Evaluating a Sudden Stop Warning System: Effect on the Response Time of the following driver

Robert B. Isler#, Nicola J. Starkey, and Margaret Drew
Traffic and Road Safety Research Group
Psychology Department
University of Waikato
Private Bag 3105
Hamilton, New Zealand

Abstract

This study used a video-based braking simulation dual task to evaluate the effectiveness of a sudden stop warning system of a leading private passenger vehicle on the response time of the following driver. The primary task required the participants to respond to sudden braking maneuvers of a lead vehicle during simulated day and night driving, wet and dry conditions and in rural and urban traffic, while concurrently performing a secondary tracking task, simulating the steering of real driving. The sudden stop warning system in the lead vehicles consisted of a g-force controlled activation of the hazard lights in addition to the braking lights. The results showed that overall, the 25 participants (16 females) who were holding a full New Zealand driver licence were responding on average 0.34 seconds faster to sudden braking maneuvers of the leading vehicles when the hazard lights were activated by the warning system compared to the same braking maneuvers when only the standard braking lights were visible. The warning system was particularly effective when the 'response window' of the participants was larger than 2.0 seconds and would not have required an immediate and abrupt braking response to avoid a rear-end crash in real driving. However, in those scenarios, the earlier responding of the participants to the warning system could have led to smoother deceleration and also could have left a safety margin to the leading car, as recommended for defensive and eco-driving. No clear patterns were found for the warning system to be more advantageous when it was in high frequency flashing mode, during night driving or during wet conditions.

Correspondence author: Tel. +64 7 838 4466 ext 8401
E-mail address: r.isler@waikato.ac.nz

1. Introduction

It is estimated that worldwide, that 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. In 2005, there were a total of 1125 rear-end collisions on New Zealand roads, the human consequences of which were 7 fatalities, 78 seriously injured and 1427 people sustaining minor injuries. The majority of these crashes (665) occurred on urban roads during hours of daylight with only 108 (16.2%) of the 665 occurring during periods of darkness. Although there were fewer rear end crashes on rural roads (453), a higher proportion were during hours of darkness (109 – 24%), and there were 5 fatalities on rural roads (3 during hours of darkness) compared with only 2 in urban areas, neither of which occurred during hours of darkness (LTNZ statistics, 2006).

When factors contributing to all crashes in New Zealand in 2005 are examined, it has been estimated that 1095 crashes occurred due to driver inattention or division of attention, and of these 1095 crashes, by far the biggest majority (700) were due to a failure of the driver to notice the car in front slowing, stopping or having stopped. A further 68 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.

The prevalence of driver inattention has been revealed in a recent '100-car naturalistic' study (Klauer, Dingus, Neale, Sudweeks, Ramsey (2006). This study confirmed that young drivers in particular, frequently fail to fixate their visual attention on crucial traffic information and often do not look at the right place at the right time. Day to day driving behaviour was continuously monitored in instrumented cars over a six month period and this revealed that the young drivers (18-20 years) in the study were disproportionately involved in distraction related crashes. One proposed solution to this problem, is the introduction of an alternative form of brake light system. Specifically, the aim of such a system would be to improve the reaction/braking time of the following vehicle by being more effective at capturing the attention of the driver in the tailing car.

In 1973 one such field test was conducted 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 twelve 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 five year mean rate of 7.9 crashes over 125 million miles in the five 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 $1,041 per million miles to $398.

Although these reductions were significant in themselves, given the more recent escalation in health and vehicle maintenance costs, the reductions in personal injury and vehicle repair costs achieved in the San Francisco trial would be even more significant in today's terms.

The positive effects of an enhanced braking system have also been demonstrated in a 'real world' situation where two alternative prototypes were tested (Wierwille, Lee, DeHart, & Perel, 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 to 0.35s, which at 45miles/hr (72.4km/h) corresponds to 5.0 – 7.0 meters 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. Such a system must, in the first instance, be easily distinguished from its background context. However, it has been shown, that a simple change in colour, detected primarily by the relatively slower processing 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 (Franconeri, Hollingworth, & Simons, 2005, Theeuwes, 1995).

Thus, as the peripheral visual system is more efficient at detecting motion and luminance changes, it would seem that a braking light system characterized by flicker or oscillation would be more effective than a static light system. This was demonstrated by Berg, Berglund, Strand and Baum, (2007), who concluded initially that reaction time to a red light with a 20Hz luminance flicker was faster than when the red light was static. However, this study also revealed that when the simulated driving task included following a lead vehicle (greater workload), the reaction time differential was greater at wider visual eccentricities (45 and 80 degrees).

