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Evaluation of a sudden brake warning system: Effect on the response time of the following driver

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ABSTRACT

This study used a video-based braking simulation dual task to carry out a preliminary evaluation of the effect of a sudden brake warning system (SBWS) in a leading passenger vehicle on the response time of the following driver. The primary task required the participants ($N = 25$, 16 females, full NZ license holders) to respond to sudden braking manoeuvres of a lead vehicle during day and night driving, wet and dry conditions and in rural and urban traffic, while concurrently performing a secondary tracking task using a computer mouse. The SBWS in the lead vehicle consisted of g-force controlled activation of the rear hazard lights (the rear indicators flashed), in addition to the standard brake lights. Overall, the results revealed that responses to the braking manoeuvres of the leading vehicles when the hazard lights were activated by the warning system were 0.34 s (19%) faster compared to the standard brake lights. The SBWS was particularly effective when the simulated braking scenario of the leading vehicle did not require an immediate and abrupt braking response. Given this, the SBWS may also be beneficial for allowing smoother deceleration, thus reducing fuel consumption. These preliminary findings justify a larger, more ecologically valid laboratory evaluation which may lead to a naturalistic study in order to test this new technology in 'real world' braking situations.

1. Introduction

It is estimated that worldwide, 25% of all crashes are rear-end collisions which are most often caused by driver inattention, following too closely, or looking at the wrong place at the wrong time (Rumar, 1990; Wierwille et al., 2006). In New Zealand, there were a total of 1309 rear-end collisions reported in 2007 to the police (Ministry of Transport of New Zealand, 2008). The human consequences of these were nine fatalities, 86 seriously injured and 1672 people sustaining minor injuries. The majority of these crashes (801) occurred on urban roads during hours of daylight with only 164 (20.5%) occurring during periods of darkness. Although there were fewer rear-end crashes on rural roads (499), a higher proportion were during hours of darkness (111; 22%) and there were six fatalities on rural roads (two during hours of darkness) compared with only three in urban areas, one of which occurred during hours of darkness.

When factors contributing to all crashes in New Zealand in 2007 are examined, it has been estimated that 1479 crashes occurred due to driver inattention or division of attention, and of these, by far the biggest majority (860) were due to a failure of the driver to notice the car in front slowing, stopping or having stopped. A further 65 of the crashes resulting from insufficient attention were deemed to be due to a lack of awareness of the indication signal of the vehicle in front (Ministry of Transport of New Zealand, 2008).

This situation is not unique to New Zealand. The '100 car naturalistic study' continuously monitored day to day driving behaviour in instrumented cars over a year in the U.S. (Klauer et al., 2006; Neale et al., 2005). They found that 78% of crashes and 65% of near crashes could be attributed to driver inattention, with young drivers (18–20 years) being disproportionately involved in distraction related crashes. During the study period, 15 rear-end collisions occurred, 380 near collisions, and 5783 incidents (greater than any other category of event), of which 93% of the rear-end collisions involved driver inattention (not looking at the road in front).

One proposed solution to this problem is the introduction of an alternative form of brake light system which aims to improve the reaction/braking time of the following vehicle by being more effective at capturing the attention of the driver. Various different brake light systems have been proposed and evaluated including those which; illuminated when the driver removed pressure from the accelerator (Shinar, 1995; Shinar, 2000); provided optical looming cues of the lead vehicle (Li and Milgram, 2008); or

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increased in size and luminance as the deceleration rate increased (Gail et al., 2001).

Most of these recent brake light modification suggestions stemmed from a landmark field study conducted in 1974 using a fleet of San Francisco taxi cabs, where a number of the fleet were fitted with a deceleration warning light system, centre mounted on the rear of the vehicle (Voevodsky, 1974). This warning light was activated by the use of the brake pedal and pulsed at a rate that increased exponentially with the increase in gravity force generated by the deceleration. Over a 12 month period, this trial saw a decrease in the rear-end collision rate from the 8.91 collisions per million miles over a total of 7.2 million miles for the control group (not fitted with the warning light), to 3.51 collisions per million miles over a total of 12.3 million miles for those fitted with the warning light. The crash rate for the control group over this time was consistent with previous data, in that it was comparable to the 1971 figures of 8.89 crashes per million miles over 21.5 million miles, and was close to the 5-year mean rate of 7.9 crashes over 125 million miles in the 5 years prior to 1972. This trial also resulted in a reduction in the driver injury rate from 1.67 per million miles for those in the control group to only 0.67 for those driving vehicles fitted with the warning light, and a drop in the cost of vehicle repairs from US$1041 per million miles to $398 (Voevodsky, 1974).

The U.S. National Highway Traffic Safety Administration partially replicated Voevodsky's study (the centre high mounted stop light (CHMSL) did not flash) on a larger scale and since 1986 in the U.S., CHMSLs have been standard safety equipment on all new passenger cars. Most developed countries also made them mandatory in their new car models in the 1990s, including New Zealand after their own naturalistic evaluation (Allan and McCormick, 1987). Initial evaluations in fleet vehicles suggested a 50% reduction in relevant rear-end collisions in vehicles with CHMSLs, but over time its effectiveness has decreased to around 4.3% (Kahane and Hertz, 1998). However, the savings associated with fewer rear-end collisions still far outweigh the cost of CHMSLs.

