation of two features. To our knowledge no-one has explored the accuracy to which speed or TTP can be estimated from the separation of two features, but everyday experience would seem to suggest that an advantage is conferred by two headlights as opposed to one. It may also be possible that the introduction of a multiple headlight configuration that incorporated some level of separation on a standard motorcycle frame could improve speed estimations in nighttime conditions.

Our aim was to assess how accurately individuals are able to discriminate between the speeds of motorcycles and cars in daytime and nighttime conditions. To explore this we used computer simulations of different headlight configurations approaching an observer. For nighttime conditions we predicted that the speed of the car stimuli would be judged more accurately than that of the motorcycle stimuli due to the separation of the two headlights. We then included a tri-headlight formation that could be mounted on a standard size motorcycle to see if that would improve the speed judgments for the motorcycles. We also tested the accuracy of judgments when the configurations above were used in daylight conditions, where the natural contours of both vehicles were visible, and predicted there would be no difference in speed judgments between all headlight configurations. Finally, the present study investigated a number of different tri-headlight configurations in order to examine whether individuals are more sensitive to looming along the vertical or horizontal axis.

2. Method

2.1. Participants

A sample of 13 participants, six male and seven female, were recruited from the Psychology Department at Royal Holloway, University of London. The participants ranged from 21 to 44 years of age with an average age of 28 years (S.D. = 8.02 years). All participants had normal or corrected to normal vision, held a valid United Kingdom driving license, and were naïve to the purposes of the study. None of the participants held motorcycle licenses. The study was approved by the Psychology Department ethics committee, and all participants completed informed consent forms prior to taking part in the experiment.

2.2. Apparatus

Stimuli were presented on a 34 cm × 27 cm Cathode Ray Tube monitor display (1024 × 768 pixels). All simulations were scripted in Python and used Vizard 3D simulation tools (WorldViz, USA). The Vizard libraries sit on top of OpenSceneGraph and provide the ability to render highly realistic 3D simulations that are perspective correct and run at the maximum screen refresh rate (60 Hz). The rendering hardware was an Intel® dual core CPU with an NVidia high performance GPU running under Windows XP. The simulation code used a 60 Hz timer-loop, which ensured that the correct vehicle size and rate of expansion was presented for every frame of the each trial. Participants viewed the stimuli under bi-ocular conditions in a dimly lit university laboratory.

2.3. Experimental conditions and design

The methodology deployed for each of the three experiments was a discrimination paradigm utilized in previous research (Todd, 1981; Field and Wann, 2005). In this instance, participants were asked to indicate which of two visual stimuli presented sequentially was travelling at the fastest speed. The appropriate car stimulus was used as a reference vehicle in all trials, travelling towards the observation point at a fixed speed of 30 mph (13.4 m/s). The order in which the probe and reference vehicle were presented was randomized. The speed of the probe vehicle was manipulated using a parameter estimation by sequential testing procedure (Best-PEST; Lieberman and Pentland, 1982), which calculates the optimal increment in speed for each trial based on the observer's previous responses in order to efficiently converge on their threshold performance. The PEST staircases were stopped after the seventh reversal, and the threshold was calculated as the average of the last four reversals. Using this procedure the speed differences between the probe and reference vehicles ranged from −20 mph to 180 mph.

2.3.1. Nighttime driving conditions

The stimuli were displayed in a randomized sequence of a reference stimulus, consisting of two headlights, versus a probe stimulus consisting of either one headlight, two headlights or three