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The role of looming and attention capture in drivers' braking responses

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ABSTRACT

This study assessed the ability of drivers to detect the deceleration of a preceding vehicle in a simulated vehicle-following task. The size of the preceding vehicles (car, van, or truck) and following speeds (50, 70, or 100 km/h) were systematically varied. Participants selected a preferred following distance by engaging their vehicle's cruise control and when the preceding vehicle began decelerating (no brake lights were illuminated), the participant's braking latency and distances to the lead vehicle were recorded. The experiment also employed a secondary task condition to examine how the attention-capturing properties of a looming vehicle were affected by driver distraction. The results indicated that a looming stimulus is capable of redirecting a driver's attention in a vehicle following task and, as with detection of brake lights, a driver's detection of a looming vehicle is compromised in the presence of a distracting task. Interestingly, increases in vehicle size had the effect of decreasing drivers' braking latencies and drivers engaged in the secondary task were significantly closer to the lead vehicle when they began braking, regardless of the size of the leading vehicle. Performance decrements resulting from the secondary task were reflected in a time-to-collision measure but not in optic expansion rate, lending support to earlier arguments that time-to-collision estimates require explicit cognitive judgements while perception of optic expansion may function in a more automatic fashion to redirect a driver's attention when cognitive resources are low or collision is imminent.

1. Introduction

Maintaining an appropriate distance between one's own vehicle and vehicles ahead (headway distance) is an important component of driving. The prevalence of nose-to-tail crashes, however, would suggest that in many circumstances drivers are often deficient in this aspect of driving. Nose-to-tail crashes are the most frequent form of motor-vehicle crashes, constituting more than one quarter of all crash types (Wierwille et al., 2006). These statistics imply that some drivers apparently misjudge or disregard selection of safe headway distances. There has long been a widely accepted standard for selecting headway distance based on the general rule that driver reaction times and vehicular braking capabilities sum to a minimum safe following time of 2 s (Evans, 1991). Although a range of models of drivers' car following have been advanced (Brackstone and McDonald, 1999; Van Winsum, 1999) they have not been able to account for the wide degree of variability in headway distances seen across different drivers and situations (Boer, 1999; Hancock, 1999; Ranney, 1999).

Researchers have identified individual differences in adopted headway due to driver age, gender, and risk-taking behaviour (Evans and Wasielewski, 1983; Taieb-Maimon and Shinar, 2001) but there has been comparatively little published research into how contextual variables such as vehicle size and driving speed influence drivers' selection of headway distance. An early study of participants' judgements of apparent headway distance from static images found that vehicles ahead were judged to be nearer when more of the roadway was obscured by the length of the vehicle hood in the picture, but that lead target size did not reliably affect the distance judgements (Evans and Rothery, 1976). In an observational study of car following on motorways it was found that drivers' adopted headway distances were much closer than optimal or safe, with over 95% of headway times less than the recommended 2 s (Brackstone et al., 2002). A field study of gap acceptance in car following showed that drivers reliably underestimated gaps; with the underestimates worse for cars ahead (as compared to cars following behind) and at high speeds (as opposed to standing still) (Nilsson, 2000). Another field study found that drivers underestimated their headway distance but overestimated headway time, with the absolute error in the overestimates of time increasing as speeds increased (Taieb-Maimon and Shinar, 2001). In contrast, a study employing a simulated driving task found that drivers' underestimation of their headway distance was magnified at low speeds

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and longer distances (Baumberger et al., 2005). Other researchers have reported that drivers followed light trucks more closely than passenger cars by an average of 5.6 m (Sayer et al., 2000). Drivers' headway distances have also been shown to decrease in the presence of low visibility conditions such as fog (Broughton et al., 2007).

Selection of an appropriate headway distance is only one-half of the problem underlying the frequency of nose-to-tail crashes; initiation of a braking response when required is of equal importance. Interestingly, this aspect of car following may involve quite different cognitive processes. The characteristics of braking reaction times (BRTs) have been the subject of several well-known parametric investigations (Evans, 1991; Green, 2000; Johansson and Rumar, 1971). Most have used experienced, alert drivers reacting to discrete stimuli such as the onset of a leading vehicle's brake lights (McKnight and Shinar, 1992). Using this paradigm the relative effectiveness of various types of brake lights have been investigated, including center high-mounted lamps (McKnight and Shinar, 1992), flashing lamps (Berg et al., 2007; Tang, 2003), and oscillating or alternating lamps (Wierwille et al., 2006). The onset of a stimulus such as brake lights provides a highly salient cue to drivers and serves to redirect or capture their attention (Franconeri et al., 2005; Franconeri and Simons, 2003). The term attention capture in this context refers to an unconscious and involuntary reorienting of attention produced by stimulus events (e.g., changes in luminance) regardless of what top-down search strategies or other cognitive processes may be active (Theeuwes, 2004).