Therefore, while research evidence to date suggests that a sudden stop warning system could be advantageous in terms of reducing the number of rear end crashes, it would also be effective from a defensive and eco -driving perspective (braking early and therefore smoothly). Therefore, along with a reduction in crash numbers, a more effective (attention captivating) braking system would also facilitate the more important reduction in human cost (injury or death), the associated health costs, as well as fuel costs and not insignificant vehicle maintenance costs.

The current research was conducted to evaluate the effect of a sudden stop warning system on the response time of the following driver. The system was an electronic safety device that monitors the deceleration of the vehicle to which it is fitted. It is activated when certain deceleration thresholds are met during a sudden stop – causing the hazard warning lights to flash on two different frequencies depending on the threshold, indicating a hazard for the following driver. A laboratory and video-based braking dual task was used to record and compare the response times of participants when the leading passenger vehicle was braking, activating the sudden stop warning system or, as control, with only the standard braking lights, during many simulated day and night driving scenarios and under wet and dry conditions.

2. Method

2.1. Participants

A total of 25 participants volunteered to take part in this evaluation study and received a $10 petrol voucher as a token of appreciation for their participation. Sixteen were female and the remaining 9 were male. The mean age was 26 years (SD = 9.2) and ranged from 18 to 52 years. All participants held a full New Zealand drivers license and the mean length of time the license had been held was 89 months, but ranged from 10 months to 34 years.

2.2. Materials and Measures

A computer based digital video system was used to display the simulated video-based dual braking task on a 800 mm(32inch) computer monitor, which was viewed from the perspective of a driver following a private passenger vehicle (the 'lead vehicle'). The participants were seated approximately 750 mm in front of the screen, in a small sound proof laboratory and had access to a computer mouse.

The dual braking task was specifically designed and software engineered for this study. It consisted of a primary braking simulation task and a secondary tracking task. The braking simulation task involved watching video-based driving scenarios (check: dimensions visible on the monitor: 500 x 80 mm embedded in a bright blue frame), seen from the perspective of a driver, following a lead vehicle, but there was no steering or speed control required. The task consisted of pressing the mouse button each time the participant felt a braking response was required in order to keep a safe following distance from the lead vehicle or to avoid a rear-end collision. Pressing the mouse button caused a braking sound and the bright blue frame around the video simulation changing colour to purple. For each braking situation, a predetermined 'response window' was defined as the critical period during which the participant was expected to respond by clicking the mouse button. It started from the earliest point of time when a braking situation became visible (i.e., when the lead vehicle was braking) and ended at the point when the braking response was considered as too late to avoid a rear–end collision. If a mouse click was detected during a response window, the corresponding response time was taken from the start of the critical period to the time when the mouse press occurred.

The secondary task required the participants to carry out a tracking task, simulating the steering in real driving. As can be seen in Figure 1, the tracking task consisted of a stationary rectangle (130 x 80mm) that was digitally superimposed on to the video-based traffic simulation, in the central lower area of the driving scenario, approximately at the location of the road ahead. The participants were required to keep a moving target dot (5mm, speed approx 10mm/seconds) within a smaller square (30x30mm). The position of the dot was controlled by the participants via the computer mouse device. The smaller square was contained within a larger stationary rectangle, bouncing off its sides like a ball would on a billiard table. Each time the target dot was 'miss-tracked' by the participants and moved out of the square, a low pitched 'peep' sound was produced and the frame around the simulation changed colour from blue to red for 500 milliseconds, alerting the participants to the tracking error. These occasions were recorded as the dependent variable 'number of tracking errors' for each trial. A second dependent variable 'tracking error time' was derived from the amount of time that the target spent outside the square for each trial.

Figure 1. Sample screen shot of a video-based simulation of the braking dual task from the perspective of the driver following a lead vehicle which is braking. The secondary tracking task is also visible in the lower centre of the traffic scenarios, including the rectangle, user controlled square and the (moving) target.

2.3. Sudden stop warning system

The evaluated sudden stop warning system (SSWS, commercially known as 'BrakeAlert') was manufactured by DataBrake International Ltd, New Zealand and consists of a small credit card size, 2 cm thick electronic interface device that could be installed in any vehicle. The system involves an accelerometer and each time the vehicle reaches certain braking g-force thresholds, the interface activates the hazard braking lights. Once a braking g-force threshold of 0.8 is reached, the hazard lights start flashing at the rate 2 Hertz ('low frequency flashing mode') and when a g-force threshold of 0.9 is reached (very abrupt deceleration), the rate is increased to 5 Hertz ('high frequency flashing mode').

