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A Smart Driving Smartphone Application: Real-World Effects on Driving Performance and Glance Behaviours

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Abstract

A smart driving Smartphone application – which offers real-time fuel efficiency and safety feedback to the driver in the vehicle – was evaluated in a real-world driving study. Forty participants drove an instrumented vehicle over a 50 minute mixed route driving scenario, with 15 being selected for video data analysis. Two conditions were adopted, one a control, the other with smart driving advice being presented to the driver. Key findings from the study showed a 4.1% improvement in fuel efficiency when using the smart driving system, and an almost 3-fold reduction in time spent travelling closer than 1.5 seconds to the vehicle in front. Glance behavior results showed that drivers spent an average of 4.3% of their time looking at the system, at an average of 0.43 seconds per glance, with no glances of greater than two seconds. In conclusion this study has shown that a smart driving system specifically developed and designed with the drivers' information requirements in mind can lead to significant improvements in real-world driving behaviours, whilst limiting visual distraction, with the task being integrated into normal driving.

Introduction

A wealth of previous research has shown that using In-Vehicle Information Systems (IVIS) can be distracting to the driver, cause an increase in workload and also be detrimental to certain driving performance characteristics – specifically when they require the driver to engage in a non-driving related secondary task. However, many IVIS (either OEM or aftermarket) have recently been developed which aim to actually increase driving safety, efficiency, comfort or convenience. What is unknown is whether or not these IVIS have any real, measurable positive effect of driving behaviours in the real-world, and if they do what is the consequence of these on driver distraction? This paper aims to address these issues by reporting on a comprehensive field trial conducted using an in-vehicle smart driving advisor.

The Foot-LITE Smart Driving System

The smart driving system used was developed for a UK project called Foot-LITE. The Foot-LITE system aims to bring information on safety and fuel efficiency together on a single, integrated, adaptive interface presented on a Smartphone application. The smart driving advice offered is based on the analysis of real-time information related to vehicle operation and local road conditions, with data being collected via an adapted lane departure warning (LDW) camera, the vehicles On-Board Diagnostics (OBDII) port, as well as 3-axis accelerometer and a Global Positioning Satellite (GPS) module.

The Foot-LITE human-machine interface (HMI) concept (figure 1) was developed according to Ecological Interface Design principles (EID; Burns & Hajdukiewicz, 2004). Specifically relevant to the driving task EID offers to dynamically reflect the driving environment and integrate complex information onto a single, direct perception display (Burns & Hajdukiewicz 2004). Safety and Eco information is grouped together with all parameters being displayed concurrently and changing in real-time depending on the driver's inputs. Given the safety critical nature of evaluating in-vehicle systems in the real-world and interacting with other road users, the HMI was rigorously tested and iterated until the version, shown in figure 1, was released for on-road trials. The ergonomic development and evaluation of the HMI has been reported previously (see Birrell and Young 2011, Young and Birrell 2012).

In-vehicle smart driving information presented to the driver in real-time were:

- Headway: A visual representation of time headway (figure 1, picture 2) was presented to the driver as a cautionary threshold (amber) when the driver was less than 2 seconds to the car in front, and a warning threshold (red) when below 1.5 seconds. When the driver was greater than two seconds, or when headway information was not presented to the driver (i.e. below 15 mph or headway confidence was not sufficient) the display shows as the default green (figure 1, picture 1).
- Lane Departure Warning: A red warning was given to the driver when they deviated from their lane (figure 1, picture 2). For this experimental setup the lane deviation threshold was set to be very sensitive, i.e. when the driver was close to the lane lines a warning was displayed, as well as if having actually deviated.

Figure 1 **Example screenshots from the Foot-LITE[1] smart driving advisor. Only one 'oval' is ever presented on the IVIS at any one time, but all aspects depicted can change in real-time and in combination. Picture 1 (left) Default Green display. Picture 2 (centre) – top-left to bottom – Headway Warning, Lane Deviation Warning, Headway Caution.**

[1] This design is protected by Brunel University as a UK Registered Design (UK RD 4017134-41 inc.); the unauthorized use or copying of these designs constitutes a legal infringement.

