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POTENTIAL BENEFITS OF AN ADAPTIVE FORWARD COLLISION WARNING SYSTEM

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Abstract

Forward Collision Warning (FCW) systems can reduce rear-end vehicle collisions. However, if the presentation of warnings is perceived as mistimed, trust in the system is diminished and drivers become less likely to respond appropriately. In this driving simulator investigation, 45 drivers experienced two FCW systems: a non-adaptive and an adaptive FCW that adjusted the timing of its alarms according to each individual driver's reaction time. Whilst all drivers benefited in terms of improved safety from both FCW systems, non-aggressive drivers (low sensation seeking, long followers) did not display a preference to the adaptive FCW over its non-adaptive equivalent. Furthermore, there was little evidence to suggest that the non-aggressive drivers' performance differed with either system. Benefits of the adaptive system were demonstrated for aggressive drivers (high sensation seeking, short followers). Even though both systems reduced their likelihood of a crash to a similar extent, the aggressive drivers rated each FCW more poorly than their non-aggressive contemporaries. However, this group, with their greater risk of involvement in rear-end collisions, reported a preference for the adaptive system as they found it less irritating and stress-inducing. Achieving greater acceptance and hence likely use of a real system is fundamental to good quality FCW design.

Keywords

rear-end collision; collision warning; alarm timing; driver behaviour; driving simulator

1 Introduction

1.1 Forward Collision Warning

Rear-end collisions or “shunts”, in which a vehicle collides with the rear of a slower moving, preceding vehicle, are among the most common of vehicle-related accidents. Research in both the U.S. (National Highway Traffic Safety Administration, 2003) and U.K. (Perrett and Stevens, 1996) has suggested that between one-quarter and one-third of all road accidents can be categorised as shunts. Whilst such accidents are relatively common, they tend to involve minor injuries and vehicle damage: only around 4% of road fatalities occur due to shunts (National Highway Traffic Safety Administration, 2005a). However, even ten-years ago, such incidents were causing approximately one third of all crash-caused delays, 57 million vehicle hours of delay annually in the U.S. (National Safety Council, 1996).

Technological advancements have resulted in many vehicle manufacturers taking interest in the development of Forward Collision Warning (FCW) systems. A FCW is an on-board electronic safety device that has the potential to warn the driver of the host vehicle of impending collision with preceding traffic. The system uses a forward-looking radar that continuously monitors traffic obstacles in front of the host vehicle and warns the driver when a risk of collision is imminent. FCW clearly has the potential to improve safety and reduce accident-related congestion on the road network.

The vast majority of published studies have shown the benefits of FCW in reducing the number and severity of shunts (e.g. Hirst and Graham, 1997; Lee, McGehee, Brown and Reyes, 2002). However, the timing of a FCW alarm is fundamental to the functionality of the complete system. The algorithm used by a FCW which results in this alarm timing is usually based on objective assumptions of a driver's response when required to brake, along with the physical characteristics of the vehicle in its stopping ability. For example, a FCW under development at Honda calculates the braking distance based on velocity, relative velocity and deceleration of the two vehicles (Seller, Song and Hedrick, 1998). Whenever the real distance between the following and the leading vehicle is less than the "braking critical distance" calculated by the algorithm, the FCW sounds its warning. Others systems have used time to collision (ttc) as a type of "worst-case scenario", such that the FCW provides its warning when ttc dips below a threshold value, (e.g. Janssen and Thomas, 1997). But both of these systems are "objective" in that they are based on the kinematics of the driving situation and will present identical warnings given common kinematic conditions.

Late warnings, that allow insufficient time for a driver to react to an unfolding scenario, result in more collisions than no system at all. Furthermore, the earlier the presentation of a warning, the less likely a collision is to occur (McGehee et al., 1998). However, a driver's trust in the system and hence their propensity to adhere to its alarms has also been found to depend on the timeliness of the warnings; the earlier a warning occurs, the more likely it is to be interpreted as a false alarm, which in turn leads to a reduction in drivers' future system use (Seller et al., 1998). Abe and Richardson (2006) demonstrated that if drivers have already made an individual decision to brake prior to a FCW alarm, their trust in subsequent alarms is reduced. Drivers then become more inclined to ignore the system, relying on their own individual judgements of impending danger and thus nullifying the potential benefits of the FCW. This effect has also been shown in a field operational test of FCW (National Highway Traffic Safety Administration, 2005a). Whilst drivers were well able to recognise the safety benefits of FCW, one-third of participants would have switched the system off had they been given the opportunity. There is also evidence to show that poorly timed warnings can also adversely affect driver workload (Wiese and Lee, 2004)

Since the benefits of FCW are well established, efforts have been made to design a system that is also well accepted by drivers. Brown et al. (2001) compared a kinematics-based algorithm (Burgett et al., 1998) and one that used a time-to-collision threshold with an adjustment for vehicle speed (Hirst and Graham, 1997). Results showed that the assumptions concerning driver reaction times have important consequences for algorithm performance, with underestimates dramatically undermining the safety benefit of the warning.

A logical development of this work would be to adapt an “objective” FCW into a “subjective” system, individually tailored to drivers based on their driving style and abilities. Such an adaptive FCW would allow the presentation of warnings timed towards the particular driver and hence more likely to be accepted by a broader range of the driving population. An adaptive FCW could also potentially reduce the trust and safety implications of poorly timed warnings. Such was the thrust of three collaborative driving simulator studies, undertaken as under Sub-Project 1 (Behavioural Effects and Driver-Vehicle-Environment Modelling) of the EU-funded AIDE project. Two projects evaluated adaptive FCW in combination with driver distraction (TNO-Human Factors) and weather conditions (VTI). This paper reports the work undertaken at the University of Leeds, adapting the FCW with respect to an individual driver's reaction time.