2.4. Video-based driving scenarios

More than 120 traffic situations were filmed using a Sony mini digital HDD video camera (normal 52 mm lense) mounted on a fixed tripod beside the driver in a dedicated research vehicle that had the front passenger seat removed. A Toyota Camri was used as the 'lead vehicle' which had the sudden stop warning system (SSWS) installed and was staging the various braking scenarios which were filmed by the following research vehicle with the video camera.

Fourteen video test clips were selected which were between 20 and 30 seconds long and covered a wide range of braking situations (see Table 1 for a brief description). These included, rural (9 clips) and urban traffic areas (5), wet (2) and dry conditions (12), each of which triggered a g-force threshold that activated the hazard lights in either the low (9) or high frequency flashing mode (5).

Eight of the selected test clips (series A, Table 1) required an immediate 'braking response' (mouse click) from the participants. These clips had small response windows of up to 1.5 seconds during which an 'abrupt braking response' was required to avoid what would be a 'rear-end collision' if the simulation was in a real driving situation. The remaining six test clips (series B, Table 1) had a bigger response window and the participants were required to 'brake' within a timeframe of up to 5 seconds. For these scenarios, early detection of the lead vehicle braking could have allowed a less abrupt braking response with smoother deceleration due to the greater available safety margin which is also recommended for defensive and eco-driving.

The 14 selected test clips were sent to a professional post-production company which digitally removed the hazard lights to create 14 matched control clips, showing the same braking situations but with only the standard braking lights visible. From the pool of 120 traffic scenarios, an additional 14 scenarios were selected where no braking response was required. In 7 ‘no braking’ scenarios, the SSWS was activated but the lead vehicle was either very far ahead or off the road and was therefore not creating a hazardous situation. In the remaining 7 no ‘braking’ scenarios, the SSWS was never activated, but in some occasions the standard braking lights of the lead vehicle were visible but the participants were not required to respond as the lead vehicle was not in their driving path.

Table 1. Short Description of the Traffic Scenarios (Test Clips):
A=Scenario Number; B=Road type and characteristics; C= Reason Braking for the lead vehicle to brake, D=Approx. speed (km/hr) of the following driver (participant) before braking; E=Reaction Window in seconds; F= Day (D) or Night (N), Wet (W) or Dry (D); G= Frequency of flashing hazard lights, L=low (2Hz), H=high (5Hz).

Test clips series A (response windows of up to 1.5 seconds						
A	B	C	D	E	F	G
1	Urban, build up area	Approaching roundabout	50	1.5	N, D	H
2	Urban, build up area, oncoming traffic and street lights	No apparent reason	50	1.5	N,D	H
3	Rural, straight, street lights	No apparent reason	70	1.5	N.D	L
4	Rural, straight, no street lights	No apparent reason	70	1.5	N, D	L
5	Straight road	Stop sign	70	1.5	N, D	L
6	Rural, Curves, some traffic	No apparent reason	70	1.5	D,D	L
7	Rural, straight	Stop sign	50	1.5	D, D	L
8	Urban, parked cars left side	Pedestrian crossing	50	1.5	D, W	H
Test clips series B (response windows of at least 2 seconds and up to 5 seconds)						
A	B	C	D	E	F	G
9	Rural, gentle bends - no other traffic and no street lights	Sharp curve sign	40	3.5	N, D	L
10	Rural road, straight flat	No apparent reason	50	5	D, D	L
11	Rural, traveling over the brow of a hill	Standing still on top of brow, no braking	45	4	N, D	H
12	Urban, one way, parked cars on left side	Give way sign	50	2	D,W	L
13	Rural, straight, no street lights	No apparent reason	60	2	N, D	H
14	Rural, straight	No apparent reason	70	5	D, D	L

2.5. Procedures

The participants were first given a brief outline of the nature of the study. It was explained that after they completed a short demographics questionnaire they would be presented with 43 video clips, including a practice clip, each of which they would activate with a mouse click when they were ready. They were then instructed that they should click the mouse button in each situation where they would normally apply the brakes, and the number of times they needed to ‘brake’ could differ for each clip. They were also told that there was a secondary task which required them to move the mouse so as to keep a moving dot contained in the smaller square.

They were then seated in front of the computer monitor and were given a flat surface to place on their lap to operate the mouse on. When they were ready the participant activated the practice video with a mouse click. They repeated this practice clip until they were comfortable with the procedure, at which time the 42 experimental clips were presented. At the conclusion of the session the participants were then asked to complete a questionnaire giving their views on the advantages or disadvantages of the SSWS.