Picture 3 (right) – top-left to bottom-right – Braking Caution, Acceleration warning, Change up caution, Change down warning

- Gear Change Advice: The bottom half of picture 3, figure 1 shows gear change advice. The amber arrow suggests either a single gear change up or down in a sequential manner, red either a block change (e.g. 2nd to 4th) is preferable or a single shift if high power demand is needed. When the drivers adheres to the gear change advice, or when in the correct gear the gear change section of the HMI will revert to the green default display.
- Acceleration and Braking: As presented in the top half of picture 3, figure 1, braking and acceleration advice is offered to the driver in order to limit excessive acceleration / throttle use, and also to try and encourage a smoother speed profile. Again cautionary (amber) and excessive (red) warnings are offered to the driver.

Methodology

Design and Dependent Variables

This study utilised a control verses intervention, within-subjects repeated measures experimental design. In the control condition no smart driving feedback was offered, in the intervention condition feedback was offered by the Foot-LITE system. The order of which participants completed the conditions was counterbalanced to negate order and potential gender effects.

Two very different types of data were collected for this study: Driving performance data; and Driver glance behaviour. Variables collected related to driving performance are described below:

- Time headway: continuous (s) and % journey spent under 1.5 s
- Number of lane deviations
- Engine speed (RPM) and load (%), throttle position (%)
- Current and ideal gear position, % time in each gear
- Vehicle speed (mph) and journey time (s).

Variables collected related to driver glance behaviour were:

- Glance frequency: absolute and percentage of glances to certain locations
- Glance duration: average, maximum and percentage of time spent at each location, and number of glances greater than 2 seconds.

Driving Scenario

The driving scenario adopted for this study was a fixed route in and around the Leicestershire (central England) area, it was 40.1 miles (or 64.5 km) in length and took approximately 1 hour and 15 minutes to complete. The scenario encompassed three clearly defined sections of road which included only one type of road category – ‘Motorway’, ‘Urban’ and ‘Inter-Urban’ (figure 2). The motorway (highway) section consisted of 3 or 4 lanes with a speed limit of 70 mph (≈113 kph) and took approximately 11-12 minutes to complete, with one section where two motorways merged together. The urban section of roadway was completed on unregistered, residential single carriageway and one-way roads with numerous pedestrian crossings, roundabouts and T-junctions present; the speed limit throughout was 30 mph (≈48 kph) and took approximately 8 minutes to complete. Within the inter-urban section the main carriageway was all one lane in width with multiple lanes at traffic light controlled intersections and roundabouts, speed limits varied between 40, 50 and 60 mph (≈64, 80 and 97 kph). This was the longest section of roadway taking approximately 18 minutes to complete, and could also be classified as rural. All participants drove the same instrumented vehicle throughout the study; this was a UK right-hand drive 2006 Ford Focus Zetec, 1.6 L diesel with manual transmission.