1.2 Driver support systems and driving style

In terms of drivers' individual differences, there is a positive relationship between sensation seeking and risky driving such that high sensation seekers are more likely to drive while impaired, to speed and to follow too closely (see Jonah, 1997, for a review). However, there is a paucity of literature investigating the relationship between sensation seeking and trust in on-board driver aids. Rudin-Brown and Parker (2004) demonstrated that driver trust in an adaptive cruise control (ACC) increased with system familiarity. The authors also reported that there was an interaction of system use and sensation seeking. Drivers performed better on a secondary task when using ACC than when driving unsupported; however, their response times to a hazard detection task increased. For those scoring highly on a sensation-seeking scale, this effect was more pronounced. Rudin-Brown and Noy (2002) investigated the effect of sensation seeking on trust in a lane departure warning system, observing that low sensation-seekers were more likely to report an increase in trust in the system, regardless of its accuracy. However, this was for a non-adaptive system that employed the same warning algorithm to lane departure regardless of a driver's individual abilities. Perhaps the high sensation seekers would have placed more confidence in a system that was tailored more towards their particular style of driving?

The driving literature does not appear to support evidence that high sensation seekers have the ability to respond more quickly to unfolding traffic events. Indeed, laboratory evidence suggests that the opposite is true: high sensation seekers are prone to reduced arousal levels and susceptible to boredom that delays their response to a stimulus (de Brabandera et al., 1995). Given that high sensation seekers maintain a shorter headway with the vehicle in front (Heino et al., 1992), maybe this accounts for their increased representation in the traffic accident statistics in the majority of the 40 studies reviewed by Jonah (1997)? Does an adaptive FCW system possess the capabilities to improve acceptance for high sensation seekers, allowing their over-representation in the accident statistics to be mitigated? Their low boredom threshold and hence reduced arousal brings with it an increased risk. Annoying FCW alarms will do nothing to minimise this risk, but does an adaptive FCW system have the potential to be better accepted by this higher risk group, minimising the likelihood to disregard the system and therefore improving driver safety for all styles of driver? Hence, an adaptive FCW offers the potential for a “double whammy” safety benefit. Those drivers most turned off by driver assistance systems may more readily accept them and thus, in the form of shunts at least, be more likely to change their driver behaviour in order to avoid them.

The present study aims to investigate this by investigating drivers’ interaction with and acceptance of an adaptive FCW in a driving simulator. The adaptive FCW was designed to present alarms in a timely manner to each individual driver by relating the timing of that warning to a individual driver’s own personal response time. Hence, slow reactors were presented with early warnings whilst fast reactors were given later ones. It was hypothesised that the adaptive system would be more readily acceptable than the non-adaptive, particularly to those drivers who adopt a more aggressive driving style (close following) and tend towards high sensation seeking.

2 Method

2.1 Test site

The Leeds Driving Simulator (Figure 1) was used for the study. At the time, the simulator was based on a complete Rover 216GTi, with all of its driver controls and dashboard instrumentation still fully operational. A real-time, fully textured and anti-aliased, 3-D graphical scene of the virtual world was projected on a 2.5 m radius cylindrical screen in front of the driver. This scene was generated by a SGI Onyx2® Infinite Reality2 graphical workstation. A Roland digital sound sampler created realistic sounds of engine and other noises via two speakers mounted close to each forward road wheel. The projection system consisted of five forward channels, the front three at a resolution of 1280 x 1024 pixels. The images were edge-blended to provide a near seamless total image, and along with two peripheral channels (640 x 480 each), the total horizontal field of view is 230°. The vertical field of view was 39°. A rear view (60°) was back projected onto a screen behind the car to provide an image seen through the vehicle's rear view mirror. The frame rate was fixed to a constant 60Hz. Although the simulator was fixed-base, torque feedback at the steering wheel was provided via a motor fixed at the end of the steering column and a vacuum motor provided the appropriate brake pedal servo assistance. Data were collected at the frame rate.

Figure 1 The Leeds Driving Simulator

2.2 Participants

Participant drivers were drawn from a database of experienced simulator drivers; each had between one and five hours of previous experience with the simulator. This provided a stable level of simulator specific driving familiarity and skill, minimised the possibility of simulator sickness, and ensured that participants were not overexposed or desensitised to the simulated environment. The 45 drivers who took part (23 males, 22 females) had a mean age of 37.4 (SD = 13.9) years. In the previous year, they had driven between 5,000 and 35,000 miles (8,000–56,000 km) with a mean mileage of 8,260 (13,216km). The standard deviation of mileage was 5,614 (8,982km). Participant drivers had between 5 to 20 years of driving experience (mean 9.9, SD = 5.9). They were paid £20 for their participation.

2.3 FCW systems

The driving simulator was equipped with a FCW system based on the ISO-recognised Stop Distance Algorithm (SDA). The SDA defined a warning distance, based on the difference between the stopping distances of the leading and following vehicles. If the distance between the two vehicles was less than the warning distance, an auditory collision warning alarm was presented to the driver. It is expected that the SDA will be introduced as the main alarm trigger logic in the design of future collision warning systems (Wilson et al., 1997). The SDA was defined as follows:

$$D_w = (V_{driver} \bullet T_{driver}) + \left({V^2_{driver}}/{2d_{driver}} \right) - \left({V^2_{drone}}/{2d_{drone}} \right)$$

- D_w [m] = warning distance
- V_{driver} [m/s] = speed of following simulator driver
- T_{driver} [s] = the assumed driver’s reaction to an event
- d_{driver} [m/s^2] = assumed deceleration of the following vehicle
- V_{drone} [m/s] = speed of leading drone vehicle
- d_{drone} [m/s^2] = assumed deceleration of the lead vehicle

The SDA had three fixed parameters: T_{driver}, d_{driver} and d_{drone}. The real-time speeds of the two vehicles (V_{driver} and V_{drone}) varied as the simulation progresses.