3. Results

All 25 participants completed the video-based dual braking task and provided 682 valid braking response times for the primary braking task and also completed the short SSWS evaluation questionnaire. There were 18 missing braking response times (0.02%) in the data file either because the mouse clicks were not recorded due to a technical issue or to the participants failing to respond.

The performance of the participants in the secondary task of the dual task, which simulated the steering task in real driving, was analysed first in order to determine if all participants divided their attention similarly between the two tasks. That is, was a reasonable effort made to maintain performance in the secondary tracking task. Next, the 'braking response' performance of the participants in the primary task was analysed. First all 14 of the matched test-control braking scenarios - with the lead vehicle braking and activating the SSWS and the corresponding matched control scenarios with the lead vehicle braking with only the standard braking lights visible, were compared. After the overall analysis, the braking scenarios in series A with small response windows (up to 1.5 seconds) were analysed separately from the test clips, series B, which had the longer response windows (up to 5 seconds). A within subject design was used as each participant provided their own control data and one-way repeated measures ANOVAs were used as inferential statistics in order to determine significance (alpha level of significance was set at 0.05; a 'trend' was defined a $p > 0.05$ but $p < 0.1$, 95% confidence levels, standard deviations and standard errors were used a variability measures. Partial eta squared (η_p^2) indicated effect size. Traditionally, η_p^2 values of .01, 0.06 and .14 represent small, medium and large effect sizes (Cohen, 1988). Observed power was also obtained.

3.1. Secondary task

All participants performed well in the secondary tracking task with a mean number of tracking errors of M = 0.52 (SD = 0.46) per trial and a mean tracking error time of M = 0.21 seconds (SD = 0.34). Over the 42 trials (28 braking trials and 14 non braking trials), 14 participants had less than 10 tracking errors, 9 had between 10 and 20 errors and only

4 had more than 20 errors (21, 23, 49, 57). The 23 participants who had less than 20 tracking errors had a total error tracking time of less than 10 seconds (Mean = 4.3 seconds, SD = 2.07) and the 4 participants who had more than 20 tracking errors had total tracking error times of more than 10 seconds (11.2, 14.3, 30.5, 44.1). Further inspection of the data revealed that two of those participants who had unusually long overall tracking error times (>30 seconds) did not continue the secondary tracking task once they delivered a braking response. It was concluded that all participants were making a good effort to maintain their performance in the secondary task and therefore completed the primary task under divided attention conditions.

3.2. Primary task

3.2.1. Overall effect of the Sudden Stop Warning System (SSWS)

The analysis of the data for the primary task revealed that overall the participants responded faster when the lead vehicle braked with the hazard lights activated by the SWSS (overall mean response time M = 1.41 seconds; standard deviation SD =.58) compared to the comparable simulations when only the standard braking lights were visible (M = 1.75 seconds; SD = 0.99). This means that on average, the participants responded 0.34 seconds faster to the braking maneuver of the lead vehicle when the SSWS was activated. A one-way (SSWS versus non SSWS) repeated measures ANOVA confirmed significant shorter response times of the participants when the SSWS was activated, $F(1, 13) = 4.73$, $p < 0.05$, a large effect size $\eta_p^2 = 0.27$, and an observed power = 0.52.

3.3.2. Braking scenarios of series A

The braking scenarios 1-8 (series A, see Table 1) each required an immediate ‘braking response’ via mouse click within a response window of up to 1.5 seconds. Figure 2 shows the mean response times and variability measures of the participants for these test scenarios.