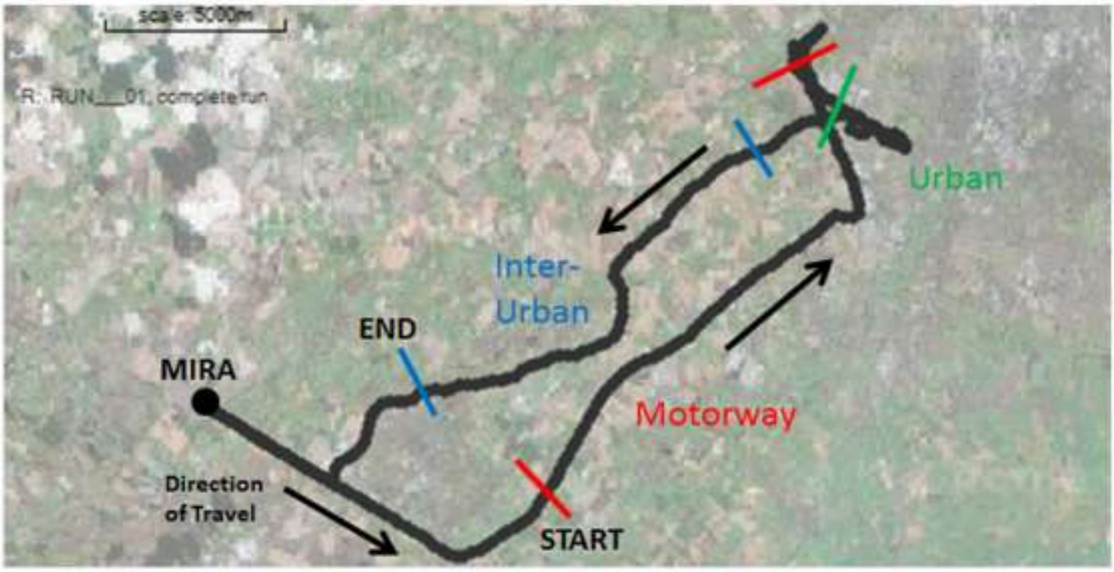

Figure 2 Driving scenario adopted for the study

In all driving conditions participants were given route guidance instructions verbally by the experimenter, who also dealt with any issues that arose with any logger or system within the vehicle. Directions were offered according to a fixed script to ensure all drivers received the same instructions. The route description also included some tactical information such as upcoming changes to 30 mph speed limits, approaching traffic lights, as well as standard instructions such as ‘At the roundabout turn RIGHT, 2nd exit, right hand lane’.

Participants

Forty participants (30 male and 10 female; table 1) were recruited to take part in this study, all of whom were members of staff at the trial management company. Prospective volunteers replied to a companywide circular email if they were interested in taking part. The principal inclusion criterion was that participants were covered to drive a company vehicle on the company insurance policy, and who were not involved in the Foot-LITE project or had a working knowledge of the project.

For the glance behaviour analysis 15 participants (10 male and 5 female; table 1) were selected from the original 40 to be included based on the quality of video data collected in both the control and experimental conditions, and also if the smart driving system was working effectively throughout the entire route.

Table 1 Study participant demographics

Trial	Subset	n	Age		Driving Experience	
			Mean	SD	Mean	SD
Driving Performance	Group	40	41.90	11.64	22.03	11.74
	Male	30	42.33	12.28	22.60	11.94
	Female	10	40.60	9.10	20.30	11.24
Glance Behaviour	Group	15	39.40	12.95	19.07	12.52
	Male	10	39.64	14.89	19.55	13.36
	Female	5	38.75	6.60	17.75	11.53

Data Collection and Analysis

Data for this study were collected using two principal logging methods, firstly via the Foot-LITE system itself which collects numerous parameters from different sources (OBDII port, adapted LDW camera, GPS on Smartphone, accelerometer in the processing unit) and fuses this data to form the feedback presented via the Smartphone application. This data were stored on journey specific .csv files which were imported into MS Excel for analysis. The second logging method was a GPS data logger supplied by Race Technology (DL1 Mk3), which records GPS at 20 Hz and accelerometer and gyroscope at 100 Hz. The DL1 was also connected to Race Technology's Video4 hardware to collect raw video data from four internal cameras, with data being analysed using their bespoke software package (Analysis v8). Finally, end of journey fuel consumption was recorded according to the vehicles internal trip computer.

Driving performance data collected were trimmed to only include data collected between the start of the motorway section and end of the inter-urban section – this was termed data for the 'entire' journey (figure 3). Data from seven participants were excluded from the driving performance analysis, this was either a result of logger errors (2 cases), data not being collected from the Foot-LITE system (2 cases), or the Foot-LITE system not providing effective feedback in the experimental condition (3 cases). This left 33 participants with complete datasets available for analysis. Statistical testing was conducted using SPSS 16.0 and significance was accepted at $p<0.05$. Two MANOVAs evaluated potential differences between the data collected from the Foot-LITE system and GPS data logger, with a Paired T-test used to assess fuel efficiency.