Two different types of FCW were simulated: non-adaptive and adaptive. In the both systems, the fixed deceleration parameters of the SDA (d_{driver} and d_{drone}) were selected in the mid-range at 5.0 m/s^2. The main difference between the two systems was in the use of driver’s reaction time (T_{driver}). In the non-adaptive system this was fixed at 1.5s, the value used by Dingus et al. (1997). The adaptive system used an individual driver’s brake reaction time, measured in the driving simulator. This procedure is explained in more detail later.

When the simulator driver encroached on the lead vehicle, following at a distance less than the warning distance, the auditory FCW was presented. The alarm was a sinusoid, varying in frequency between 700Hz and 7000Hz with a time period of 0.3s. The alarm was presented through the in-vehicle entertainment speakers of the simulator’s cab at a level of 73dB, measured at the driver’s head position. In order to simplify the experimental design, the simulated FCW system always worked perfectly, and was not subject to any errors in target detection that are possible with a real world radar.

2.4 Experimental design

A mixed experimental design was employed. The main within-subjects factor was FCW system type (three levels: no system, non-adaptive, adaptive). There were three between-subjects factors:

- *Sensation seeking*. Sensation seeking (SS) “is a trait defined by the seeking of varied, novel, complex, and intense sensations and experiences and the willingness to take physical, social, legal, and financial risks for the sake of such experiences” (Zuckerman, 1994). According to Jonah (1997), Zuckerman’s Sensation Seeking Scale Form V is the most frequently used in driver behaviour research and therefore was used in this study. Two levels of SS were used in the analysis, high and low.

- *Preferred following headway.* Preferred following headway was used to investigate driver behaviour and system acceptance for groups of drivers who tended towards close following and those that chose longer headways.
- *Individual brake reaction time*. Brake reaction time was used to investigate behaviour and acceptance for groups of drivers who reacted quickly and those that responded more slowly.

2.5 Procedure

Each experimental session lasted for approximately two hours, and was split into three main phases: simulator familiarisation, adaptive FCW system training and experimental data collection. Although the participants already had experience driving the simulator, simulator familiarisation enabled them to re-acquaint themselves with the controls and handling of the simulator. This took around 10-15 minutes and involved driving at their own speed in a rural environment with gentle, sweeping curves and light oncoming traffic. The rural scenario was chosen since the study was one part of a three-site evaluation of adaptive FCW. It proved to be by far the easiest to ensure similar virtual road scenes.

Following simulator familiarisation, adaptive FCW system training was undertaken. For this, participants also found themselves in a repeatable braking scenario designed to allow the measurement of their individual brake reaction time. The virtual environment contained alternating 500m straight and curved sections. Drivers were required to maintain 50mph (80km/h) and obliged to follow a lead vehicle. This lead vehicle attempted to maintain a 1s headway in front of the simulator driver using a second order speed controller. Feedback on participant's speed choice was given in form of a coloured overlay over the computer-generated visual display. If the driving speed was within ±5% of the required 50mph, the overlay disappeared. A scenario in which the lead vehicle braked was choreographed at every other straight section (i.e. approximately every 2km). In the braking scenario, the lead vehicle slowed at a deceleration of 4m/s^2 until it reached 5mph (8km/h), continuing at this speed for 10s before accelerating back to 50mph (80km/h). The scenario was only "triggered" if the driving speed (50mph ± 2.5mph) AND the following headway (1s ± 0.05s) were within tolerance, plus the simulator driver did not have the accelerator pedal released. The choreographed simulation ensured that the braking scenario was identical for every participant. Brake reaction time was measured from accelerator release to brake activation. The braking scenario (Figure 2) was repeated six times during system training and at its conclusion the mean brake reaction time for each participant was recorded. Each individual's brake reaction time was used for the parameter T_{driver} in the SDA of the adaptive FCW system so that the system was "trained" to an individual's driving style.

Figure 2 braking scenario for adaptive system training

Since a repeated-measures design was used, participants were then required to complete three separate drives during experimental data collection, once with no FCW system, once with the non-adaptive system and once with the adaptive system. FCW system type was counterbalanced across the participants. Participants were briefed on the study as follows:

"This experiment … is looking at driver experience with an 'adaptive' forward collision warning system. Such a system takes your driving characteristics into account when issuing the forward collision warning and hence it is adapted to individual drivers. The collision warning system will beep at you when you are getting too close to the lead car. However the system issues warnings merely based on the distance between you and the lead car; it does not detect whether the lead car brakes or not. Therefore it is up to you to decide if the lead car slows down and if braking is required to avoid collision with the lead car."

Each drive was made up of seven, 5km sections of rural road (total road length 35km). Each section was made up of alternating 400m long straight segments and 300m-400m curved segments. The curved segments varied in radius between 400m and 1100m. The posted speed limit of the road was 50mph (80kph). A car following scenario was introduced early in the drive with the lead vehicle maintaining a fixed 50mph. On-coming vehicles, on average every 4s, made overtaking difficult, but if it did occur, another lead vehicle was introduced such that the following situation was maintained. Participants were instructed as follows:

*"… you will be required to follow a lead car. We would like you to **follow the lead car as closely as you feel comfortable** – just imagine that **you are in an absolute hurry to reach the destination**."*

Each experimental data collection drive consisted of six "expected" braking events, one per each 5km section. During an "expected" event, the lead vehicle also slowed at a deceleration of $4m/s^2$, again reaching 5mph for 10s and accelerating back to the nominal 50mph. "Expected" events were scripted to occur only during five of the eight 400m-long straight segments per section, pre-selected to minimise learning effects. The braking event was "triggered" if the simulator driver's headway to the lead vehicle was between 1s and 3s AND the simulator driver had the accelerator pedal depressed by at least 5%. If these constraints had still not been met by the end of the fifth and final pre-selected straight segment in a particular section, the braking scenario was presented regardless.