While CHMSLs are effective, they do not relay information to the following driver on the intensity of braking of the lead car – it is simply an additional brake light. This differs markedly from the enhanced brake light system originally evaluated by Voevodsky (1974) in which the additional brake light pulsed at a rate related to the gravity force generated by the car's deceleration. Thus, there remains scope to enhance the safety benefits of the CHMSL.

The positive safety effects of two alternative prototypes of enhanced braking systems have been demonstrated in a 'real world' situation (Wierwille et al., 2006). The first prototype consisted of an oscillating narrow beam lamp and the second was an alternating pair of lamps. In a situation where the drivers were given a secondary 'mildly distracting' task to perform while driving, both alternative rear lighting systems produced significantly improved reaction times in comparison to the standard rear lighting system. This effect was evident for both brake activation time and time to come to a full stop. In this experiment, it was estimated that driver responses were improved by 0.25–0.35 s, which at 45 m/h (72.4 km/h) corresponds to 5–7 m additional stopping distance, a figure which is, however, dependent on actual speed and various other factors which would characterise each particular situation.

For a brake light system to be most effective, it must be capable of capturing the attention of the peripheral visual system, as a driver's attention is frequently diverted from the road ahead by the numerous distracters present in the driving environment (Summala et al., 1998). Such a system must, in the first instance, be easily distinguished from its background context (Berg et al., 2007). However, a simple change in colour, detected primarily by the central visual system, does not attract attention as quickly as motion or changes in luminance. These changes are detected primarily by the faster processing peripheral visual system which responds selectively to abrupt changes in visual stimuli, such as a rapidly appearing object (e.g., a car approaching at speed as you are crossing the road) (Enns et al., 2001; Franconeri et al., 2005; Theeuwes, 1995).

Thus, as the peripheral visual system is more efficient at detecting motion and luminance changes, a braking light system characterized by flicker or oscillation should be more effective than a static light system. There is some support for this, with decreased reaction times (25–50 m improvement) in response to brake lights flashing at 4 Hz (Gail et al., 2001), and 20 Hz (14–29 m improvement) compared to static lights in simulated car driving tasks (Berg et al., 2007). Similar improvements in reaction time were observed with motorcycles when the brake lights were supplemented with flashing indicator lights (1.5 Hz) both in the laboratory and on the road in bright sunlight and during night-time driving (Tang, 2003). However, Alferdinck (2004) failed to find a beneficial effect of either 1.5 Hz or 5 Hz flashing lights positioned as a fog lamp or as brake lights but this may be due to their rather unusual experimental setup. Participants were required to carry out a steering task on a simulated motorway presented on a computer screen. Just above the screen were two large plywood cut outs in the shape of the rear-end of the car, with various light configurations. Participants had to respond whenever the car in the right hand lane braked. Thus, the simulated road and the cars were not integrated. Furthermore, the 'cars' remained a set distance in front of the participant and the task was essentially a detection task rather than one which emphasized avoidance of a rear-end collision.

Thus, research evidence to date suggests that a sudden brake warning system (SBWS) based on flashing lights could be advantageous to further reduce the number of rear-end crashes. In addition, if the system not only attracted drivers' attention, but also provided an indication of braking intensity, this would enable following drivers to brake early and drive more smoothly, reducing fuel consumption (Metz et al., 2007). Indeed, one of the four Eco-Drive rules is to "think ahead and drive evenly; avoid unnecessary braking and gear changing" (QUAD, 2004). Therefore, along with a reduction in crash numbers, a more effective (attention captivating) braking system would facilitate a reduction in human cost (injury or death), the associated health costs, as well as fuel costs and not insignificant vehicle maintenance costs.

To date, there have been some promising evaluation studies on enhanced braking systems which improve the response times of the following driver. However, none of the tested systems (except for the well known CHMSL, which does not indicate braking intensity) have been adopted as safety equipment in passenger cars. Therefore, more research is needed to further justify the use of such systems to help prevent rear-end collisions. The current study addresses two gaps in the literature. Firstly, it uses a newly designed video-based braking simulation dual task. Secondly, it is the first evaluation of a system which uses the car's existing rear hazard lights to signal the intensity of a braking response. This system can be installed in a passenger car in less than 30 min, and it won two Road Safety Innovation Awards from the New Zealand Road Safety Trust in 2004.

Therefore, the current research was conducted to evaluate the effect of this SBWS on the response time of the following driver. The system was an electronic safety device that monitored the deceleration of the vehicle to which it was fitted. It was activated when certain deceleration thresholds were met during a sudden stop, causing the hazard warning lights (the two rear indicators) to flash on one of two different frequencies (2 Hz and 5 Hz) depending on the threshold, indicating a hazard for the following driver. A laboratory video-based dual task was used to record the response times