Glance behaviour data was analysed slightly differently. To ensure comparisons could be made between each of the sections of roadway, three-eight minute segments were outlined for the video analysis. These were defined from a pilot benchmarking run where the test experimenter drove the route in typical traffic densities, adhering to the speed limit and UK Highway Code throughout. The start and end points for segments were based on fixed GPS points relating to eight minutes of the benchmarking run, therefore each participant completed same distance but total driving time may vary slightly depending on self-selected driving speeds, traffic conditions etc. Glance behaviours for these three sections of roadway were then combined to create 24 minutes of video data analysed, and again termed data for the 'entire' journey.

With no automated analysis of driver glance behaviour from raw video files available (to the authors' knowledge) an alternative method was needed. For this study an innovative method was established which used the JWatcher software. JWatcher is a freeware tool originally developed as an observational recording programme for the behavioural sciences. Certain behaviours or activities could be identified and associated with specific keys on the keyboard, with the time in-between these keystrokes being recorded and saved as .text files. In this case each keystroke was associated with a glance towards a specific location, these were defined as:

- IVIS – the Foot-LITE smart driving Smartphone application
- Mirrors – left and right wing mirrors, rear-view mirror (coded separately)
- Driving Equipment – instrument panel, gear stick, handbrake etc.
- Road: Centre – centre of the roadway, which may not always be straight ahead when cornering or when 'tracking' an object
- Road: Off-Centre – looking out of the windscreen (but not centrally) or side windows (but not mirrors). This could include viewing side roads, oncoming traffic or traffic signs, but also glances considered as not relevant to the driving task as defined by Hughes and Cole (1986), i.e. immediate road and general surroundings, vegetation and advertising
- Other – glances to the experimenter, non-driving related in-vehicle equipment (e.g. HVAC controls) or any other unspecified glances (daydreaming or where a glance cannot be determined).

Further pilot analysis was conducted using JWatcher which determined that video playback at one quarter speed was sufficient to accurately and reliably record glances. ISO 15007 (2002) defines glance duration as being from the initial movement of the eye away from its location to when it is fixed on its new location (transition), and ending just before the next transition begins (dwell time). For real-time video analysis this proposes a significant problem, as it is not known what the driver is going to look at (fixation) when they start the first transition. For this reason a slightly adapted definition of glance duration was used, i.e. going from fixation to fixation rather than transition to transition. This allowed the analyst to determine where a glance fell before recording it. The key to this method was accurately and reliably defining the start of each glance fixation. Driver glance behaviour was again evaluated using a MANOVA in SPSS.

Procedure

Participants completed the same driving scenario on two separate occasions separated by one week, but on the same day and at the same time of day in an attempt to limit external factors such as traffic. One condition was a 'Control' (no smart driving feedback offered), the other 'Experimental' where feedback via the IVIS was offered. When participants arrived to take part in the study for their first randomised condition they were given a verbal and written explanation of the project and the specific aims of study. After this they were shown the Risk Assessment and finally signed, informed consent was gained. Following this participants were shown to the test vehicle where they were instructed to adjust the seats, steering wheel and mirrors so they were comfortable and accessible. All participants had the opportunity to take the test vehicle on a brief drive to familiarise themselves with the vehicle before the actual trial began. In addition to this the first 10 minutes of the journey was excluded (figure 2: 'MIRA' to 'Start') to ensure the drivers were comfortable with the vehicle controls.

Data logging (both GPS and Foot-LITE) was initiated prior to the commencement of each condition and the internal trip computer was zeroed. Before the start of the experimental condition participants were given a detailed introduction to the Foot-LITE system, including being shown what feedback the system would offer, they also had chance to ask any questions. In the control condition the Smartphone was set to silent and placed out of sight of the driver but data were still collected. As explained previously the first 10 minutes of each driving scenario was for vehicle familiarisation, additionally in the experimental condition participants were also shown the interface and each event highlighted as it appeared on the Smartphone. In both driving conditions participants were instructed to drive as they would do normally, however in the experimental conditions taking on board the smart driving information if they deemed it reliable and applicable information, and also safe to do so.