After the sixth and final expected event had occurred, the lead vehicle left the main roadway by slowing and pulling into one of the numerous parking areas located at the mid-point of each straight segment.

Whilst the participant made his/her way unhindered along the seventh 5km section, a parked vehicle began to move and pulled onto the roadway, accelerating slowly at $0.5m/s^2$, in front of the simulator driver. To minimise learning effects, the "unexpected" event occurred randomly during one of the eight 400m-long straight segments situated within the 5km section (Figure 3). This unexpected event occurred when the simulator driver had a time-to-contact of 7s to the parked vehicle and a localised plethora of on-coming vehicles prevented the simulator driver from simply swerving around the new lead vehicle, thus forcing him/her to brake. The conclusion of the unexpected braking event denoted the end of the trial.

Figure 3 "unexpected" braking event (vehicle emerges from parking area)

2.6 Measures and analysis method

For each type of FCW (non-adaptive, adaptive, including baseline), each 35km route enabled driver behavioural data to be collected during six expected and the one unexpected braking events. Post-drive questionnaires evaluated user acceptance of that system. A single-blind technique was employed to ensure that the participants had no a-priori knowledge of which of the two system conditions they were driving which may have affected their stated preferences.

For the expected braking scenarios, the event was defined between the commencement of lead vehicle braking and the lead vehicle reaching its 5mph minimum speed. For the unexpected scenario, the event start was defined as the moment the emerging vehicle began to move forwards. Two main driver behavioural measures were used:

- *Brake reaction time:-* time between the illumination of the lead vehicle's brake lights (onset of braking) and the application of some brake pedal effort.
- *Minimum headway:-* a minimum value of time headway recorded during the complete event.

Between each experimental session, several questionnaires were administered. Completed questionnaires gave self-reports for:

- FCW alarm timeliness and frequency (rated on a five-point Likert scale anchored at too early/too late and too few/too often.
- Mental effort using the FCW (Zijlstra, 1993).
- User acceptance of the FCW (Van der Laan et al., 1997).
- Trust in the FCW (Lee and Moray, 1992).
- Personal factors affected by the FCW (safety, irritation, stress, feeling of being controlled, joy of driving, attentiveness in traffic)

A repeated-measures ANOVA was undertaken with the within-subjects factor of **FCW system type** (three levels: baseline, non-adaptive, adaptive). Three between-subjects factors of **driver style** were included in the analyses – sensation seeking (low, high), preferred following headway (short, long) and individual brake reaction time (fast, slow).

A frequency plot of sensation seeking score (SSS) showed that the sample was normally distributed according to a Kolmogorov-Smirnov test with a mean score of

19.27 and a median score of 19. Based on this evidence, driver were divided into two groups of sensation seeking score: low (< 19) and high (≥ 19).

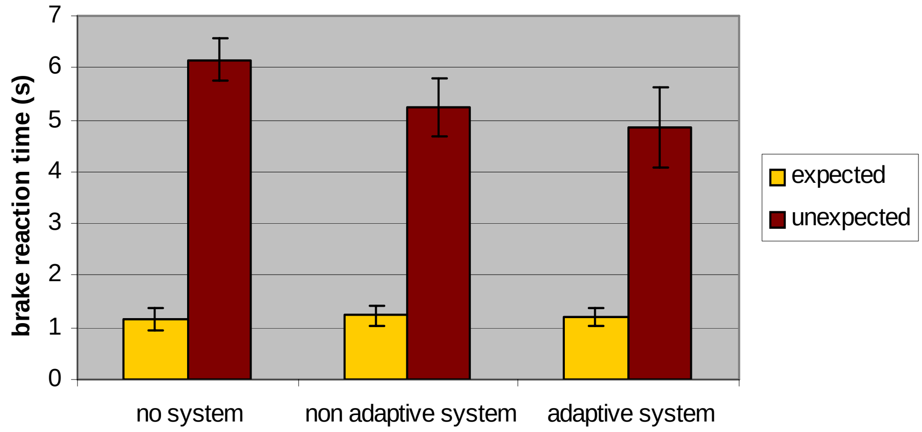
An individual driver's preferred headway was defined as the mean headway recorded throughout the baseline drive with the exception of those segments of road with braking events. Two participants maintained very long headways (7.50s and 4.84s) and so were removed from the analyses as outliers. Without the outliers, the sample was normally distributed with a mean score of 2.13s and a median score of 1.85s. Based on this evidence, preferred headway was split into *short* (< 1.85s) and *long* (≥ 1.85s).

The individual brake reaction time groups were split based on the RT recorded during the adaptive system training drive. The sample was normally distributed with a mean score of 0.967s and a median score of 0.937s. Based on this evidence, preferred headway was split into *fast* (< 0.937s) and *slow* (≥ 0.937s).

3 Results

3.1 Brake reaction time

Figure 4 shows the sample mean brake reaction time from the six expected and two unexpected braking events. The reason for the large difference in brake reaction time is due to the definition of the start of each braking event.



baseline – non-adaptive	p = .067	p < .001
baseline – adaptive	p = .414	p < .001
Non-adaptive – adaptive	p = .105	p = .23

Figure 4 brake reaction time for expected and unexpected events

Even though the expected braking events were more numerous, the unexpected events suggested a much more powerful effect of system (*expected*: F(2,86)=2.79, p=0.067; *unexpected*: F(2,86)=10.7, p<.001). The greater power demonstrated by the unexpected events was consistent across all the behavioural measures and so only these events are included in this analysis.

Figure 5 shows the effect of all three measure of driver style on brake reaction time. There was no significant main effect of either sensation seeking or individual brake reaction time, however, preferred following headway did show a significant effect: F(1, 41)=6.77, p=.013. There was also a significant interaction (F(2, 82)=6.85, p=.002) such that long followers tended to have a fairly consistent brake reaction time whatever system they used. Short followers, on the other hand, displayed shorter brake reaction times with the non-adaptive FCW, and shorter still with the adaptive system.

