Accident Analysis and Prevention 48 (2012) 341–345

Contents lists available at SciVerse ScienceDirect

Accident Analysis and Prevention

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

Judgments of approach speed for motorcycles across different lighting levels and the effect of an improved tri-headlight configuration

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ARTICLE INFO

Article history:
Received 22 December 2011
Received in revised form 1 February 2012
Accepted 3 February 2012

Keywords:
Perception
Vision
Looming
Tau
Motorcycle
Conspicuity

ABSTRACT

The misperception of vehicle approach speed is a key contributory factor to road traffic crash involvement. Past research has indicated that individuals use the rate of visual looming to calculate the time to passage (TTP) of a vehicle, and that smaller vehicles loom to a lesser extent than larger vehicles. Despite a disproportionate number of fatal injuries occurring on the road after dark, and a higher than average number of accidents involving automobile drivers violating the right of way of a motorcyclist occurring in low light conditions, there has been very little consideration of the accuracy of TTP for smaller and larger vehicles under low levels of luminance. We investigated drivers' judgments of motorcycle and car approach speeds across a number of levels of luminance within a virtual city scene, as well as the effectiveness of a tri-headlight formation on motorcycle speed judgments. The accuracy of car approach speed judgments were not affected by changes in lighting conditions, but speed judgments for the solo headlight motorcycle became significantly less accurate as lighting reduced in the early night and night-time conditions. Incorporation of a tri-headlight formation onto the standard motorcycle frame resulted in improved accuracy of approach speed judgments, relative to the solo headlight motorcycle, as ambient light levels reduced. The practical implications of the findings are discussed in terms of road safety and motorcycle design.

1. Introduction

The misperception of vehicle approach speed is a key contributory factor to road traffic crash involvement (Hurt et al., 1981; Pai et al., 2009; Peek-Asa and Kraus, 1996; Brenac et al., 2006; Department for Transport, 2010a). For example, the risk of collision is increased if an observer underestimates the distance and speed of an oncoming vehicle, as the vehicle will be perceived as reaching them later than it actually would, thus leaving less time available to perform a manoeuvre such as pulling out from a junction. Furthermore, perceptual limitations in judgments of vehicle approach may be compounded in lower light conditions. Indeed, a disproportionate number of fatal injuries occur on the roads after dark (Pai et al., 2009; Plainis et al., 2006). According to the Community database on Accidents on the Roads in Europe (CARE), while the number of drivers on the road during low level lighting conditions is far fewer than during daylight hours, statistics indicate that approximately 50% of all fatal accidents occur between the hours of 6 pm and 6 am (ERSO, 2008).

Research has provided a substantial amount of evidence to suggest that drivers are less capable of avoiding collisions under reduced lighting conditions compared with daylight conditions, and accidents involving pedestrians (Sullivan and Flannagan, 2002) and rear-end collisions with other motor vehicles (Sullivan and Flannagan, 2003) are particularly prevalent. Consequently, there is little disagreement that driver vision in the dark is seriously impaired when compared with daylight conditions (Sullivan et al., 2004). Very little research, however, has focussed on the perception of vehicle approach under low light conditions.

Gauging the time-to-passage (TTP) of an oncoming vehicle has traditionally been expressed as a ratio of the vehicle's distance (z) and speed of approach (v) for a given period of time (t). However, estimating metric properties such as relative distance is problematic as judgments can be biased by other cues such as the vehicle's height in the scene (see Wann et al., 2011 for further discussion). A more reliable indicator of relative distance and speed is the vehicle's optical size $\theta(t)$ divided by its rate of expansion $\dot{\theta}(t)$ (Lee, 1976):

$$\text{TTP} = \frac{z(t)}{v(t)} = \frac{\theta(t)}{\dot{\theta}(t)} \tag{1}$$

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doi:10.1016/j.aap.2012.02.002

As discussed in Gould et al. (2012), a problem can arise with Eq. (1) due to the fact that the rate of expansion is dependent on the size of the vehicle (S), which could be taken as either the width, height or combined surface area:

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

When applied to a driving scenario, Eq. (2) demonstrates that when travelling at the same speed, a larger vehicle will loom to a greater extent than a smaller vehicle. This raises the possibility that for two different sized vehicles at the same distance from the observer, and travelling at the same speed, the smaller one will appear to be travelling slower and thus will be perceived as reaching the observation point at a later time than the larger vehicle. Under optimal lighting conditions, an effect of vehicle size is noticed in terms of drivers' ability to judge speed accurately (Caird and Hancock, 1994; Horswill et al., 2005). More specifically, individuals may be less accurate when judging the speed of smaller vehicles, such as motorcycles, compared with larger vehicles, as a consequence of their smaller frontal surface area (Pai, 2011). This may explain in part why motorcycles are overrepresented in crashes when a driver commits a right of way violation by pulling into the path of an oncoming motorcyclist (Pai et al., 2009; Peek-Asa and Kraus, 1996). This problem will be exacerbated for motorcyclists when night falls, as the contours of the rider and vehicle can no longer be depicted. Therefore only the diameter of the solo headlight can be used to determine TTP, yielding less accurate judgments of approach speed (Gould et al., 2012). Research on gauging vehicle approach, however, has typically been conducted under optimal lighting conditions, with little consideration of how the accuracy of TTP estimates may be affected under lower luminance levels.