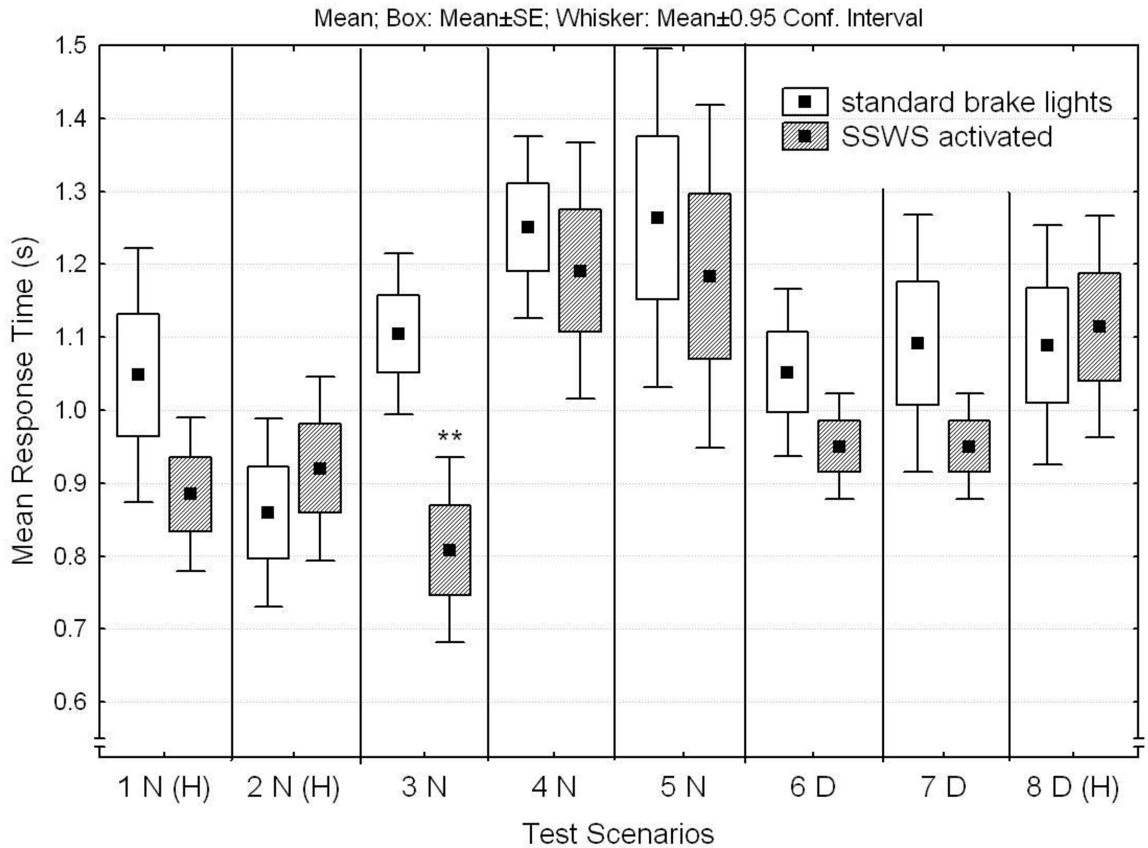

Figure 2. Mean response times for test braking scenarios 1-8 (series A) with the sudden stop warning system (SSWS) activated (right) and with only the standard braking lights visible (left), including standard errors and 95% confidence intervals (N = night driving , D = day driving, (H) = SSWS on high frequency flashing mode)

The figure shows that on average, the participants responded faster to braking maneuvers of the lead vehicle when the SSWS activated the hazard lights, except for two scenarios (2 and 8). The mean response time of the 25 participants for the braking maneuvers with an activated SSWS was M = 1.01 (SD = 0.18) and for the 8 corresponding scenarios with only the standard braking lights activated was M = 1.11 (SD = 0.15). This means that overall for the braking scenarios of series A, the participants responded on average 0.10 faster when the leading car was braking with the SSWS activated than without the SSWS.

A one-way (SSWS vs non SSWS) repeated ANOVA comparing the mean response times of the 8 scenarios from the series A revealed a near statistically significant effect (a ‘trend’) of the SSWS with $F(1,7) = 4.58$, $p = 0.07$, a large effect size of $\eta_p^2 = 0.40$ and a statistical power of 0.45. The biggest effect of the SSWS was revealed by test scenario 3, which was filmed at night, when the lead vehicle abruptly braked for no apparent reason. For this scenario, the participants responded on average 0.25 seconds faster to the braking of the lead vehicle with the SSWS activated ($M = 0.86$, $SD = 0.32$) compared to the braking with only standard braking lights visible ($M = 1.11$, $SD = 0.34$, a difference which reached significance with $F(1,24) = 19.20$, $p < 0.01$, a large effect size $\eta_p^2 = 0.45$, and observed power of 0.98. None of the other 7 braking scenarios of the series A revealed any significant effects of the SSWS.

Figure 2 revealed no clear patterns for the effects of the SSWS comparing the response times for the night driving scenarios with response times of the day driving scenarios, although as pointed out above, the braking scenario 3 which revealed the only statistically significant effect of the SSWS, was a night driving scenario. However, on the other hand, the scenarios 2, 4 and 5 were also night driving scenarios with the SSWS revealing no significant effects.

As mentioned before, there were two test braking scenarios (night driving scenario 2 and day driving scenario 8) for which the participants had longer average response times (although not significantly) when the lead vehicle was braking with the SSWS compared to the standard braking lights. Interestingly, in both of these scenarios, the SSWS triggered the high frequency flashing mode of the hazard lights (5 Hertz), indicating that compared to standard braking lights such high frequency flashing does not necessarily lead to faster braking response during both, day and night driving.