Results

Aspects such as driving speed and journey time are parameters universally important for both safety and efficiency. Results from the current study showed no differences ($p>0.05$) in either parameters between the conditions.

Driving Performance

Safety parameters that the Foot-LITE smart driving system offered feedback to the driver in real-time were headway (distance to the car in front) and lane position. Results showed that lane position did not differ significantly ($p>0.05$), with the mean number of lane deviation warnings offered by the system for all participants over the entire journey in the control condition being 17.7 and 15.1 in the experimental condition. Where the smart driving system did elicit a difference was with respect to headway. Mean headway for the entire journey (calculated when a vehicle was detected within 5 seconds) increased from 2.05 (SD = 0.32) to 2.33 (0.33) seconds from the control to experimental conditions; this difference was significant ($F_{(1,65)} = 17.41$, $p<0.001$). The percentage of the entire journey which the participants spent travelling closer than 1.5 seconds to the car in front (or when receiving a 'Red' headway warning as in figure 1, picture 2) decreased significantly ($F_{(1,65)} = 16.86$, $p<0.001$) from 6.61% (5.77) in the control condition to 2.32% (1.78) in the experimental condition.

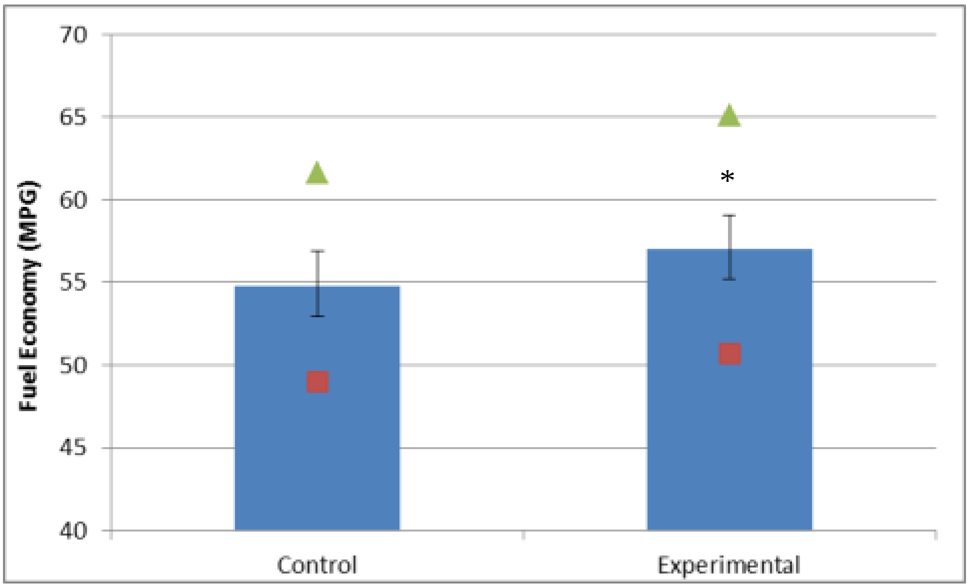

Figure 3 **Fuel economy (MPG) for each condition. Blue bars represent mean MPG for all participants, Red squares minimum MPG achieved, Green triangles maximum MPG, and error bars the standard deviation of data. Asterisk (*) indicates a significant difference (p<0.001) to the control condition**

The principal parameter of driving efficiency is actual fuel economy or the number of miles driven per gallon of fuel used (MPG); this was recorded post journey according to the vehicles internal trip computer. Results show that average fuel economy increased significantly by 4.1% between the control and experimental conditions ($F_{(1,65)} = 15.96$, $p<0.001$), this was an increase from 54.8 (SD = 3.10) to 57.0 (2.90) MPG (figure 3). Specifically related to fuel efficiency certain changes in driving performance were also observed which may account for the difference noted above. Drivers in the experimental condition spent 13.8% (SD = 3.82) of the drive in the wrong gear, this was 15.0% (5.32) in the control condition (figure 4). Whilst this difference was not significant, it was when we consider the use of 1st gear, which reduced from 5.4% (2.88) to 4.5% (0.93) between control and experimental conditions respectively ($F_{(1,65)} = 4.56$, $p<0.05$), and 5th gear which showed a strong trend ($F_{(1,65)} = 2.82$, $p<0.1$) for an increase from 39.0% (9.43) to 41.1% (5.79). Engine load and RPM also differed when using the smart driving system, with maximum engine RPM reducing significantly ($F_{(1,65)} = 3.69$, $p<0.05$) from 2921.6 (409.5) to 2791.5 (272.2) and mean engine load increasing ($F_{(1,65)} = 5.78$, $p<0.05$) from 42.6% (2.38) to 43.9% (2.09) between the conditions.