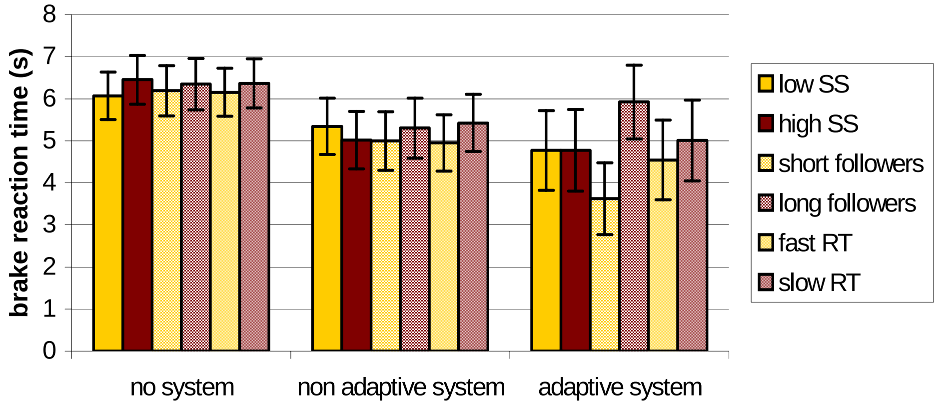


Figure 5 brake reaction time by driving style (error bars show 95% C.I.s)

3.2 Minimum time headway

Figure 6 shows the minimum headway recorded during the unexpected events. There was a main effect of system, F(2, 88)=12.4, p<.001. Post-hoc tests (Tukey LSD) showed that drivers without a FCW came closer to a collision with the lead vehicle (min headway = 1.11s) than when they interacted with the non-adaptive (1.66s) or adaptive (1.45s) systems. There was no significant difference in minimum headway for the two systems. High sensation seekers tended to end up closer to a collision (1.20s) than low sensation seekers (1.54s); F(1,43)=3.14, p=0.085.

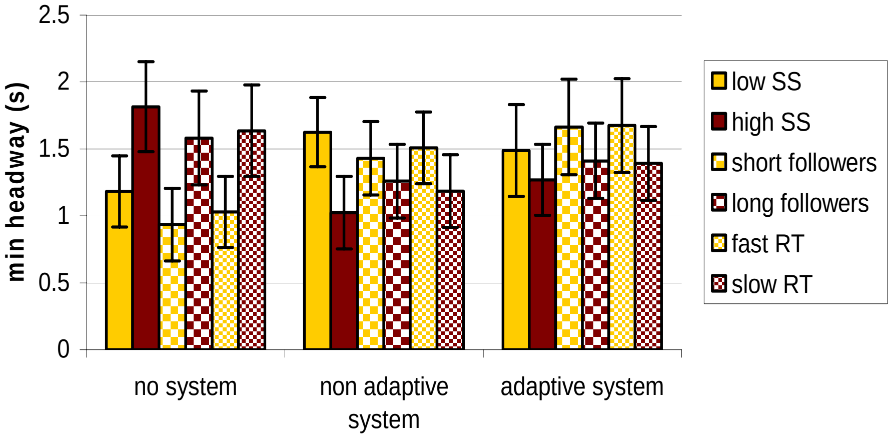


Figure 6 minimum headway by driving style (error bars show 95% C.I.s)

3.3 Alarm timing and frequency

Alarm timing and frequency were rated from -2 (too often / too late) to +2 (too few / too early). In general, participants felt that with both FCW systems, alarms occurred too early. However, there was a highly significant main effect of system, F(1,41)=14.3, p<.001: drivers rated the adaptive system as giving more appropriately timing alarms (-0.23) than the non-adaptive system (-0.78). There was also a main effect of system type on the alarm frequency ratings, F(1,41)=7.14, p=.011. Again, the non-adaptive system was rated worse, reported as giving too many warnings (0.75) than the adaptive (0.43).

3.4 Mental effort (RSME)

There was no significant main effect of system type on RSME. As shown in Figure 7, of the three measure of driving style, there was an effect of preferred headway, F(1,41)=5.26, p=.027. Drivers who preferred close following reported a significantly higher rating of mental effort (44.9) than those who followed at a longer headway (34.7). There was a non-significant trend towards an interaction between FCW system type and sensation seeking, F(2,86)=2.52, p=.087. High sensation seekers reported a relatively stable mental effort regardless of system, whereas the adaptive system reduced the reported effort of low sensation seekers.

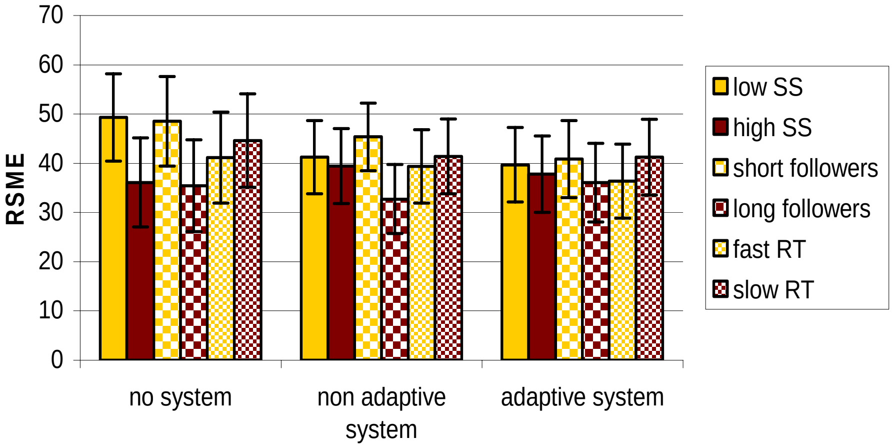


Figure 7 ratings of mental effort (error bars show 95% C.I.s)

3.5 User acceptance

Satisfaction and usefulness were rated from -2 (poor) to +2 (good). In general, participants gave positive feedback on the usefulness of both FCW systems, but rated them less than satisfactory. There was no significant main effect of system on user acceptance, however low sensation seekers tended to be more satisfied with FCW, F(1,43)=3.03, p=.089, and also found them more useful, F(1,43)=3.63, p=.063, than high sensation seekers. More powerful results were shown for preferred headway with short followers rating FCW lower than long followers (satisfaction: F(1,41)=5.83, p=.020; usefulness, F(1,41)=6.82, p=.012).