3.3.3. Braking scenarios of series B

The braking scenarios 9-14 (series B, see Table 1) each did not require an immediate ‘braking response’ as they had response windows of up to 5 seconds. Figure 3 shows the mean response times and variability measures of the participants for these scenarios. Similar to braking scenarios A, this Figure shows that on average the participants responded faster to braking maneuvers of the lead vehicle when the SSWS activated the hazard lights. The two exceptions were scenarios (13 and 14).

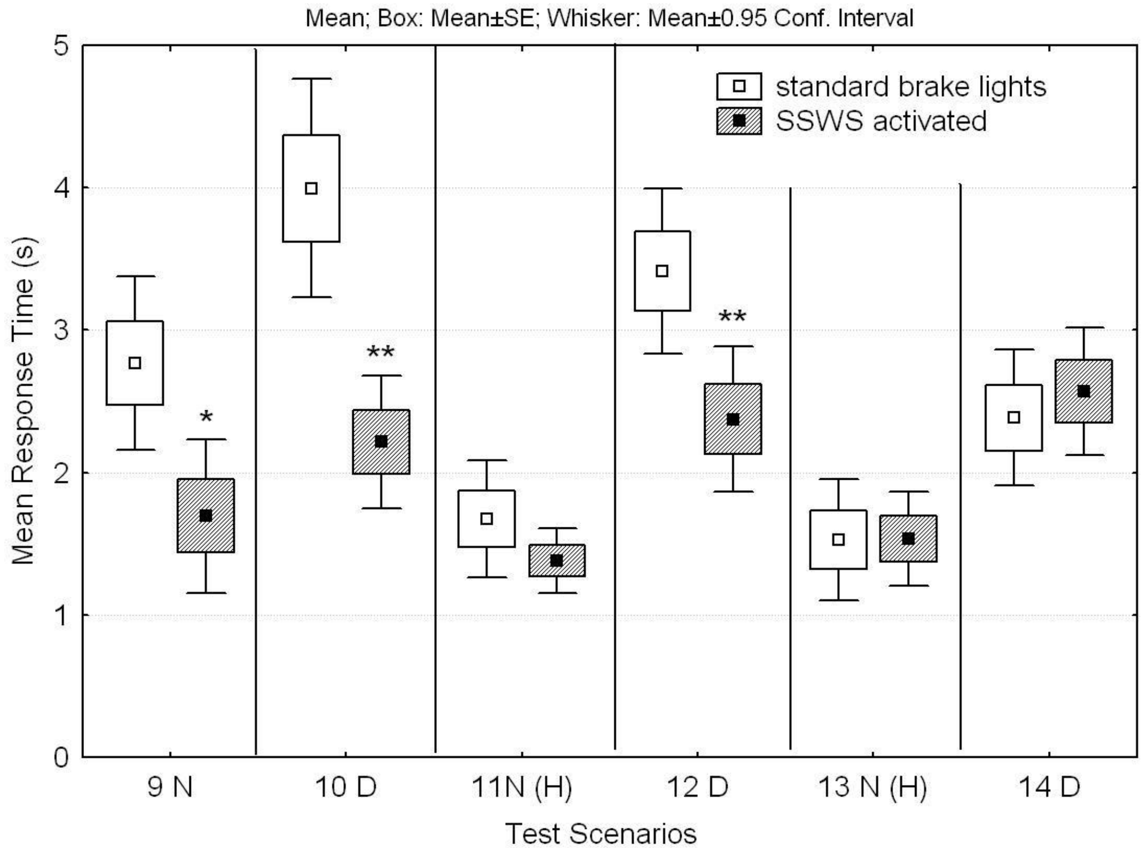

Figure 3. Mean response times for test scenarios 9-14 (series B) with the sudden stop warning system (SSWS) activated (right) and with only the standard braking lights visible (left), including standard errors and 95% confidence intervals (N = night driving , D = day driving, (H) = SSWS on high frequency flashing mode.

The mean response time of the participants for the braking maneuvers in series B with an activated SSWS was M = 1.96 (SD = 0.49) and for the 6 corresponding scenarios with only the standard braking lights activated was M = 2.62 (SD = 0.98). This means that overall, for the scenarios of series B, the participants responded on average 0.66 faster when the leading car was braking with the SSWS activated than without the SSWS.

A one-way (SSWS vs non SSWS) repeated measures analysis of variance (ANOVA) comparing the mean response times of the 6 scenarios from the series B revealed a near statistically significant effect of the SSWS with $F(1,5)=4.42$, $p=0.09$, a large effect size of $\eta_p^2 = 0.47$ and a statistical power of 0.40.