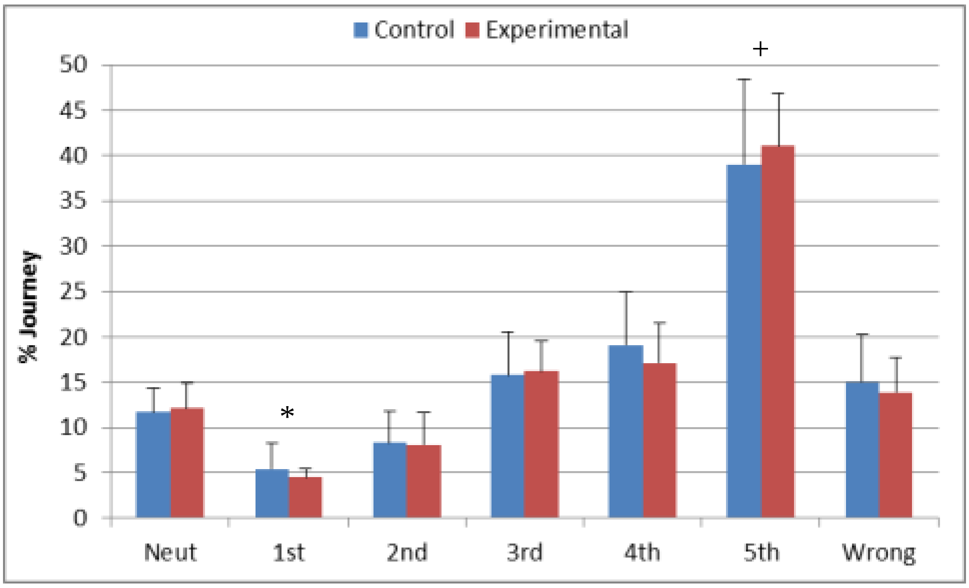

Figure 4 **Percentage of the entire journey spent in each individual gear. Asterisk (*) indicates a significant difference (p<0.05) to the control condition, and Plus (+) a trend (p<0.1). Error bars represent standard deviation of the mean data**

Glance Behaviour

The mean number of glances (in absolute form) made to any of the locations by participants was 1103.3 (SD = 130.3) glances in the control condition verses 1128.7 (110.9) in the experimental condition. Regarding the breakdown of glances to each recorded location for the entire journey, figure 5 shows that the introduction of the smart diving IVIS resulted in a significant reduction ($F_{(1,29)} = 12.80$, $p<0.01$) in the percentage of glances to the 'Road: Off-Centre'. This is to compensate for the glances to the IVIS which accounted for 11.4% (or 128.7 out of 1128.7) of the glances for the entire journey in the experimental condition. No other significant differences with respect to glance frequency were observed.

Table 2 **Mean glance frequency and glance duration results for both Control and Experimental conditions**

	Percentage of Total Glances		**Ave Glance Duration (s)**		**% Total Glance Duration**		**Max Glance Duration (s)**	
	Con	Exp	Con	Exp	Con	Exp	Con	Exp
Centre	47.87	47.50	2.32	2.20	77.98	77.56	19.58	18.41
Off-Centre	30.61	21.97	0.54	0.53	12.70	9.52	4.65	5.25
Mirrors	9.78	7.49	0.49	0.49	3.99	3.04	1.39	1.38
Equip	7.47	8.04	0.62	0.61	3.63	3.98	1.30	1.37
Other	4.17	3.38	0.46	0.64	1.67	1.53	1.06	1.70
IVIS	NA	11.37	NA	0.43	NA	4.32	NA	1.28