In terms of the effect of lighting conditions on motion processing, past research has demonstrated that the processing of visual information under low luminance and contrast is much poorer than for brighter objects and that furthermore, individuals are extremely poor at judging the speed of objects under low lighting conditions (Gergenfurtner et al., 1999; Plainis et al., 2006). Researchers have provided evidence that this is primarily due to the reliance of the visual system on information provided by rod photoreceptors during low light level conditions, opposed to the cone photoreceptors that are used during higher lighting levels. More specifically, motion perception using rods is seriously impaired, while spatial and temporal resolution also suffer (Hess et al., 1990; Gergenfurtner et al., 1999).

Given the evidence that human processing of visual motion is degraded when luminance levels are reduced under strict psychophysical conditions, it is possible that judgments of approach speed are also affected in lower light conditions (Pai et al., 2009). Over the course of the year in the UK, motorcycle traffic volume is at its highest between the hours of 7–9 am and 3–7 pm, with the peak travel time evident between 4 and 6 pm (Department for Transport, 2010b). While research has suggested that road accidents are less prevalent during the longer hours of the summer months (Sullivan and Flannagan, 2002), in mid-December the sun does not rise until 8 am and sets before 4 pm, thus creating a situation where motorcycles are likely to be travelling during dim light conditions. More specifically, in a mixed logit analysis of UK police reports on traffic collisions (Stats19), Pai et al. (2009) demonstrated that a higher than average number of accidents involving automobile drivers violating the right of way of a motorcyclist occurred during dusk street lighting periods, in the evening and midnight/early morning periods of the day and during the autumn/winter months.

One potential countermeasure to improve sensitivity to motorcycle approach is the addition of extra motorcycle headlights. Previous research has demonstrated that a greater separation distance between headlights can lead to improved distance judgments when speed remains constant (Castro et al., 2005). Furthermore, the introduction of a tri-headlight formation on a standard motorcycle frame, where the distance between the lights increases on both the horizontal and vertical axes during visual looming, can greatly improve speed judgments for motorcycles (Gould et al., 2012). In the latter study, headlights were presented as approaching the observer on a black background, with absolutely no vehicle contour visible. The control condition featured a daylight condition, where the photographic vehicle stimulus approached the observer viewpoint on a mosaic tarmac background. In addition to making the visible profile larger, this condition included cues such as relative size and occlusion which can affect arrival judgments (DeLucia et al., 2003). Ambient light levels, however, do not change from broad daylight to absolute night in one step, so in this study we looked at judgments of approach speed in a contextual virtual road scene, and investigated how judgments were affected as simulated lighting levels fell.

The aim of the present study was to determine the extent to which sensitivity to approach speed declines as luminance levels decrease and how judgments for motorcycles and cars might be differentially affected. We utilised computer simulations of photographic images of a car, a solo headlight motorcycle, and a tri-headlight motorcycle approaching the observer viewpoint in a virtual city environment. These simulations took place across five different simulated ambient light level conditions, ranging from levels approximating broad daylight to night-time conditions. We predicted that the accuracy of speed judgments for the car would be least affected across the reduced lighting conditions, but that the accuracy of judgments for the solo headlight motorcycle would decrease as the simulated light level was reduced. We predicted that the motorcycle fitted with the tri-headlight formation would improve the accuracy of speed judgments for the motorcycle across all lighting conditions.

2. Method

2.1. Participants

A sample of 14 participants, 8 male and 6 female, were recruited from Royal Holloway, University of London. The participants ranged from 22 to 49 years of age, with average age of 32 years (SD 8.93 years). All participants were required to have possessed a valid United Kingdom driving licence for at least one year and were requested to wear their usual corrective eyewear during the experiment. The study was approved by the Department of Psychology ethics panel.

2.2. Apparatus

The experiment utilised a 34 cm × 27 cm cathode ray tube monitor display, with an aspect ratio of 1.26 and resolution of 1024 × 768. The 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 each trial. The reference ambient light levels that formed a basis for the simulated luminance in the experimental scenes were recorded using a Minolta photometer.