There was a significant interaction between system type and sensation seeking for satisfaction, F(1,43)=11.0, p=0.002. Low sensation seekers reported similar satisfaction with both systems, whereas the high sensation seekers preferred the adaptive system. There was also a significant interaction between system type and sensation seeking for both satisfaction, F(1,43)=5.83, p=0.02, and usefulness, F(1,43)=10.0, p=.002. Slow reactors did not discriminate much between the two systems, whereas fast reactors preferred the adaptive system.

3.6 Trust

There was a main effect of system type on the perceived enhancement to safety, F(1,43)=5.87, p=0.02, with the adaptive system achieving a higher rating. There were also several significant interactions between system type and sensation seeking for trust: F(1,43)=5.66, p=0.022, reliability: F(1,43)=8.37, p=0.006, dependability: F(1,43)=6.00, p=0.018, and integrity: F(1,43)=4.46, p=0.041. In each case, low sensation seekers did not discriminate particularly between the systems, but the high sensation seekers tended to report higher ratings in the adaptive system over the non-adaptive.

The same four measures of trust also approached or achieved significance for an interaction between system type and driver brake reaction time; trust: F(1,43)=3.94, p=0.047, reliability: F(1,43)=7.86, p=0.008, dependability: F(1,43)=6.36, p=0.016, and integrity: F(1,43)=9.01, p=0.004.

3.7 Personal factors

Personal factors were scored between -2 (reduces) and +2 (improves) and shown in figure 8. There was a main effect of FCW type on participants perception of traffic safety, F(1,43)=6.90, p=0.012, with the adaptive system scoring higher (.91) than the non-adaptive (.62). There was also a non-significant trend to suggest that both FCW reduced the joy of driving, but to a lesser extent for the adaptive system; F(1,43)=3.57, p=0.067.

All three measures of driver style had a significant effect on driver irritation. High sensation seekers; F(1,43)=7.13, p=0.011, short followers; F(1,41)=5.95, p=0.019 and fast reactors; F(1,43)=4.25, p=0.045, all becoming more impatient with FCW compared to low sensation seekers (0.58 v 1.18), long followers (0.59 v 1.15) and slow reactors (0.63 v 1.10) respectively. Results also suggested the high sensation seekers, F(1,43)=11.3, p=0.002, and the short followers, F(1,43)=4.27, p=0.025, became more stressed when driving with FCW.

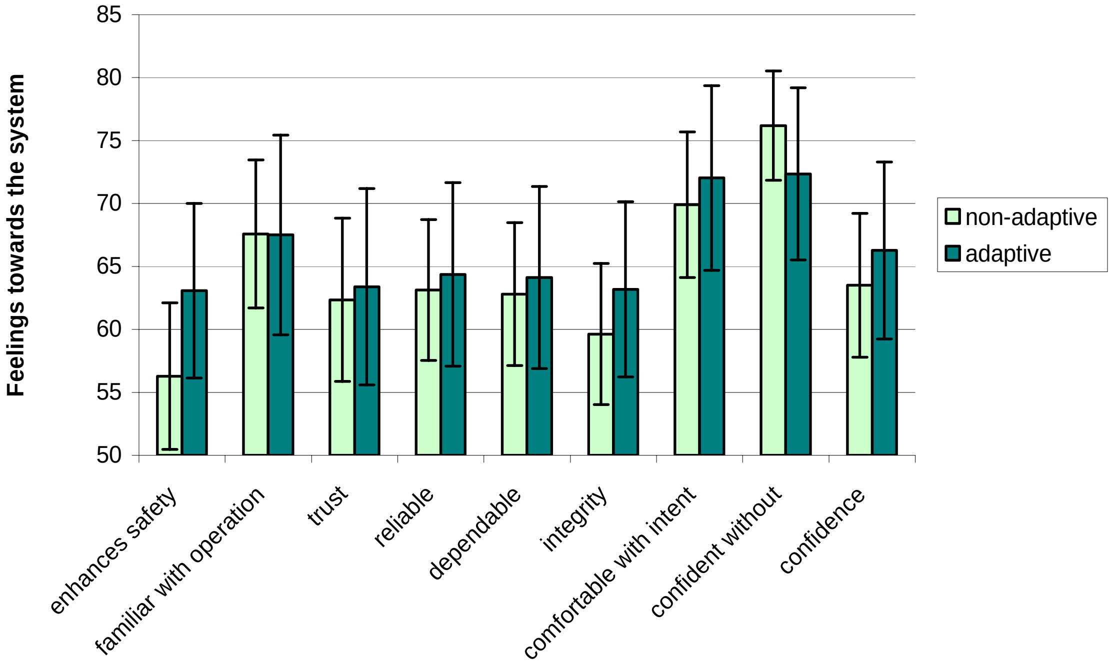


Figure 8 Ratings of personal factors associated with FCW type (error bars show 95% C.I.s)

4 Discussion

The study aimed to evaluate driver behaviour when interacting with an adaptive Forward Collision Warning (FCW) system. Driver style was also taken into consideration by splitting the sample into groups of high and low sensation seeking, short and long preferred following headway and fast and slow brake reaction time.