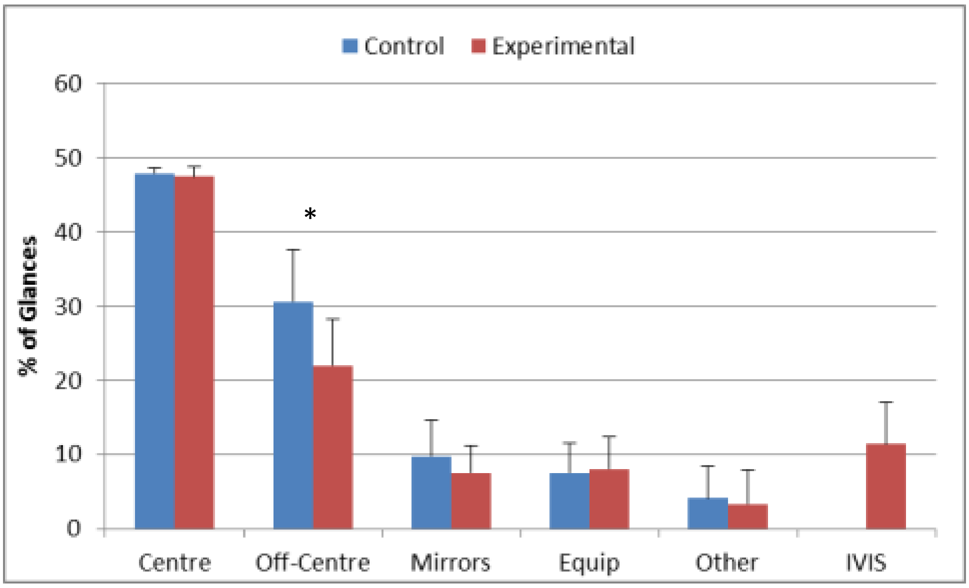

Figure 5 **Mean percentage of glances to each location in the control and experimental conditions. Errors bars represent standard deviation of the mean data. Asterisks (*) indicates a significant difference (p<0.05) between the conditions**

Mean single glance duration is shown in table 2, with times of around 0.5 to 0.6 seconds when considering the driving equipment, mirrors and off-centre road glances in both conditions. The average time spent looking at the smart driving system was 0.43 (SD = 0.08). Maximum glance durations were again similar for both conditions, with times to areas other than the road being consistently around 1.3 to 1.4 seconds (table 2). Interestingly the maximum glance duration to the IVIS was the lowest recorded (although not significantly) at 1.28 seconds. With few changes being observed in average or maximum glance durations we would expect to see the percentage of total glance durations to each location to follow similar trends to glance frequencies (figure 5), i.e. to allocate visual resource to the IVIS during the experimental condition we would see a reduction in the percentage of glance duration off-centre compared to the control condition. This was observed in the analysis with the reduction being significant ($F_{(1,29)} = 6.25$, $p<0.05$), with no other interactions occurring.

Discussion and Conclusions

Findings presented in this paper show that using an in-vehicle smart driving aid during real-world, on-road driving resulted in the drivers spending an average of 4.3% of their time looking at the IVIS, at an average of 0.43 seconds per glance, with no glances of greater than two seconds, and accounting for 11.4% of the total glances made. Hughes and Cole (1986) suggested that drivers might have up to 50% 'spare' attentional capacity during 'normal' driving, and Green and Shah (2004) suggest that during 'routine' driving approximately 40% of attention could be allocated to non-driving tasks. A notion proposed by this current study is that spare capacity could be considered as glances to two main categories – 'Other' and 'Road: Off Centre', as these contain glances that may not be considered safety or operationally critical to the driving task. Given that results presented in this paper suggest that using the IVIS offered limited safety implications (assessed by mean and maximum glance durations), the authors propose that the allocation of visual resource towards the IVIS could be considered to be taken from these ‘spare’ glances. Importantly glances to the mirrors, driving equipment and at the centre of the road didn’t alter significantly with the introduction of the IVIS. Comparing the findings presented in this study for the use of the Foot-LITE system to other recognised in-vehicle systems shows that using a Satnav (for route guidance only not destination entry) is more visually demanding in terms of mean glance duration and percentage of time looking at the IVIS (Morris et al. 2013). Using an in-car entertainment systems has been found to be more visually demanding (when considering glance durations), and the secondary task has been linked to distraction related parameters such as increased lane deviations (Blaschke et al. 2009).