The most profound effects of the SSWS were revealed by the braking scenario 10 (rural road, daylight driving, lead vehicle braked for no apparent reason) followed by scenario 12 (rural road, night driving, lead vehicle braked because of sharp curve traffic sign), and 9 (urban, daylight driving, lead vehicle braked because of give way traffic sign). For scenario 10, the participants responded on average 1.36 seconds faster to the braking of the lead vehicle with the SSWS activated ($M = 2.42$, $SD = 1.29$) compared to the braking with only standard braking lights visible ($M = 3.78$, $SD = 1.76$, a difference which reached significance with $F(1,22) = 13.38$, $p < 0.01$, large effect size $\eta_p^2 = 0.38$, and observed power of 0.98.

For scenario 12 (and scenario 9), they responded on average 1.06 seconds faster (scenario 9: 0.66 seconds faster) when the SSWS was activated with $M = 2.38$, $SD = 1.23$ (scenario 9 : $M = 1.87$, $SD = 1.40$) compared to the standard braking lights with $M = 3.44$, $SD = 1.38$ (scenario 9: $M = 2.53$, $SD = 1.33$) with $F(1,22) =78.28$, $p < 0.01$, (scenario 9: $F(1,22)= 4.96$, $p<0.05$, large effect size size $\eta_p^2 = 0.29$ an observed power of 0.86 (scenario 9: large effect size $\eta_p^2 = 0.19$, and observed power of 0.53) None of the other three braking scenarios revealed any significant effects of the SSWS.

Figure 3 revealed no clear patterns for the effects of the SSWS comparing the response times for the night driving scenarios with response times of the day driving scenarios with one night driving scenario (9) revealing an effect of the SSWS while two other scenarios did not (11 and 13), and for two day driving scenarios (10 and 12), the SSWS had an effect while there was no effects for another (14).

There were two pairs of test scenarios (night driving scenario 2 and day driving scenario 8) for which the participants had longer average response times (although not significantly) when the lead vehicle was braking with the SSWS compared to the standard braking lights. Interestingly, in both of these scenarios, the SSWS triggered the high frequency flashing of the hazard lights (5 Hertz), indicating that such flashing failed to make the braking of the lead car more conspicuous during both, day and night driving than standard braking lights.

4. Discussion

This study was conducted in order to compare the time taken to respond to a Sudden Stop Warning System (SSWS) with the time taken to respond to a standard brake light system. A video based dual task was used, which consisted of a braking simulation task (mouse click) and a secondary tracking task. This design was chosen in order to most closely replicate ‘real world’ conditions, in which a driver’s attention is rarely focused solely on the road ahead.

Initially it was ascertained that the participants did pay considerable attention to the secondary tracking task, with an average of less than one tracking error per video clip. This indicated that the simulated braking task was not performed under the unrealistic condition of being the sole focus of the participant’s attention. In a real driving situation, children in the back seat, unpredictable pedestrians, radio, cell phones and numerous environmental factors can all divert a driver’s attention from the primary task. However, even with the participant’s attention partially diverted by the secondary task, it was still evident, that over all the conditions represented in the video based braking scenarios, braking time following the activation of the SSWS was faster than when standard brake lights were applied.

Although the average difference in braking time was only 0.34sec, at 50 kms per hour this translates to a stopping distance saving of 4.7 meters. At 100 kms per hour the saving is even greater at 9.5 meters. Obviously in the real environment, each driving situation is different and these differences would influence the exact stopping distance, however it is evident that the distance saved has the potential to considerably reduce the number of rear end collisions. These savings distances closely mirror the findings of Wierwille, Lee, DeHart and Perel (2006), who used an oscillating brake light system to demonstrate improvements of between 0.25 and 0.35secs in the brake time response when compared with response time to a standard bake light system.

A more comparable study, which used a simulated driving task to examine the effect of a flickering light on reaction time, also found that the response to the flickering light was significantly faster than the response to a static light, (Berg, Berglund, Strang, &

Baum, 2007). The response time differences in this study however, were only between 14 and 29ms. This smaller difference could be due to the use of a higher frequency flicker (20Hz) which is closer to the flicker fusion rate (approximately 30Hz) than the slower rates used in our study. Although there is some difference of opinion regarding the optimal 'attention capturing' flicker rate, optimal rates of between 3 to 10Hz have been suggested (Berg, Berglund, Strang, & Baum, 2007).