Two FCW systems, with adaptive and non-adaptive Stop Distance Algorithms (SDA) were evaluated. Whilst it is recognised that in a real-world application, a driver would understand the functionality of an adaptive FCW and its relation to their own reaction time, a single-blind design was used in this study to ensure that participants' reports were not influenced by prior knowledge of the SDA in use.

Based on the data collected in this study, conclusions should potentially be restricted to the rural environment in which subject drivers participated. However, it is unlikely that the results would differ significantly in other driving environments. The, the rural environment provided a relatively low driving demand in the lack of "clutter" from other objects in the driving scene. Hence, participants had the benefits of an adaptive FCW whilst also being able to manage their own individual following headway to the lead vehicle without significant distraction. Drivers would be more likely to be irritated by FCW alarms in this "uncluttered" environment, since the low driving demands leave plenty of spare capacity for a driver to make his/her own decision to brake rather than relying on the advice of the system. In a more complex driving environment, the driver is more likely to be distracted and hence grateful for a pertinent collision warning.

In picking up target objects, real world FCW are limited by the vagaries of their radar system. For example, the radar may select static roadside objects or, especially on a curved road, a target in an adjacent lane may be chosen as the lead vehicle. By mistaking another target as the lead vehicle, a FCW is likely to provide false alarms. It is well recognised that false alarms adversely affect drivers' trust in FCW (e.g. Horowitz and Dingus, 1992). However, the present study focussed on the comparison between an adaptive and non-adaptive system and whether this adaptation was accepted by drivers without evidence any significant safety detriment. Hence, in order not to cloud the experimental design, the simulated FCW always functioned perfectly and provided no false alarms. We suspect, given that trust in FCW is jeopardised by mistimed warnings (e.g. Abe and Richardson, 2006), acceptance of a real adaptive FCW may suffer due to potential of incorrect target detection.

Overall, both FCW systems had a highly significant beneficial effect on driver safety, a result in line with other similar investigations (Abe and Richardson, 2004; Wilson et al., 1997). When the system was functional, brake reaction time was reduced and during the braking events, drivers remained further from a collision with a lead vehicle. Neither sensation seeking nor an individual driver's brake reaction time affected the speed of their response to the traffic events, in line with De Brabandera et al., 1995. However, in the present study it was observed that drivers who preferred shorter headways responded to events more quickly than long followers. This intriguing result suggests that those drivers who choose to drive closer to preceding vehicles do so in the belief that their driving abilities are such that their risk of collision is not increased. Since minimum headway during the braking events was not significantly lower for the short followers, the evidence suggests that their beliefs and abilities concur. Unfortunately, this result was not backed up by a significant correlation between preferred headway and individual brake reaction time. Neither could the established correlation with sensation seeking and driving speed (Zuckerman and Neeb, 1980) be replicated in areas of roadway when drivers were unconstrained by a lead vehicle. However, the relationship reported in Zuckerman and Neeb's (1980) study was based on self reports as opposed to actual recording of an individual’s speed choice in an instrumented vehicle or simulator. There is always the potential with self-reports that what drivers say that they will do and what they actually do may differ.

In general, driver behavioural measures indicated a safety benefit of both FCW and the magnitude of the benefit was similar between the two systems. However, one advantage of the adaptive system was demonstrated by the highly significant interaction between preferred headway and FCW type. For the long followers, the introduction of the either FCW type reduced brake reaction time to around the same degree. Short followers, on the other hand, saw an additional reduction in reaction time when they made use of the adaptive system. By allowing a greater following distance, the long followers give themselves more opportunity to react and there was not such a pressing need to brake severely. Clearly, short followers are more likely to be involved in a rear-end collision and reducing this possibility by further reducing an already short reaction time is an important effect of the adaptive system in its role of reducing collisions.

Except for the interaction between preferred headway and FCW type, other behavioural measures did not particularly discriminate between the two systems. However, self-reports on the timeliness of warnings and acceptance of system indicated significant benefits of the adaptive system. Both low sensation seekers and long followers rated their acceptance of each system to a similar degree. Potentially this is due to the fact that low sensation seekers are more inclined to favour any system with a perceived safety benefit – in the same manner as the low sensation seekers in Ruddin-Brown and Noy’s (2002) study were more likely to accept the lane support system. However, in this study, the importance is in the interactions, with high sensation seekers and short followers reporting a greater acceptance to the adaptive system. Similar interactions of sensation seeking / following propensity demonstrated similar preferences of the adaptive system for reports of trust, dependability, reliability and integrity. The increased trust in automation for low sensation seekers, demonstrated here, was also previously been highlighted by Ruddin-Brown and Noy (2002).

Furthermore, the adaptive system had benefits in terms of mental effort. When using the FCW, short followers reported a relatively stable mental effort regardless of system type, whereas the adaptive system reduced the reported effort of long followers. A similar trend, but not one that quite reached significance, was found for sensation seeking. The more appropriately timed warnings of the adaptive system appear to have a similar positive effect on mental effort, a result not dissimilar to that reported by Wiese and Lee (2004).

However, not all groups of drivers embraced of the concept of FCW systems in general. Whilst all drivers recognised the safety benefits of FCW, they reported irritation by both the adaptive and non-adaptive system and felt both intruded on the joy of driving. Self-reports also suggested the high sensation seekers and the short followers became more stressed when driving with FCW. Whilst these results tended to be mitigated by the adaptive system, there is still a concern that even its demonstrated benefits may still be outweighed by its annoying features. It should be noted, however, that in this study, braking events occurred relatively frequently and far more often that would be expected in a real world application. Potentially this over-experience of the FCW systems may have exacerbated participants' reported irritation.