When using the smart driving system an average improvement of 4.1% was seen in fuel economy over the control condition, and importantly with no increase in journey time or reduction in average speed. Primarily these efficiency savings were enabled by limiting the use of lower gears (facilitated by planning ahead to avoid unnecessary stops) and an increase in the use of 5th gear (as advised by the in-vehicle system); both these aspects have been independently shown to correlate significantly with good fuel economy (Johansson et al. 2003). This is supported by research into the effectiveness of using gear shift indicators (GSI) with Vermeulen (2006) suggesting that adhering to gear shift advice resulted in a 3-5% reduction in CO_2 output (and corresponding increase in fuel efficiency) for the standard emissions legislative driving cycle. This effect increased to between 7 and 11% when considering urban and rural driving respectively. A secondary effect of the change in gear shift behaviour was a significant decrease in maximum engine revs (or RPM) and an increase in mean engine load. Changing gear before 2,000 revs is considered a ‘Golden Rule’ of eco-driving, and whilst the Foot-LITE systems gear shift algorithms are not this simplistic, late gear change is clearly an inefficient driving behaviour which was corrected when using the smart driving system – as shown by the decrease in maximum engine RPM.

Significant and important changes in driving safety behaviours were also observed, with results showing that mean headway for the entire journey increased by 13.7% to 2.33 seconds in the experimental smart driving feedback condition compared to 2.05 seconds in the control condition. In addition to a significant three-fold reduction in the percentage of the journey spent travelling closer than 1.5 seconds time headway. Results from other research which have evaluated the use of a headway warning systems are interesting with Ben-Yaacov et al. (2002) showing that drivers spent 42.2% of their driving time at headways of less than one second, and when headway warning were activated this reduced significantly to just 3.5%. A longitudinal study conducted by Shinar and Schechtman (2002) evaluated 43 participants using instrumented vehicles over 6 weeks (3 weeks with the system off, 3 on) with in-vehicle headway feedback. Results showed a 25% decrease in time spent under 0.8 seconds headway from experimental to control, and 14% more time maintaining headways of above 1.2 seconds. As we can see the headway times presented in the research above are much shorter than experienced in the current trial. This may be a function of the fact that participants were given initial headway feedback (amber visual warning, no audio) at 2 seconds rather than 1.2 seconds (Shinar and Schechtman 2002) and 1.0 seconds (Ben-Yaacov et al. 2002). This suggests that presenting headway warnings at 2 seconds, rather than 1 second, leads to greater following distances being employed by drivers, and hence a positive effect on driving safety. However, care needs to be taken regarding user acceptance, as people may be less likely to accept a system which may allow them to be ‘cut up’ more frequently in high density traffic. A likely trade-off between acceptance and safety is needed.

Findings from a previous simulator study evaluating an early prototype of Foot-LITE showed that the HMI design was not visually demanding with no detriment (in fact an improvement was observed) in peripheral detection task performance, and did not lead to an increase in subjective workload (Birrell and Young 2011). This is supported by results from this current study which showed that positive changes in driving behaviour came at no significant cost to eyes on road time. The 100-car naturalistic driving study suggests that very simple secondary tasks do not appear to have a crash risk that is greater than normal driving (Klauer et al. 2006). This current study concludes that an ergonomically designed in-vehicle interface, utilising ecological interface design principles, presenting both safety and eco-driving information via an integrated and adaptive interface can lead to measurable and beneficial changes in real-world driving performance, whilst not resulting in visual distraction and the subsequent compromise in driving safety.

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