When the driving scenarios were divided into those requiring an immediate response and those whose response time windows were up to 5 seconds, some differences became evident. For the 8 scenarios which had a response window of 1.5 seconds or less, the average response time was faster when the SSWS was activated, but the average difference in response time between the two brake light systems was only 0.10 seconds. However, the greatest effect of the SSWS in these short response time clips was seen in a night time scenario when the lead car braked for no apparent reason. For this condition the braking response time for the SSWS was on average 0.25 seconds faster than for the standard brake lights. Travelling at 100kms per hour, this differential equates to a saving in stopping distance of 6.9 meters, an effect which could, in certain circumstances, save lives. However, in conditions of close following, where the response time window is small, any improvement in the time taken to make the appropriate response could be invaluable if a collision is to be avoided.

It was also evident that for two of these eight scenarios the response time for the SSWS was slightly slower than for the standard brake lights. In both of these two clips the higher flicker rate of the SSWS had been activated. Although the optimal flicker rate has not yet been ascertained, it could be expected that the slower flicker rate would be less effective than the faster rate, especially when an immediate response is required, as the slower rate would be indistinguishable from a static light for a perceptibly longer period than a more rapid flicker. This effect could be expected to be enhanced when focus is not directed solely at the road ahead and peripheral vision is required to pick up the warning signal. It therefore seems possible that for this study some artefact has rendered the 5 Hz flicker rate less effective than the 2 Hz flicker rate, at least when the response time window was small. As the viewing screen was not large, it may also be, however, that the participants' were able to keep focused primarily on the driving task, while low eccentricities of peripheral vision and a minimal level of attention were sufficient to the perform the tracking task.

For the six scenarios with a longer response time window, the response time advantage of the SSWS was on average 0.66 seconds. Again at 100 km per hour, this translates into a stopping distance saving of 18.3 meters, which provides a considerable window of opportunity for the driver to assess the situation and make a non urgent response. Additionally, for three of these scenarios, the response time difference was sufficiently large as to be statistically significant. However, for two of the remaining three clips the response time difference was very small, and in both of these scenarios the faster flicker rate had been activated. Therefore, taking all scenarios together, it would seem, contrary to expectations, that the 5Hz flicker did not result in the same response time advantage as the 2Hz flicker rate.

The additional stopping time window created by the use of the SSWS, especially in the non-urgent conditions, also provides motoring advantages from both defensive driving and eco driving standpoints. From a defensive driving standpoint, the earlier a driver becomes aware of a situation where some response is required the more effectively and safely that response can be executed. Additionally, when ample warning of the need for a braking response is given, the braking can be done incrementally rather than suddenly. This technique has been proven to be a much more fuel efficient method of slowing or stopping.

Overall, this study has demonstrated a significant advantage of the SSWS over the standard brake light system in reducing the time to respond to their activation. Given the prevalence of driver inattention and the resulting number of crashes, when the response time improvement of the SWSS is translated into stopping distance, the potential to avoid an accident and improve the statistics is considerable. This system also has the advantage of being able to be installed in any car without requiring extensive modification to the vehicle.

Contrary to expectations, the higher frequency flashing mode was not as effective as the slower flicker. Whether this was due to the limited visual field requirements of the study, compared to the 180 degree plus range of distractions encountered in the driving environment, or whether it was some factor related to the video presentations, should be the subject of further research. Therefore it is recommended that field trials, for example using taxi cabs, should be undertaken to assess more fully the effectiveness of the SSWS system in real driving situations.

4. References

Berg, W. P., Berglund, E. D., Strang, A. J., & Baum, M. J. (2007). Attention-capturing properties of high frequency luminance flicker: Implications for brake light conspicuity. *Transportation Research Part F: Traffic Psychology and Behaviour, 10*(1), 22-32.

Cohen, J. (1988). Statistical power analyses for the behavioural sciences. NewYork: Lawrence Erlbaum Associates

Enns, J. T., Austen, E. L., Di Lollo, V., Rauschenberger, R., & Yantis, S. (2001). New objects dominate luminance transients in setting attentional priority. *Journal of Experimental Psychology: Human Perception and Performance, 27*(6), 1287-1302.

Franconeri, S. L., Hollingworth, A., & Simons, D. J. (2005). Do New Objects Capture Attention? *Psychological Science*, *16*(4), 275-281.

Theeuwes, J. (1995). Abrupt luminance change pops out; abrupt color change does not. *Perception & Psychophysics*, *57*(5), 637 - 644.

Voevodsky, J. (1974). Evaluation of a deceleration warning light for reducing rear-end automobile collisions. *Journal of Applied Psychology*, *59*(3), 270-273.