Other real world implications include the ability of a real system to be adapted using a measure of an individual driver's brake reaction time, recorded in this study from identically choreographed events. To achieve this in reality would be relatively straight forward. To function, such a system has an intrinsic requirement for a forward-looking radar. This could be used record real braking events, when the headway between the two vehicles begins to rapidly decrease. The driver's reaction time could be recorded using a vehicle's engine management system and this information could be used to "train" the adaptive system for an individual driver, even if several different drivers actually use the vehicle. Furthermore, the vehicle could potentially recognise a change in reaction time with changing driver state and continue to create pertinent alarms, even on an individual driver level.

The implications of these results are important to the designers of FCW systems. By allowing an individual's brake reaction time to affect FCW functionality, there is the clear implication that a short reaction time leads to later warnings for an individual driver. Later warnings could be interpreted by some as sanctioning the design of a less safe system since there is less available time between the alarm and the need for a driver to brake. Furthermore, it places a reliance on the driver to maintain the reaction time that the system is using within its SDA. As this study has shown, there is a benefit of both adaptive and non-adaptive FCW in terms of reduced reaction time, but the important fact is that drivers will more readily accept the adaptive system over the non-adaptive one, a result consistent with other research in the area of driver support systems. Improved acceptance is likely to lead to greater usage – some one-third of participants in recent NHTSA-funded Field Operational Trial of non-adaptive FCW indicated they would have turned FCW off if given had they been given the opportunity (National Highway Traffic Safety Administration, 2005a). And so, rather than its irritating features forcing a driver to switch off or disable a FCW system, the adaptive FCW is likely to be used more consistently and hence in a position to give a collision warning when a driver truly needs it.

5 References

Abe, G and Richardson, J., 2006. Alarm timing, trust and driver expectation for forward collision warning systems. Applied Ergonomics 37(5), 577-586.

Brown, T.L., Lee, J.D. and McGehee, D.V., 2001. Human performance models and rear-end collision avoidance algorithms. Human Factors 43(3), 462-482.

Burgett, A. L., Carter, A., Miller, R. J., Najm, W. G. and Smith, D. L., 1998. A collision warning algorithm for rear-end collisions (Tech Report 98-S2-P-31). Washington, DC: National Highway Traffic Safety Administration.

de Brabander, B., Boone C., Gerits P and van Witteloostuijn, A., 1995. Relationship between arousal and activation and sensation seeking. Personality and Individual Differences 18 (3), 373-384.

Heino, A., van der Molen, H. H., and Wilde, G.J.S., 1992. Risk homeostasis process in car following behaviour: individual differences in car following and perceived risk. Report VK 92-02, Rijksuniversiteit Groningen Haven, The Netherlands.

Hirst, S. and Graham, R., 1997. The format and perception of collision warnings. In Y. I. Noy (Ed.), Ergonomics and Safety of Intelligent Driver Interfaces, Lawrence Erlbaum Associates, Mahwah, NJ, pp. 203–219.

Horowitz, A.D. and Dingus, T.A., 1992. Warning signal design: a key human factors issue in an in-vehicle front-to-rear-end collision warning system. Proceedings of the Human Factors Society 36th Annual Meeting (Santa Monica, CA: Human Factors and Ergonomics Society), pp. 1011-1013.

Janssen, W. and Thomas, H., 1997. In-vehicle collision avoidance support under adverse visibility conditions. In I. Noy (Ed.), Ergonomics and Safety of Intelligent Driver Interfaces, Lawrence Erlbaum Associates, Mahwah, NJ, pp. 221-229.

Jonah, B.A., 1997. Sensation seeking and risky driving: A review and synthesis of the literature. Accident Analysis and Prevention 29(5), 651-665.

Lee J.D., McGehee D.V., Brown T.L. and Reyes M.L., 2002. Collision warning timing, driver distraction, and driver response to imminent rear-end collisions in a high-fidelity driving simulator. Human Factors 44(2), 314-334.

Lee, J. and Moray, N., 1992. Trust, control strategies, and allocation of function in human-machine systems, Ergonomics 35(10), 1243-1270.

McGehee, D. V., Brown, T. L., Wilson, T. B. and Burns, M., 1998. Examination of driver's collision avoidance behavior in a lead vehicle stopped scenario using a front-to-rear-end collision warning system (Tech Report DTNH22-93-C-07326). Washington DC: USDOT/NHTSA Office of Crash Avoidance Research.

National Highway Traffic Safety Administration, 2005a. Automotive collision avoidance system – field operational test report. DOT HS 809 900. U.S. Department of Transportation.

National Highway Traffic Safety Administration, 2005b. Traffic safety facts 2003: a compilation of motor vehicle crash data from the fatality analysis reporting system and the general estimates system. DOT HS 809 775. U.S. Department of Transportation.

National Safety Council, 1996. Accident Facts. Itasca, IL.

Perrett, K.E. and Stevens, A., 1996. Review of the potential benefits of road transport telematics. TRL Report 220. Transport Research Laboratory, Crowthorne, U.K.

Seller, P., Song, B. and Hedrick, J. K., 1998. Development of a collision avoidance system. Automotive Engineering International 109, 24–28.

Rudin-Brown, C.M. and Noy Y.I., 2002. Investigation of behavioral adaptation to lane departure warnings. Transportation Research Record (1803), 30-37.

Rudin-Brown, C.M. and Parker H.A., 2004. Behavioural adaptation to adaptive cruise control (ACC): implications for preventive strategies. Transportation Research Part F - Traffic Psychology and Behaviour 7(2), 59-76.

Wiese E. and Lee J., 2004. Auditory alerts for in-vehicle information systems: The effects of temporal conflict and sound parameters on driver attitudes and performance. Ergonomics 47 (9), pp. 965-986.

Wilson, T.B., Butler, W., McGehee, D.V. and Dingus, T.A., 1997. Forward-looking collision warning system performance guidelines. SAE Technical Paper Series 970456. Society of Automobile Engineers, Warrendale, PA.

Zuckerman, M., 1994. Behavioural Expressions and Biosocial Bases of Sensation Seeking. University of Cambridge Press, Cambridge.