Drivers attend to a range of non-driving stimuli (Hughes and Cole, 1986; Stutts et al., 2005) and when distracted by these stimuli, drivers tend to decrease their headway distance (Rosenbloom, 2006), their detection of vehicles decelerating ahead of them is impaired (Lamble et al., 1999), and their BRTs are significantly increased (Alm and Nilsson, 1995; Hancock et al., 2003). These changes in driver performance are presumably due to the 'costs' associated with attentional switching, divided attention, and/or changes in where a driver is directing their gaze. Although it can be extremely difficult so separate the relative cost of each of these factors, the pattern of results suggests that the bottom-up attention capturing properties of brake lights are not able to compensate for top-down (focussed attention) driver distractions in a car following situation.

Visual looming produced by objects moving towards the observer has been demonstrated to produce automatic attention capture in a manner similar to abrupt stimulus onsets (Franconeri and Simons, 2003). The optic expansion rate of objects in an observers' visual field has been proposed to have a strong automatic pull on attentional resources by virtue of signalling potentially behaviourally urgent events (Franconeri and Simons, 2003). In a car following situation, the relative rate of looming correlates directly with the behavioural urgency of a braking response when following another vehicle. In a comparison of distracted drivers' detection performance with and without brake lights it was observed that brake lights may not produce sufficient attention capture to allow detection when drivers are looking at in-car stimuli, and may be inferior to the optic expansion rate of the leading vehicles in the driver's peripheral vision (i.e., a looming object) (Summala et al., 1998). The optic expansion rate of a decelerating vehicle ahead has been characterised as involving rapid automatic perceptual processing, in contrast to drivers' explicit estimates of the time-to-collision (TTC) at the prevailing speeds (Kiefer et al., 2006). TTC judgements in a braking task are influenced by a range of contextual variables including the size of the lead vehicle and the speed of travel (Fajen and Devaney, 2006; Rock and Harris, 2006) adding support to the idea that TTC judgements are integrated at an explicit cognitive level as opposed to the automatic and implicit perceptual processes activated by looming stimuli.

Of the parameters available to characterise TTC, significant attention has been given to the Tau ratio (or simply Tau); expressed as (H/V_r); the time it would take a following vehicle to collide with a leading vehicle if the current relative velocity (V_r) were maintained from the current headway rate (H) (Hoffman and Mortimer, 1994). Tau, which can be described from the point of view of the observer as the size of an object over its rate of change in size, has been shown to reliably predict the action point at which drivers' judgements of TTC produce braking to a lead vehicle (Lee, 1976). Like optic expansion rate, Tau is based on simple visual information but the two measures characterise the visual information from approaching objects in different ways; optic expansion rate has been characterised as optically explosive immediately prior to collision while Tau displays a more gradual and linear decrease throughout the approach to a target. Experimental evidence has shown that Tau is a good predictor of drivers' braking distances in many situations. Yet to be resolved, however, is the degree to which it remains an effective predictor when contextual cues are manipulated to provide drivers' with more or less information about speed and target distance (Yilmaz and Warren, 1995; Rock and Harris, 2006).

In this context it is of interest whether attention capture by a looming vehicle (in the absence of brake lights) will show the same sort of performance decrements for distracted drivers as brake light onset; and further, whether optic expansion rate or Tau will better reflect any performance decrements observed to occur. Inasmuch as the presence of brake lights may serve to minimise the effects of size differences in leading vehicles (whereas looming will in part be determined by target size) one might reasonably ask how drivers' adopted headway distances may be affected by vehicle size and speed when brake lights are not available to serve as warning signals. Thus, the purpose of this study was to: (1) investigate how the perceptual cues of speed and vehicle size influence drivers' adoption of headway distance when brake lights are unavailable; (2) examine the degree to which these cues affect drivers' BRTs in the presence of distracting secondary task; and (3) compare TTC (as expressed by Tau) and optic expansion measures of the point at which drivers initiate a braking response to a looming vehicle.

2. Method

2.1. Participants

A sample of 78 participants, 43 male and 35 female, were recruited from the local area, via notices placed in the newspaper, to take part in the experiment. The participants ranged from 16 to 66 years of age with an average age of 32.44 years (S.D. = 13.27). Participants were required to possess a current New Zealand driver's licence. The participants were asked to wear any corrective lenses during the experiment if they were required to do so as a condition of their driver's licence.

2.2. Apparatus

The experimental apparatus was the University of Waikato driving simulator consisting of a complete automobile (BMW 314i) positioned in front of three angled projection surfaces (shown in Fig. 1). The centre projection surface was located 2.42 m in front of the driver's seat with two peripheral surfaces connected to the central surface at 62° angles. The entire projection surface was angled back away from the driver at 14° (from the bottom to the top of the projection surface) and produced a 175° (horizontal) × 41° (vertical) forward view of the simulated roadway from the driver's position. The image projected on the central surface measured 2.64 m wide × 2.10 m high (at a resolution of 1280 × 1024 pixels)